INVESTIGATING MALAWIAN PHYSICAL SCIENCE TEACHERS' TEACHING STRATEGIES: A CASE STUDY IN NUCLEAR PHYSICS

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DECLARATION

I declare that this thesis is my own, unaided work. It is being submitted for the degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University

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ABSTRACT

Malawian physical science teachers (PSTs) perceive nuclear physics to be the most difficult physics topic. This study investigated: reasons PSTs would give for this perception, teaching strategies that some PSTs would use to address learning difficulties in nuclear physics, reasons the teachers would give for using certain strategies and nature of the PSTs' pedagogical content knowledge (PCK) in nuclear physics. Assumptions of the interpretivist paradigm and the theoretical framework of PCK guided the data collection, organisation and analysis processes.

Thirty teachers completed a questionnaire, which enabled me to identify PSTs who chose nuclear physics as the most difficult, difficult aspects of nuclear physics and reasons those aspects are difficult. Stratified purposive sampling was then used to choose four case teachers. I observed two lessons on nuclear physics for each case teacher by video recording them. I interviewed each case teacher before and after both lessons. I also interviewed a group of students after each lesson. Video recordings were discussed with the respective teachers. Some documents were collected. All interviews and video recordings were transcribed into text, coded using *Atlas.ti 5.2* and analysed inductively. Content analysis was used with documents.

Some learning difficulties surface during lessons and they mainly related to student conceptions, nature of concepts and mathematical manipulations. The case teachers could not anticipate most of them, irrespective of qualification. It would seem the teachers were hardly aware of lesson-specific difficulties.

The case teachers used combinations of strategies that focused on transmission of information. The teachers hardly probed student thinking. Reasons given for strategies adopted revealed that qualified teachers emphasised only content while the under-qualified ones also emphasised pedagogy.

Also qualified case teachers ascertained student understanding more frequently than the less qualified ones. Also one of the qualified teachers was able to articulate main ideas of the lessons, while the other three could hardly do so.

I conclude that teachers with similar characteristics as those studied here need assistance to develop the following aspects of PCK in nuclear physics: awareness of learning difficulties, use of strategies that are based on student thinking and ability to articulate main ideas.

KEY WORDS

Teaching Strategies, Learning Difficulties, Nuclear Physics, Pedagogical Content Knowledge.

To my loving wife
Tapona Luwe

Also to my children
Patson, Mwabi, Thokozile and Grace

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ABBREVIATIONS

MSCE	Malawi School Certificate of Education
MANEB	Malawi National Examinations Board
PST	Physical Science Teacher
PCK	Pedagogical content knowledge
PSS	Senior Secondary School Physical Science Teaching Syllabus
PK	Pedagogical knowledge
SMK	Subject matter knowledge
CSS	Conventional Secondary School
CDSS	Community Day Secondary School
MPSRP	Malawi Poverty Reduction Strategy Paper
CoRe	Content Representation
PaP-eR	Pedagogical and Professional-experience Repertoire
PD	Primary document
CER	Chief examiners' report

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CHAPTER 1
INTRODUCTION

1.1 Introduction

In this chapter, I describe observations done in Malawi that influenced the conception of this study. I then present the aims and questions that guided the study. Other aspects that are covered in this chapter include: limitations of the study, organisation of the whole thesis and definition of terms.

1.2 The Research Problem

1.2.1 Poor student performance during national examinations

In Malawi, the education system is divided into primary (standards one to eight), secondary (forms one to four) and tertiary levels. For students to proceed for tertiary education, they have to pass the Malawi School Certificate of Education (MSCE) examinations, which are national examinations administered by the Malawi National Examinations Board (MANEB) in form four at the end of secondary education. In recent years, performance during these examinations has plummeted to unacceptably low levels. For instance, in 2003, less than 20 percent of the candidates who sat for these national examinations passed and the pass rate was worse in physical science compared to other subjects. Thus, people raised concerns about the quality of education through radio phone-in programmes, newspapers and television, with teachers taking most of the blame. I observed that teachers did not add their voice to the concerns. What did teachers think of the results? What were they doing about it?

In the same year [2003], I conducted a survey to explore if Malawian secondary school science teachers reflect on the teaching and learning process. It was found that 52 out of the 93 teachers surveyed did not engage much in reflection, as they tended to shift the blame to students. In the same survey, 37 of the 93 science teachers surveyed were under-qualified. The Malawi Government stipulates that a secondary school teacher should have a minimum qualification of a teaching diploma (Ministry of Education Sports and Culture, 2001). The following questions then arose: *How are the under-qualified teachers coping with teaching of science? How do they respond to students' learning difficulties and for what reasons? What differences, if any, exist between classes taught by under-qualified and qualified science teachers in terms of teaching methods, explanations, questions asked and assessment methods?*

1.2.2 Rating of nuclear physics as the most difficult topic

In the year 2000 I started working at Mzuzu University in Malawi as a lecturer in physics and physics methodology. My major task is to participate in the training of secondary school physical science teachers (PSTs). One component of the training programme is to familiarise student teachers with the senior secondary school physical science teaching syllabus (Ministry of Education Science and Technology, 2001), which is covered in form three and form four, that the student teachers are expected to handle once they start teaching. The senior secondary school physical science teaching syllabus (PSS) contains chemistry and physics topics and the physics topics fit into the following broad areas: properties of matter, forces and motion, electricity and magnetism, oscillations and waves and nuclear physics (Ministry of Science and Technology, 2001). One group activity that the student teachers engage in is to analyse these physics topics and arrange them in order of perceived difficulty, starting with the one they think is the most difficult. Between 2001 and 2006 I observed with five different cohorts that nuclear physics was always rated as the most difficult topic. When asked to explain why they choose nuclear physics as the most difficult, they responded that its concepts are abstract. Yet, the other topics, too, do contain abstract concepts. For instance, the concepts of current, resistance and energy, which appear under electricity, are abstract. It seemed appropriate to ask questions like: *What is it about nuclear physics that makes it difficult? Do practising teachers share the view that nuclear physics is the most difficult? If they share the view that nuclear physics is the most difficult, what criteria do they use to rate it as such? What is the teachers' understanding of nuclear physics concepts covered in the physical* *science syllabus and how does this understanding affect teaching? How do the teaching strategies employed compare with those recommended in the physical science syllabus?*

1.2.3 Summary of the research problem

From sections 1.2.1 and 1.2.2, the research problem for this study could be summarised as shown in Figure 1.1. The figure indicates that there are some topics that are perceived as difficult. For example, nuclear physics is perceived as the most difficult in the forms three and four physical science curriculum. It also indicates that there is poor performance of students during MSCE examinations.

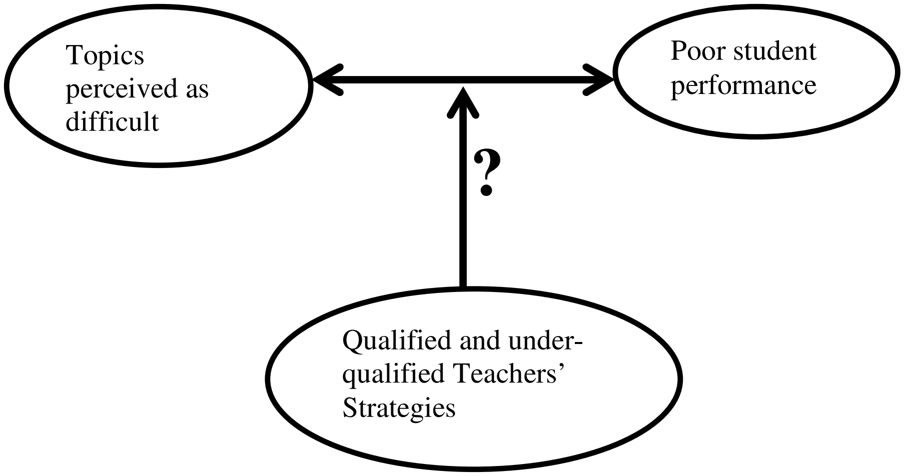

Figure 1.1: Schematic representation of the research problem

One could argue that the difficult topics are responsible for the poor student performance or that poor performance indicates that students find some topics difficult (Indicated by the double arrow in Figure 1.1). The problem is that it is not known how Malawian PSTs handle difficult topics in order to improve student understanding and performance.

1.3 Aims of the study

The aim of this study was to provide a qualitative and interpretive account, and hence better understanding, of the teaching strategies that the participating

Malawian PSTs used to help secondary school students understand physics concepts.

Specifically, the study addressed the following objectives:

1. To explore the reasons PSTs would give for choosing nuclear physics as the most difficult topic to teach.
2. To describe the nature of teaching strategies that Malawian PSTs use to deal with learning difficulties.
3. To explore the differences in the reasons that qualified and under-qualified Malawian PSTs give for choosing a particular teaching strategy.
4. To understand the nature of Malawian PSTs' pedagogical content knowledge (PCK) with respect to teaching and learning of concepts perceived as difficult.

1.4 Research questions

The questions I raised in sections 1.2.1 and 1.2.2 were reshaped and reduced into four questions in order to achieve focus. The four questions that formed the focus of this research were:

1. What reasons do Malawian PSTs give for rating *nuclear physics* as the most difficult topic to teach?
2. What teaching strategies do Malawian PSTs use to address difficulties students face in learning *nuclear physics* concepts?
3. What reasons do the teachers give for choosing some teaching strategies over others?
4. What can be learnt from the teaching strategies about the nature of Malawian PSTs' pedagogical content knowledge (PCK) with respect to nuclear physics?

1.5 Justification of the study

1.5.1 Preamble

The learning of physics is often considered by teachers and students to be a difficult pursuit (Jimoyiannis & Komis, 2001; McDermott, 1998). For teachers the difficulties could be due to the gap between the intellectual demands of the subject and their preparation in science, in this case physics (McDermott, 1991). For students there are often differences between what teachers think students have learnt and what the students might have actually learnt (Driver, Guesne, & Tiberghien, 1989; McDermott, 1991).

I argue that these mismatches between competence of teachers and demands of the subject on the one hand and between what teachers think students learn and what the students actually learn on the other hand lead to teaching difficulties for teachers and learning difficulties for students. This explains why over the last two decades a great deal of educational research has been directed towards the exploration of students' ideas and difficulties in learning physical concepts and processes (Jimoyiannis & Komis, 2001; McDermott, 1998). To my knowledge, no research has been done in Malawi to investigate how teachers address learning difficulties in physics. So, the gap highlighted in Figure 1.1 that it is not known how teachers help students understand difficult concepts remains. Therefore, I felt that studying how Malawian PSTs dealt with students' learning difficulties in physics topics would shed light on how the teachers interact with content to be able to elucidate it to students. It was expected that such understanding could lead to recommendations on how to develop the teaching skills of practicing and pre-service PSTs.

The PSS was introduced in Malawian secondary schools in 2002 (Malawi Government, Undated), so it could be treated as a new curriculum. According to Rogan and Grayson (2003), teachers re-conceptualise changes in their own terms and for their own context. This study would also shed light on how the PSTs are translating contents of the new curriculum into classroom activities.

1.5.2 Reasons for classifying a topic like nuclear physics as difficult

As already pointed out, pre-service PSTs at Mzuzu University identified nuclear physics as the most difficult topic in the PSS. They gave reasons like: it involves microscopic particles; it uses some mathematical concepts and practical work is difficult to arrange. It was possible for practising teachers to mention different criteria because, as Shulman (1987) observes, teachers are able to enrich their knowledge base through practice. It was envisaged that knowledge about criteria teachers use to classify a topic as difficult would help when planning to mount in-service programmes for science teachers and that science teacher educators in Malawi would build such knowledge into initial teacher training programmes. Such knowledge would also contribute to understanding of the teachers' PCK in nuclear physics.

1.5.3 Teaching strategies for dealing with learning difficulties

As mentioned earlier, students find the learning of physics difficult (Jimoyiannis & Komis, 2001; McDermott, 1998). McDermott (2001) has used the example of what happens in introductory courses at tertiary level to illustrate existence of learning difficulties in physics. Lecturers prepare lucid explanations, show demonstrations and illustrate procedures for problem solving in physics. The lecturers expect that in so doing students will develop important concepts, reasoning ability to apply the concepts in simple situations and the ability to relate the formalism of physics to objects and events in the real world. However, there is evidence that students do not make much progress towards these intended goals (McDermott, 2001). McDermott (2001) pointed out this in the context of the United States of America, but it should also be true for Malawi because students do struggle with physical science as evidenced by low performance during MSCE examinations. In Malawi, nothing that I know of has been done to study teaching strategies PSTs use to help students cope with topic-specific or general learning difficulties in physics topics. Therefore, the assertion that there is a missing level in science education research of trying to describe and understand what is, or should be, going on in science classrooms in terms of content-specific interactions of teaching-learning processes (Lijnse & Klaassen, 2004) is also true for Malawi. This study attempted to fill this gap in knowledge by investigating the strategies qualified and under-qualified PSTs employ in *nuclear physics*. Such knowledge was thought to be of practical importance to science teachers and educators who might tap it to improve their practice. Hence, it was argued that this research has potential to contribute in addressing the issue of low quality of education in Malawi. The study also provided an opportunity for me to understand more about how Malawian teachers try to assist students to understand apparently difficult subject matter.

1.5.4 Teachers' reasons for adopting or adapting certain practices

This study assumed that teachers do have theories and belief systems that influence their perceptions, plans and actions (Prawat, 1992; Wilson, Shulman, & Richert, 1987). This assumption is supported by findings from a study done among grade six teachers in Western Cape, South Africa, on how teachers' practices change (Scholtz, Watson, & Amosun, 2004). From their results, Scholtz et al. (2004) concluded that teachers often adapt a new strategy in response to an interaction between the new strategy and the situation in which they work. This shows that teachers engage in decision-making about how to teach particular content and there must be reasons behind the decisions taken. Identifying such reasons was expected to enrich understanding of physical science teaching in Malawi. Comparing them would shed light on what influenced the teachers to adopt certain approaches. Such understanding and knowledge would be useful in designing interventions aimed at improving the quality of science teaching.

1.6 Limitations of the study

This study used a case study approach. Thus, the major limitations were those associated with case studies: the low credibility of generalisations that could be made, the negative effect of the researcher's bias on objectivity and the effect of the researcher on the setting or individuals studied (Denscombe, 2003). To minimise effect of these weaknesses this study adopted Lincoln and Guba's (1985) approaches for ensuring that criteria for credibility, transferability, dependability and confirmability (discussed in Chapter 3) are met.

In qualitative research, credibility refers to the extent to which the researcher has portrayed the multiple constructions adequately; transferability refers to the process in which the researcher and the readers infer how the findings might relate to other situations; dependability relates to the quality and appropriateness of the inquiry process; and confirmability relates to the extent to which interpretations and recommendations are supported by the data in an internally coherent way (Lincoln & Guba, 1985).

1.7 Organisation of the thesis

This thesis has been organised into seven chapters, with each chapter divided into several sections and sub-sections. Arabic numbering has been used to indicate the different levels of section headings. Each chapter begins with an introduction and then other sections follow. In the introduction I state the problem to which the chapter is devoted, describe materials and methods for that part of the study and enumerate points to be covered. The rest of the thesis has been organised as in Table 1.1.

Table 1.1: Organisation of Chapters 2 to 7 of the thesis

Chapter	**Details**
2: Literature Review	Review of relevant literature Description and explanation of the theoretical framework
3: Research Design and methods	Type of study Negotiating access Selection of participants Data collection methods Data analysis methods
4: Difficult aspects of nuclear physics	Teaching and learning difficulties mentioned by PSTs in questionnaire responses Reasons for the difficulties Difficulties anticipated by case teachers Student learning difficulties observed in the lessons
5: Case teachers' teaching strategies	Content knowledge covered in the lessons Strategies used to try to address students' learning difficulties

	Reasons the case teachers gave for the strategies adopted
6: The case teachers' pedagogical content knowledge	The case teachers' ability to articulate main ideas, knowledge of difficulties associated with learning of those difficulties, knowledge of students or other factors that may have influenced choice of strategies, teachers knowledge of teaching strategies and the teachers ways of ascertaining student understanding
7: Summary of results, discussion and implications	Summary of results Discussion Implications Conclusions

1.8 Definition of terms

Some words and phrases have been used in ways that are specific to this study. These words are given and defined below.

Teaching strategy: This is an activity that a teacher plans to do, does or engages students in so as to achieve a specific learning outcome in students.

Learning difficulty: Learning difficulty refers to a student idea or learning outcome that is not consistent with the scientific view. It also refers to aspects of the lessons where students struggle to understand, as could be evidenced by the sort of questions or explanations from students.

Teaching difficulty: This is an aspect of a lesson or topic where students are likely to have learning difficulties. This definition has been adopted because the teacher has to anticipate and specifically plan to deal with the learning difficulty if student understanding is to be achieved, which sometimes is not easy.

Nuclear physics: Nuclear physics refers to aspects of nuclear physics taught in secondary schools in Malawi.

Pedagogical content knowledge (PCK): PCK refers to an amalgam of content and pedagogy that includes teacher knowledge about: big or key ideas of a lesson or topic, useful forms of representing ideas, what makes learning of a topic/lesson easy or difficult, ways of assessing learners' understanding of a topic/lesson and strategies likely to be fruitful in organizing learners' understanding of a specific topic, lesson or concept.

Case teacher: This phrase refers to anyone of the four teachers whose lessons I observed. *Qualified teacher:* This phrase refers to a teacher who possesses a qualification that is equivalent to or higher than a diploma in education, the minimum requirement stipulated by the Ministry of Education for one to teach at secondary school level in Malawi.

Under-qualified teacher: This phrase refers to a teacher who possesses a qualification that is lower than a diploma in education, yet is teaching at secondary school level. In most cases, such a teacher would possess a certificate that enables one to teach at primary school level.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews some of the literature that is relevant to this study. A literature review is an attempt to interpret and synthesise what has been studied, researched and published in an area of interest (Aleman, 1999). Various authors (e.g. Aleman, 1999; Denscombe, 2002; Harlen & Schlapp, 1998) agree that some of the functions of a literature review are to:

1. Clarify what is already known, what theoretical frameworks have been developed, and what has already been done, so that unintentional replications can be avoided.
2. Identify gaps in current knowledge and where further research is needed.
3. Contribute to formulation of the problem, questions and objectives of the research in question.
4. Show the researcher's familiarity with existing ideas, information and practices related to the area of study.

Knowledge about functions of a literature review acted as a guide in the creation of sections for this chapter.

The aim of this piece of research was to study teaching strategies used to address leaning difficulties in physics. Therefore, there are sections dedicated to review of literature on general and content-specific teaching strategies, reasons teachers use some strategies and learning difficulties in physics. The theoretical framework that guided this study is also described and explained. The main sections of the chapter are as follows:

1. Importance of subject matter knowledge in teaching
2. Nature of science and its relation to science teaching
3. General teaching strategies
4. Science teaching strategies
5. Teaching strategies in physics

6. Reasons for studying teaching strategies
7. Learning and teaching difficulties in physics
8. Research paradigm and theoretical framework

2.2 Importance of subject matter knowledge in teaching

To understand teaching strategies employed, subject matter that provides the teaching context is important. Borko and Putnam (1996: 690) argue that subject matter of teachers makes a difference

> In how they teach, and that novice and experienced teachers alike often lack the rich and flexible understanding of the subject matter they need in order to teach in ways that are responsive to students' thinking and that foster learning with understanding.

Even's (1990) argument that a teacher who has solid mathematical knowledge for teaching is more capable of helping his/her students achieve a meaningful understanding of the subject matter should apply to physics as well because the two subjects are related. For instance, it was found in Hong Kong with junior secondary school science teachers (most of whom had BSc degree qualifications) that these teachers did not possess sufficient substantive content knowledge to teach physics parts of the junior science curriculum (Yip, Chung, & Mak, 1998). Such deficiencies must have affected these teachers' ability to explain the subject to students. Focus on subject matter is important in understanding teaching because, as Shulman (1986) points out, it could influence researchers to focus on how subject matter knowledge is transformed from knowledge of the teacher into knowledge for instruction.

But what constitutes knowledge of subject matter? Shulman (1986) asserts that content knowledge goes beyond knowledge of facts or concepts of a domain and also includes understanding of the substantive and syntactic structures of subject matter. Shulman (1986: 9) writes,

> The substantive structures are the variety of ways in which the basic concepts and principles of the discipline are organised to incorporate its facts. The syntactic

> structure of a discipline is the set of ways in which truth or falsehood, validity or invalidity are established.

He argues that such understanding could help teachers comprehend why a topic is central to a discipline and influence pedagogical judgements regarding relative curricula emphasis. This study investigated teaching strategies in physics using the case of nuclear physics. Therefore, it provided an opportunity for me to understand how the PSTs' syntactic and substantive knowledge in nuclear physics affected their teaching strategies.

2.3 Nature of science and its relation to science teaching

Howe and Jones (1993: 6 - 7) have tried to answer the question "*What is science?*" in the following way:

> Scientists proceed on the belief that the world is understandable and that there are discoverable patterns throughout nature. Science is a way of finding out what those patterns are. Scientists use both their own senses and various instruments – sometimes very complicated ones – to observe the world, they use their minds and imaginations to create theories and hypotheses to explain what they have observed.

This description contains various aspects of science. First, there is an assumption that the world contains patterns that can be understood by people called scientists. In other words, making assumptions is part of science. Secondly, the scientists use their senses to observe the world, sometimes with the aid of instruments. Third is that scientists use minds and imaginations to create theories and hypotheses. Lastly, scientists attempt to explain what they have observed. In all these aspects, there is need for human judgement. Crowe (1999) points out that the scientific process involves profoundly human qualities. Human judgement is always subject to errors, challenge and revision. Hence, as Howe and Jones (1993: 7) argue, "Science will never be a finished body of knowledge because new ideas and theories are always being proposed and new discoveries are being made."

The question "*What is science?"* has also been answered by emphasising what scientists do as the following excerpt shows:

> Scientists seek basic truths about nature. Such truths are often called facts. … Using the facts they have learned, scientists propose explanations for the events they observe in the world. Then they perform experiments to test explanations. After a study of facts, observations and experiments, scientists may develop a theory. A theory is the most logical explanation of events that occur in nature. Once a scientific theory has been proposed, it must be tested over and over again. If test results do not agree, the theory may be changed or even rejected. … When a scientific theory has been tested many times and is generally accepted as true, scientists may call it a law. But even laws can be changed as a result of future observations and experiments (Hurd, Silver, Bacha, & McLaughlin, 1993: 7).

Hurd et al.*'s* (1993) answer illustrates a number of characteristics of science.

1. Science is about observing the world around you using senses and instruments. This aspect of science leads to a collection of facts.
2. Science is about trying to explain what is observed in the world. This is mainly achieved through the use of imagination.
3. Science is about designing and performing experiments to test the generated explanations.
4. Science is about developing theories, which are most logical explanations of events.
5. Science is about testing the developed theories.

The two approaches of answering the question '*What is science'* described here show that science can be looked at as a process, as well as a product in the form of principles, theories and laws. Thus, to be scientifically literate, a person needs to have knowledge of the concepts and theories of science and an understanding of how this knowledge has been obtained in the past and is still being learned today (A. C. Howe & Jones, 1993). This implies that teaching physics should not only involve the content of physics but also *about* physics (Crowe, 1999). Thus, I argued that design of teaching-learning sequences should be guided by one's explicit view of science (Lijnse & Klaassen, 2004). So, in studying teaching strategies in physics, it is important to relate those strategies to the nature of the subject assumed.

The theme that has come out clearly in attempting to answer the question '*What is science?'* is that scientific theories and laws are subject to change as they are subjected to testing. How do scientists test theories? One way of testing theories is that scientists derive predictions from their ideas, and test those predictions, when this is possible (Putnam, 1987). Once the experiment is made and it confirms the predictions obtained from theory, then the theory is considered to truly correspond to relations among things (Duhem, 1968). Making observations and determining the extent to which the theory explains those observations is another way of testing theories. In framing a theory, one has to consider the agents on which it depends, or the causes to which it can be regarded as referable (Herschel, 1968). An example of an agent would be 'force'. According to Herschel (1968: 102), one can get the laws that regulate the action of agents as follows:

> By inductive reasoning; that is, by examining all the cases in which we know them to be exercised, inferring, as well as circumstances will permit, its amount or intensity in each particular case, and then piecing together, as it were, these *disjecta membra*, generalising from them and so arriving at the laws desired.

The first way of testing theories is called the *critical tendency* and the latter the *explanatory tendency* (Putnam, 1987). Physics teaching needs to reflect both tendencies if students are to develop a useful conception of science in general and physics in particular.

2.4 General teaching strategies

Teaching strategies can take different forms. Scholtz et al. (2004) explored how teachers' practices changed in response to a curriculum innovation in South Africa. They focused on how the teachers grouped the students, selected and implemented their own activities and how they facilitated student activities. These activities required a combination of thinking and action; hence there is some agreement with the assertion that the heart of teaching is the capacity for intelligent and adaptive action (Shulman & Shulman, 2004). Some of the examples of intelligent and adaptive action given are: adaptation of the curriculum, classroom management, formal and informal assessment of students. In other words, teaching is a practice that integrates reasoning and action (Ball, 2000). Shulman (1987) has developed a model of pedagogical reasoning and action. It includes six aspects of the teaching act: comprehension, transformation, instruction, evaluation, reflection and new comprehension. These six aspects emphasise that teaching is a process of thinking and action. Thus, in this study, *teaching strategies* refer to the reasoning and actions a teacher engages in to facilitate student learning, especially of concepts perceived as difficult by the teachers. This definition was preferred in this research because it focuses on both: the teachers' reasoning and class activities. What shapes teaching strategies?

One factor that might shape teaching strategies is craft knowledge. Craft knowledge is integrated knowledge that represents teachers' accumulated wisdom with respect to their teaching practice (Shulman, 1987; Van Driel, Verloop, & de Vos, 1998). Such knowledge is called practitioners' knowledge and possibilities of building a useful knowledge base of teaching by beginning with such knowledge have been explored (Hiebert, Gallimore, & Stigler, 2002). Hiebert et al.*'s* (2002) argument was that everyday millions of teachers produce knowledge of teaching, so it is worth examining what would be needed to transform teachers' knowledge into a professional knowledge base. Shulman's (1987) model of teaching as pedagogical reasoning and action includes an indication of how craft knowledge is generated and developed: after instruction, teachers evaluate and reflect on it leading to new comprehension that can influence subsequent practice. It seems plausible to conclude that since this process of evaluation and reflection is continuous, craft knowledge also changes and develops continuously. In turn, teaching strategies can change and develop in light of new comprehensions. In this study, I involved PSTs with a minimum of two years' teaching experience. Therefore, I assumed that those teachers must have developed some craft knowledge about how to teach specific topics like nuclear physics. No study has been done in Malawi to investigate how PSTs teach nuclear physics, hence this study.

Other factors that might shape teaching strategies are the teachers' beliefs. Borko and Putnam (1996) reviewed literature on how teachers learn to teach. They observed that the ways in which both prospective and experienced teachers learn to teach in new ways are highly influenced by what they already know and beliefs about teaching, learning and learners. Lederman (1992) reviewed the literature and noted that initial research on teachers' and students' conceptions of the nature of science assumed that a teacher's behaviour and the classroom environment are influenced by the teacher's conception of the nature of science. For instance, Greca and Moreira (2000) assert that modelling is the scientists' main activity, and of physicists in particular, for the generation and application of scientific theories. Hence, they conclude that learning physics implies learning to play `the modelling game'. These arguments appear to suggest that if a teacher believes that science is about modelling, then her or his teaching strategies will be characterised by use of modelling.

A study done at the New Jersey Institute of Technology in America (Gautreau & Novemsky, 1997) illustrates that the power of teachers' beliefs influences teaching practices well. The physics department at New Jersey Institute of Technology compared the performance of students taught in a traditional way and those taught using concepts first followed by small group learning (OCS) approach. It was found that those taught using concepts first followed by small group approach performed well. Gautreau and Novemsky concluded that ability to make sense of physics concepts, along with the student's development of conceptual ideas, appears to take place when primary instruction is followed with small group collaborative activities. However, those instructors who believed in the traditional approach could not adopt the OCS approach as the excerpt below shows:

> One might think that the traditional physics instructors would respond positively to these results, embracing the OCS methodology as an excellent way for students to learn introductory physics. But the educational experiment comparing OCS and traditional instruction was never repeated. The reaction of the instructors teaching Phys. 111 in the

> traditional manner was to try to ignore the results. They refused to cooperate in any further comparative experiments (Gautreau and Novemsky, 1997: 423)

The reaction of those who believed in the traditional approach is not surprising because, as Borko and Putnam (1996) point out, teachers' knowledge and beliefs about teaching, learning and learners are also shaped by years of their own school experience and can be highly resistant to change. In this study, I asked teachers to state reasons for choosing certain strategies with the hope that this would reveal the teachers' underlying beliefs about their practice.

As mentioned in section 2.2, teachers' subject matter knowledge also influences teaching strategies. Gollub and Spital (2002) analysed conclusions of a two-year analysis of advanced high-school science and mathematics education in the U.S by the National Research Council. They emphasised the recommendation that effectiveness of advanced physics courses can be improved if learning physics is thought to be the development of deep conceptual understanding of principles and phenomena, including the ability to apply knowledge to new situations. This can only be achieved if a teacher understands the subject. Shulman (1987: 9) emphasises this in the following words:

> A teacher is a member of a scholarly community. He or she must understand the structures of subject matter, the principles of conceptual organisation, and the principles of enquiry that help answer two kinds of questions in each field: What are the important ideas and skills in this domain? and how are new ideas added and deficient ones dropped by those who produce knowledge in this area?

How does subject matter influence teaching strategies? Explanations are an important part of science teaching (Harrison & Treagust, 2000). Harrison and Treagust examined the role of explanation in science education by analysing Richard Feynman's *Six Easy Pieces* to identify the characteristics of an effective explanation. They concluded that content factors like importance of the concept, whether the idea is central or not, and whether the concept is a law, a theory or a hypothesis influence a teacher's explanations. In Canada, a study was done to explore the utility of Shulman's concept of PCK in articulating the manner in which chemistry teachers transform subject matter content for teaching (Geddis, Onslow, Beynon, & Oesch, 1993). The study involved two student teachers and their cooperating teachers. It was concluded that a teacher's ability to transform the subject matter into a form that is accessible to students depends on the teacher's knowledge about subject matter related to its 'teachability'. This supports the argument that a teacher who has solid content knowledge for teaching is more capable of helping his/her students achieve a meaningful understanding of the subject matter (Even, 1990).

In summary, the following three factors that affect teaching strategies have been identified: craft knowledge, the teacher's beliefs about teaching, learning and learners, and subject matter knowledge. These factors are context-dependent and differ from one teacher to another in intensity, so the variety of teaching strategies is wide. However, where these factors are fairy uniform, patterns in teaching strategies may be observed. These factors have been used to explain some of the observed patterns in teaching strategies in this study.

2.5 Science teaching strategies

2.5.1 Explanations in science teaching

Explanations are an important part of science teaching. Treagust and Harrison (2000) analysed an exemplary set of explanations from Richard Feynman's *Six Easy Pieces* to identify characteristics of an effective explanation. They found that Feynman emphasised the pivotal issues while ignoring the "noise" or unimportant content. Thus, as these authors contend, it becomes important for a teacher to consider content factors such as importance of the concept in the course and whether the idea is central or not when framing explanations. Jones and Baker (2005) also concluded from the literature they reviewed on effective pedagogy in science education that students might experience more success where pedagogy includes introducing less 'content' at any one time so that it can be more fully explored. Gollub and Spital (2002) discussed findings of the National Research Council research on Advanced Placement courses commissioned in America and argued that learning is facilitated when knowledge is structured around major concepts and principles.

Treagust and Harrison (2000) also found that another characteristic of Feynman's teaching explanations was the use of metaphors, analogies, and models to foster a sense of realism. Coll (2005) argues that the use of analogies and models within the pedagogy of science education may provide a route for students to gain some understanding of the nature of science and the scientific enterprise. Geelan (2003) presents a case study of one teacher's excellent skills in explaining physics concepts in rich, coherent ways to students. He found that the teacher talked for 95 per cent of the time and that it was easy to dismiss his approach as 'transmissivist'. According to Geelan (2003), what made this teacher's explanations excellent was that they had the characteristics spelt out by Treagust and Harrison (2000): use of rich and creative metaphors, analogies and models containing anthropomorphisms and teleological expressions.

The interaction between notions of 'teaching for understanding' and 'exemplary practice' in physics teaching were compared with examples of the actual practice of a successful Australian physics teacher named Simon (Geelan, Wildy, Louden, & Wallace, 2004). Geelan et al. (2004) interviewed Simon about his attitudes and beliefs in relation to teaching and learning and conducted focus group discussions with five of the teacher's students regarding issues of teaching and learning. Three hours of Simon's physics lessons were videotaped. Results showed that although the teacher talked for most of the time (82 % of the time), the students had good understanding of the physics ideas about which they were learning and were able to apply that understanding in novel situations. Focus group discussions revealed that students liked Simon's strategy because he had good rapport with the class, liked and respected the students and demonstrated that he knew what he was talking about. Geelan et al. (2004) argue that Simon's teaching from the front of the class was not simply lecturing and note-giving, but an on-going conversation with the class, with questions asked to particular students (widely distributed within the class), and often followed up by a number of interactions. They concluded that there was a high degree of cohesion between what students were experiencing in the classroom and what they believed to be valuable strategies for their own learning. Thus, according to Geelan et al. (2004), Simon's strategies met the following three characteristics of teaching for understanding: focused and coherent instruction, a negotiated style of interaction and an analytic or diagnostic approach by the teacher (Prawat, 1989b).

The literature reviewed in this section shows that effective teacher explanations should have the following characteristics:

1. Focus on central or important ideas, while ignoring unimportant ones.
2. Use of metaphors, analogies and models to foster sense of realism.
3. Negotiated style of interaction
4. An analytic or diagnostic approach by the teacher.

These characteristics were compared with the case teachers' explanations. This helped to gauge the effectiveness of the case teachers' explanations.

2.5.2 Cooperative learning strategies

Van Heuvelen (1991) administered a paper and pencil test to 152 engineering students who had done one semester of introductory physics and analysed patterns in performance on the test. To encourage learning with understanding, Van Heuvelen found that active cooperative learning in lectures should provide opportunities for students to:

1. Be active participants during lectures in constructing concepts, reasoning qualitatively using the concepts, and in solving problems;
2. Evaluate their own thinking and that of their classmates;
3. Make unpenalised mistakes while getting immediate feedback from the professor.

Grossman (2005) agrees with some of these strategies in a paper that introduces a classification scheme for locating and correcting places where courses are unintentionally made more difficult for students by cataloguing the kind of transformations that students are expected to make on a regular basis. He describes seven types of transformations, which he claims give students difficulties. Procedural transformations involve transforming knowledge so that abstract concepts can be converted into a procedure that can be used in concrete situations. Conceptual transformations occur when students abstract more general principles from procedural knowledge. Transforming knowledge so that a concept or procedure can be used on a problem embedded in a new situation is a case of contextual transformation. When students use symbols to represent relations or translate English sentences into algebraic equations, they engage in symbolic transformations. Metaphorical transformation is the use of one kind of symbol system to stand for or represent a concept that was originally expressed in a different symbol system such as the use of a "frictionless world", which is different from what the students have experienced, to understand motion. Students engage in analogical transformation when they are required to locate the likeness between two concepts or operations. Arbitrary transformations are those often fixed by the history of a field and therefore have little obvious rational basis like the use of common words in an uncommon way. Some procedures for deepening learning of these transformations are grouping students into cooperative work teams of four to work out problems in class and allowing students to articulate their reasoning process (Grossman, 2005).

Coll (2005) believes that the use of cooperative groups in science teaching could help students understand scientific models as the following excerpt shows:

> … a discussion with peers has the potential to provide students with alternative models of scientific phenomena and to introduce criteria as well as evidence to help learners to distinguish among scientific models. Such an activity is enhanced with the utilization of cooperative learning strategies (Page 190).

To ensure effectiveness of cooperative learning strategies, Coll emphasises the need for a more 'humanistic' kind of argument in which all students feel comfortable to listen to ideas of others, to question these without angry rebuttal and to introduce their own ideas, modifications and opinions in order to build towards shared understanding. Also, there should be explicit reference to evidence that supports such arguments so as to ensure that such discussions are focused towards clear conceptual outcomes. The research reviewed by Coll (2005) identifies the following barriers to the use of cooperative groups: teachers tend to take a more dominant role due to lack of knowledge of how to manage group discussions effectively, external pressures leading to lack of time, demands to cover the curriculum and demands of the assessment system.

The literature reviewed here indicates that teaching that encourages cooperative learning should provide opportunities for students to reason with concepts, to apply those concepts and to evaluate their thinking so as to facilitate understanding of concepts or ideas. I agree with this assertion because such a strategy allows students to practise the process skills that scientists employ. However, there might be need to address the barriers Coll (2005) raises if teachers are to fully adopt cooperative strategies.

2.5.3 Problem solving strategies

Rawy (1999) interviewed eight lower academically performing A-level students about how to solve a problem that needed application of the equations for constant acceleration and found that, although a few did have difficulties with mathematical techniques, many of their difficulties were related to the way they approached the problem. Rawy suggests the following strategies for helping students with problem solving in physics:

1. Use of algorithms: showing students steps in thinking that an expert would go through in solving problems.
2. Use of heuristics: giving students a general heuristic for solving mathematical physics problems like instructing students to read a question carefully and note important data.
3. Cooperative group work: allowing students to work in groups where they can discuss and learn from each other's ideas.
4. Reflection and metacognition: using 'metacognition' for students to reflect on their own thinking and the methods they use.

5. Bridging: getting students to think about how the methods that they used could be applied to other problems. This would allow students begin to make the methods that they have discovered more general, with a greater range of uses.
6. Modelling: encouraging students to think in terms of finding a 'model' (e.g. an equation) that describes as well as possible the phenomenon that they are investigating.

Other authors also recommend some of these methods. For instance, Howe and Jones (1993) contend that in a Vygotskian perspective, a science teacher should create opportunities for cooperative learning, modelling and peer tutoring. Schecker and Niedderer (1996) describe a six-stage teaching sequence, which they call 'contrastive teaching'. In the sixth stage students look back on their problem solving processes and also consider methodological and epistemological issues, which is metacognition.

2.5.4 Modeling strategies

Modelling is one of scientist's main activities (Coll, 2005; Greca & Moreira, 2000; Harrison & Treagust, 2000). Harrison and Treagust (2000: 1011) argue, " … science and its explanatory models are inseparable because models are science's products, methods and its major learning and teaching tools." They refer to all the analogical models used in teaching and learning, including scale models, as 'pedagogical analogical models' because the models share information with the target and are teacher-crafted explanations that make non-observable entities like atoms and molecules accessible to students. Treagust, Harrison and Venville (1998) point out the following benefits of using analogies as a teaching strategy:

1. Concrete analogs facilitate understanding of the abstract concepts by pointing to the similarities between objects or events in the students' world and the phenomenon under discussion.
2. Use of ideas from students' world of experience generates intrinsic sense of interest in the students.

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3. Analogies could enhance conceptual change learning by opening up new perspectives.

However, as Harrison and Treagust (2000) indicate, students find it hard to generate or select appropriate analogies for a given situation and that they are most likely to apply an analogy to a concept when the teacher supplies the analogue; even though the students still find mapping it difficult. Greca and Moreira (2000: 2) emphasise one of the problems associated with scientific models in the following excerpt:

> …the assumption that conceptual models - because they are logically clear and often specially designed to facilitate both comprehension and learning - should be learned by students, who, besides representing reproductions of those models in their heads, should be able to use them to establish relations between the theory presented and the phenomena, is not necessarily true. Neither do mental models end up as perfect copies of conceptual models, which are generated by experts and teachers, nor is the modeling process evident to our students.

Greca and Moreira reason that these problems arise because students do not have the necessary knowledge of the field for interpreting conceptual models and students often do not understand that a conceptual model is a simplified and idealized representation of phenomena or situations.

To solve the teaching problems of scientific models, Harrison and Treagust (2000) suggest that teachers need to systematically plan model and analogy use in their lessons and recommend the use of an approach involving the 'Focus, Action and Reflection (FAR)' approach to teaching. The following excerpt describes the FAR approach to teaching:

> *Focus* involves pre-lesson planning where the teacher focuses on the concept's difficulty, the students' prior knowledge and ability, and the analogical model's familiarity. *Action* deals with the in-lesson presentation of the familiar analogy or model and stresses the need for the teacher and students to co-operatively map the shared and unshared attributes. *Reflection* is the post-lesson evaluation of the analogy's or model's effectiveness and identifies qualifications necessary for subsequent lessons or

> modifications next time the analogy or model is used. (Harrison & Treagust, 2000: 1019 - 1020)

In using analogies and models, Harrison and Treagust (2000) also suggest that teachers should introduce models that match the student's conceptual ability. Such selection is possible because, according to these authors, there are different model types of varying complexity depending on their concrete or abstract nature. This is the case because it is possible to have more than one model for a target system (Snyder, 2000).

I feel the FAR strategy is likely to lead to better conceptual understanding for a number of reasons. During planning, the teacher would identify all the possible problems associated with a model and anticipate them by tailoring the model to students' abilities. In the action phase, students would be actively involved in mapping the shared and unshared attributes; hence it would be clear where the model breaks down. During reflection, the teacher would look for areas for improvement, which would hopefully lead to refinements in subsequent lessons. However, the FAR strategy may not work if the teacher is not dedicated because it requires systematic planning and implementation.

Schecker (1993) used examples from a project done by the University of Bremen, Germany, with several high school physics courses, in which modelling became a regular activity from grades 11 to 13. Students were encouraged to engage in student-directed discussions to develop models from scratch. In another school, students often worked in the computer lab and designed models in groups of two or three. It was found that icon-oriented modelling could make conceptual problems explicit and help to clarify the qualitative meaning of physical notions. This research demonstrated that modelling could aid understanding of scientific phenomena as Schecker (1993: 102) argues:

> Physics teaching seems to put too much emphasis on solving equations and calculating numbers without securing a qualitative understanding of the key concepts. Modelling packages can help to accentuate the concept structure of a physical domain. Icon-oriented modelling environments like *Stella* force the students to engage in a qualitative

> analysis. Before special functional relationships can be defined, the conceptual structure of the model has to be formulated.

Schecker argues that the task of a modelling program is not only to do mathematics, but that modelling software for educational purposes should help students and teachers to:

1. Decide qualitatively the variables to be considered and how they interact.
2. Define the relationship between variables quantitatively.
3. Pre-formulate the model equations for a numerical solution.
4. Choose from a variety of tables and graphs for data presentation.
5. Edit the model without the need to learn a programming language.

Schecker's findings support Coll's (2005) observation that enabling students to construct and critique their own models and scientists' models of scientific phenomena effectively supports conceptual development outcomes. To facilitate the modelling process effectively, teachers need to have a good pedagogical content knowledge about the role of models, metaphor and analogy in scientific communities of practice and to be aware of the range of possible mental models of scientific phenomena that their students may hold (Coll, 2005).

For instance, Snyder (2000) investigated the knowledge structures of experts, intermediates and novices (total of 27 subjects with nine in each category) in physics with the aim of understanding the role of models and theories in the structure of physics knowledge. The nine novices were students who had completed one semester of classical mechanics at introductory level; intermediate subjects were first or second year graduate students who had completed a bachelors degree in physics; and the nine expert subjects were university professors who had been involved in teaching and research in physics for at least 10 years. The subjects categorized a set of 18 problems iteratively from intermediate level classical mechanics text. It was found that novices' hierarchies were entirely composed of model-based attributes as compared to experts and intermediates whose categorizations were mixed between models and theories at lower levels. This result would qualify as an important aspect of PCK that a teacher who intends to use models should have. Such PCK would guide the selection of appropriate models to use with students.

2.5.5 Conceptual change strategies

A number of authors and researchers have written about the view that teaching should encourage conceptual change (e.g. Duit & Treagust, 2003; Grayson, 1996; Hewson, 1996). Hewson (1996) describes learning as a process of conceptual change in which a person changes his or her conceptions by capturing new conceptions, restructuring existing conceptions, or exchanging existing conceptions for new conceptions. Hewson observes that a key factor in the learning process is the status that new and existing conceptions have for the learner, which is the extent to which a conception meets the conditions for conceptual change of *intelligibility, plausibility* and *fruitfulness* to the learner. He argues that if a learner sees that a conception conflicts with an existing one, he or she cannot accept the new one unless the status of the existing one is lowered. Duit and Treagust (2003: 673) explain that:

> If the learner was dissatisfied with his/her prior conception *and* an available replacement conception was intelligible, plausible and/or fruitful, accommodation of the new conception may follow. An intelligible conception is sensible if it is non-contradictory and its meaning is understood by the student; plausible means that in addition to the student knowing what the conception means, he/she finds the conception believable; and, the conception is fruitful if it helps the learner solve other problems or suggests new research directions.

It should be clear that the kind of knowledge a learner possesses (i.e. his or her conceptual ecology) provide the context in which conceptual change occurs (Hewson, 1996). Thus, it would seem teaching strategies that aim to encourage conceptual change should focus on conditions for conceptual change and the conceptual ecology of the learners. Hewson (1996) suggests the following strategies:

1. Eliciting different views with the aim of making explicit range of views about the topic that the class members might hold through a quiz followed by class discussion or a demonstration that can generate discussion.
2. Engaging students in changing the status of some of the elicited conceptions, which entails decision-making.
3. Explicitly taking into account the importance of the students' views and conceptual ecology in teaching.
4. Encouraging metacognition so that learners become aware of their cognitive processes and products.

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For the above strategies to work well Hewson indicates that:

1. The teacher should assume the role of manager, active participant without dominating or being threatening, and should respect students' views.
2. Learners should take responsibility for their own learning, trust their own thinking and justify their conclusions using sensible arguments. They should also respect other views and be prepared to change their view if another seems to be more viable.
3. The classroom climate should encourage respect for alternative ideas, careful listening to other ideas, freedom to express ideas openly, freedom to disagree with other ideas, freedom to ask for clarification, separation of a person from the idea, shared understanding that the goal of discourse is the achievement of shared meanings about the topics.

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To understand why Hewson stresses importance of roles of the teacher, learner and classroom climate in encouraging the suggested conceptual strategies, one could consider what would happen if these conditions were not met. For instance, if the teacher dominates, students will be passive and passive students cannot engage in metacognition. Also if there is no respect for alternative ideas, students would not be free to express themselves and this would make it difficult for the teacher to elicit the student's conceptions.

A strategy called *concept substitution* is recommended for promoting conceptual change when students express an intuitive idea that is correct in terms of explaining some observed phenomenon, but is associated with an inappropriate physics term by the students (Grayson, 1996). Grayson suggests a method that reinforces the correct idea and substitutes the correct term. Grayson tried the strategy with foundation physics students at the University of Natal, South Africa. It was found that the strategy showed positive results. One problem is that the strategy was tried at university level and there would be need to try it at high school level as well.

Duit and Treagust (2003) suggest that a teacher could use models as teaching and learning tools in the conceptual change model. They argue this could be done by:

1. Allowing students to describe, explain and use models that scientists use to communicate science outcomes and to plan and implement its methods.
2. Determining if the students are level one, two or three modellers or a combination of these.
3. Using the model levels to determine the status of students' conceptions and modelling level changes that might provide useful evidence for conceptual changes.

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Schecker and Niedderer (1996) have proposed a six-stage strategy, which they have called *contrastive teaching*. The strategy is based on the argument that if students are not aware of their intuitive notions, they will hardly be able to learn a related concept. Hence, considerable teaching effort is required to help students notice the difference between their intuitive views derived from everyday experience and the scientific view based on theory-laden experiments (Schecker & Niedderer, 1996). Table 2.1 shows the six stages of contrastive teaching. The contrastive teaching consists of a number of other strategies as well. These other strategies are:

1. Experimentation in the first three stages, including working out questions and hypotheses.
2. Uses of cooperative groups in stage three.

3. Whole class discussion, with some room for argumentation.
4. Some aspect of critiquing scientific models and theories.
5. Uses of some metacognition in stage six.

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Table 2.1: Six stages of contrastive teaching

Stage 1: Preparation - Conventional teaching, with demonstration experiments and teacher-dominated presentation of concepts
Stage 2: Initiation - Teacher poses open-ended problem and sketches a broad framework of student activities or shows an initial experiment without explaining it. The students work out questions and hypothesis
Stage 3: Performance - Students perform experiments, calculations and derivations and formulate the results in their own words in groups. Teacher acts as counsellor by supervising organised working process by encouraging students to write down questions, ideas, intermediate results and findings.
Stage 4: Discussion of findings - Groups present results to class; teacher writes notes of student presentations, using student words, students compare findings and try to arrive at common conclusions. Teacher challenges students' ideas, pointing out inconsistencies and suggesting further experiments; students defend their notions, and perhaps modify them
Stage 5: Comparison with scientific theory - Teacher brings in scientific explanation as an alternative view and compares with students' ideas. Commonalities and differences are made explicit, emphasizing universal applicability and precise prediction of scientific theory over student notions.
Stage 6: Reflection - Students look back on their problem-finding and problem-solving processes and consider methodological and epistemological issues, tapping from findings from philosophy of science.

I argue that the use of a combination of strategies is likely to lead to better understanding of concepts because, as Gollub and Spital (2002) point out, this would lead to accommodating differences in the ways people learn. Also, there are different kinds of knowledge that students are supposed to learn (A. C. Howe

& Jones, 1993). Therefore, it can be argued that the combination of strategies takes into account these different kinds of knowledge. Howe and Jones (1993) have identified the following kinds of knowledge:

1. Social-arbitrary knowledge, which includes names, symbols, procedures, conventions and rules. This knowledge can only be learnt from other people directly or indirectly.
2. Physical knowledge, which is knowledge arising from direct experience and observation of objects and events.
3. Logical knowledge, which encompasses concepts, conclusions and higher order ideas derived from thinking about observations or experiences. The learner has to construct such knowledge in his or her mind.
4. Social-interactive knowledge, which is knowledge gained through interaction with other people like how to work cooperatively.

No single strategy can help students learn all these kinds of knowledge. Therefore, multi-strategy approaches like contrastive teaching are likely to be more effective.

2.5.6 Use of history

The literature suggests that aspects of history of science could be used in science teaching (Seroglou & Koumaras, 2001). For instance, Seroglou and Koumaras point out that by acquainting students with certain events and stories from the history of physics pertaining to methods that famous physicists used in order to experiment and evolve their theories, the students could be facilitated to understand the methodology of physics. Crowe (1999) highlights Duhem’s view that one of the methods of preparing a student to receive a physical hypothesis is the historical method. With this method, students trace the development of scientific ideas and how scientists came to agree on those ideas. Newton (1987), asserts that the use of history of physics would *humanise* it. By humanising science, Newton seems to refer to the portraying of science as a human activity, model for problem solving and as a way of viewing reality. One of the benefits of this strategy is that it would develop interest in the students.

2.5.7 Teaching science in context

A final strategy in this review is the teaching of science in context. For instance teaching in context is prescribed in the Victorian Certificate of Education in Australia (Vignouli, Hart, & Fry, 2002). One way of teaching in context is to structure a teaching unit around a series of case studies of everyday issues and contexts and then drawing out scientific concepts where they arise (Millar, Klaassen, & Eijkelhof, 1990).

Vignouli et al. (2002) used a case study approach to investigate how three experienced physics teachers in Australia, Victoria interpreted what it means to teach physics 'in context'. They found that the teachers felt the approach could promote participation in physics and reduce the reliance on the 'chalk and talk' teaching strategy. However, the teachers felt that it is hard to prepare for teaching in context. It was also felt that students might not be able to transfer their learning and apply the concepts to situations outside the contexts in which they are learnt. Actually, Millar et al. (1990) point out one difficulty with this approach: selection of appropriate contexts as such contexts differ considerably in terms of the difficulty and complexity of the science concepts needed to understand them.

2.5.8 Summary on strategies used in science teaching

In section 2.5, literature related to strategies used in science teaching has been reviewed. The review has identified seven major categories of strategies and these are:

1. Use of explanation.
2. Cooperative learning strategies.
3. Problem solving.
4. Use of models and modelling.
5. Adoption of strategies based on conceptual change.
6. Use of the historical strategy.
7. Teaching science in context.

These strategies have been found to share a lot of features. For instance, metacognition is a feature of conceptual change, cooperative learning, modelling and problem solving strategies. Analogies apply to all the above strategies. What then makes one strategy different from another? It is the emphasis put on certain features and the packaging of the strategies.

Why has the literature on teaching strategies been included in this report? Firstly, this research investigated teaching strategies in physics teaching, hence it became important for me to understand more about science teaching strategies in general. Secondly, knowledge of teaching strategies guided the coding of interview and video transcripts with respect to teaching strategies. Finally, this review provided benchmarks against which to compare the participating teachers' strategies.

2.6 Teaching strategies in physics

2.6.1 Traditional physics teaching

A number of researchers and authors have lamented the poor quality of physics teaching (e.g. Aiello-Nicosia & Sperandeo-Mineo, 2000; Flores, López, Gallegos, & Barojas, 2000; Newton, 1987). Aiello-Nicosia and Sperandeo-Mineo's (2000: 1085) have remarked as follows: "Many conferences and papers have documented a growing dissatisfaction with the quality of physics teaching and learning". Flores et al. (2000) point out that teaching of physics in Mexico, as in many other countries, can be typified as traditional, which means the teaching is focussed on transmission of content. Newton (1987) observes that although physics teaching should aim at educating in physics, through physics and about physics, it is the educating in physics that consumes a teacher's energy, while the other two are largely ignored.

The literature provides characteristics of traditional physics teaching. Schecker (1993) mentions that physics teaching seems to put much emphasis on solving equations and calculating numbers without securing a qualitative understanding of the key concepts. Van Heuvelen (1991) identifies the following traditional physics teaching sequence:

1. Telling students the physical rules that seem to guide the universe
2. Demonstrating how to use the rules to solve problems.

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3. The conceptual presentations are often supported by experimental evidence.

Van Heuvelen points out that the traditional approach persists because it is efficient in terms of time and that this is the case in spite of the negligible student reception. Therefore, there is need to identify strategies that might improve the status of physics teaching.

2.6.2 Strategies that could improve physics teaching

Most of the strategies discussed in section 2.5 also apply to physics teaching, so here the review is presented in brief. The following strategies could be used:

1. *Humanising* teaching of physics through history of physics (Newton, 1987). For example, Giancoli (1998) discusses models of the atom by tracing their historical development including the people that were involved. This approach seems to make the reading interesting and simple to follow. It also clearly portrays science as a human activity.
2. Transformation of scientific models with the aim of gradually adapting pupils' conceptions into scientific models (Aiello-Nicosia & Sperandeo-Mineo, 2000).
3. Grounding the design of a teaching sequence on a well-structured theoretical framework, including learning hypotheses taking into account initial conceptions of students (Buty, Tiberghien, & Le Mar´echal, 2004). One example of a teaching sequence is the six-stage contrastive teaching (Schecker & Niedderer, 1996) described in Table 2.1.
4. Giving students a chance to construct and critique their own and the scientists' models, metaphors and analogies (Coll, 2005).
5. Using small and large-group discourse to support students in generating explanations and building on each other's ideas (Coll, 2005; Gautreau & Novemsky, 1997).

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2.6.3 Teaching strategies in nuclear physics

Millar et al. (1990) contend that it is important that students learn about nuclear physics because they may meet applications of ionising radiation in everyday life, for example, in hospital or at a dentist. They further argue that items related to this topic appear frequently in the news media, often in the context of controversy and public debate. Millar et al. (1990) state that for students to understand issues in these debates, some knowledge of the basic phenomena and terminology used is required. However, students find nuclear physics concepts difficult (Priest & Poth, 1983). To help students understand nuclear physics concepts, the literature suggests the following approaches:

1. Allowing students to discuss nuclear power in small groups and exchange views on social and ethical issues surrounding its utilisation (Solomon, 1989), which is a cooperative groups strategy.
2. Sequencing teaching as follows: phenomenological orientation, qualitative macroscopic treatment, quantitative macroscopic treatment and microscopic treatment (Millar et al., 1990). According to Millar et al. (1990), this teaching sequence is based on children's understanding of ideas about radioactivity. Thus, this teaching sequence is an example of grounding a teaching sequence on a well-structured theoretical framework (Buty et al., 2004).
3. Giving students chances to engage in experimenting and modelling (Schecker, 1993).

Millar et al. (1990) give examples of activities that might fall into phenomenological orientation, qualitative macroscopic treatment, quantitative macroscopic treatment and microscopic treatment as follows:

1. *Phenomenological orientation*: Setting the topic in context through orientation to students' experience with radiation like having an x-ray. Students could also discuss experiences with different kinds of radiation [sound, light, infrared, ultra-violet, radio and x-rays]. They could classify these kinds according to penetrating power and discuss detection by unaided senses or by other instruments.
2. *Qualitative macroscopic treatment*: Allowing students to differentiate important concepts of the topic like radiation and radioactive material, irradiation and contamination. The teacher could arrange a demonstration

and discussion activity to challenge the pupils' prior ideas and cause cognitive conflict. The teacher could also arrange a demonstration to illustrate different types of radiation, discussing wide range of radiation sources. Discussing possible effects of radiation when absorbed by an object. The class could also compare different kinds and applications of radiation.

3. *Quantitative macroscopic treatment*: Exploring how to define and make measurements of quantities associated with radiation and radioactive materials. Elaborating ideas of activity and half-life. Discussing aspects of dosimetry.
4. *Microscopic treatment:* One could use analogies in looking at emissions from the nucleus, nature of different types of radiation, ionising effect of radiation.

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Lijnse and Klaassen (2004) propose a teaching sequence (didactic structure) similar to that of Millar et al. (1990) for the teaching radioactivity. The similarity lies in the structuring of teaching into well-defined phases, starting with orientation to the phenomenon to theoretical treatment of the topic. The difference lies in Lijnse and Klaassen's (2004) emphasis on making the motive for learning a particular aspect of the topic clear.

2.6.4 Summary on teaching strategies used in physics

Literature reviewed here shows that the following are some of the strategies that could be used in teaching physics in general and nuclear physics in particular:

1. Teaching using the history of physics.
2. Gradually adapting pupils' conceptions into scientific models.
3. Designing a teaching sequence based on a well-structured theoretical framework like the conceptual change approach.
4. Giving students opportunities to construct and critique their own and the scientists' models, metaphors and analogies.
5. Using small and large-group discourse.
6. Giving students opportunities to engage in experimentation and modelling.

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The above teaching strategies were compared to those observed with the participating teachers as one way of characterising the teachers' PCK. Some of these strategies are also suggested in the PSS in Malawi. However, there is no documented evidence about how PSTs are translating the syllabus contents into classroom activities. This study attempted to fill this gap by focusing on teaching strategies.

2.7 Reasons for studying teaching strategies

Students do have expectations about what each teaching episode should accomplish. A phenomenographic study involving South African and Swedish students found that undergraduate physics students from a range of teaching environments had various expectations (Marshall & Linder, 2005). This means that any mismatch between students' and teachers' expectations may have serious implications for the quality of learning, leading to a lack of interest and poor sense of relevance. Studying teaching strategies could shed light on the extent to which the strategies chosen meet the students' needs. But how does one know if strategies are tailored towards students' needs? According to Gomez-Zwiep (2008), such strategies are based on student thinking. This means teachers would consider the following: how students interpret learning experiences, if learning experiences add to students' instructional expectations, altering instruction in response to student performance and checking for students' understanding of concepts. Strategies characterised by these considerations fit well into the cognitive model of learning (Redish, 2000). Thus, by determining if a PST's strategies fitted into the cognitive model of learning, this study was able to ascertain if the strategies were chosen with student needs in mind.

Some researchers (Geddis & Wood, 1997; Johnson, Monk, & Swain, 2000; Loughran, Mulhall, & Berry, 2004) have investigated complexities of teaching with the aim of better understanding teaching. Loughran et al. (2004) attempted to document, capture and portray over 50 Australian science teachers' knowledge through interviews, class observations and small group discussions and claim that findings improved understanding of the complexity of the content and pedagogy under consideration. It has been argued that "Understanding how science teachers organise and conceptualise their teaching in order to enhance student understanding of the concepts being taught is a field of research which probes the very essence of teaching itself." (Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001: 290)

Johnson et al. (2000) observed classes of Egyptian teachers who had attended an in-service course in Britain. The study uncovered reasons why the teachers used only some of the knowledge and skills they had gained during the in-service programme. Apparently, the observations were used for evaluating the effectiveness of the in-service course.

Geddis and Wood (1997) studied an experienced mathematics educator's practice at the University of Western Ontario, Canada with the aim of producing a detailed account of the educator's practice. The account produced led to better understanding of teaching as consideration of a repertoire of representations. Thus, Geddis and Wood (1997) argue that case studies of teachers' practice provide a useful medium for portraying complexity of teaching.

Shulman (1986) gives direction on what to focus on when studying teaching. He argues that absence of focus on subject matter among various research paradigms for the study of teaching constitutes a *missing paradigm*. He underscores the need to treat questions about content of lessons taught, questions asked and explanations given. In a study to trace the intellectual biography of novice teachers, Shulman (1986) found that there was need for a more coherent framework to probe complexities of teacher understanding and transmission of content knowledge. Although Shulman's call to focus research on subject matter was made twenty-three years ago, I feel the need still stands because the few studies that have been done in this area have not covered all contexts. Teaching of nuclear physics, for example, has not been studied in a Malawian context.

Thus, it appears any study of teachers' practices, in relation to specific topics, would lead to better understanding of the complexities of teaching in specific contexts. This study focused on nuclear physics because there seems to be no study that has investigated strategies Malawian teachers use in this topic, which is believed to be one of the most difficult in the Malawian senior secondary school physical science curriculum.

2.8 Learning and teaching difficulties in physics

2.8.1 Difficulties arising from mathematical computations

Students face difficulties with the mathematical problems solving (Rawy, 1999). For example, Rawy reviewed relevant literature and interviewed weaker students in physics in order to outline mathematical difficulties of physics students. He summarises the difficulties identified as follows:

1. Students lack the knowledge and experience to correctly diagnose the type of problem and then deduce the method required to solve it.
2. Students have 'cognitive difficulties' in that they have deficiencies in their problem-solving methods.

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A study of how two student teachers studying with University of Western Ontario, Canada and their cooperating teachers taught isotopes found that students in their classes faced difficulties with computation of average atomic masses (Geddis et al., 1993). Grossman (2005) discusses six transformations that make science learning unintentionally difficult. One of these six is mathematical and has called it symbolic transformation, which involves using symbols to represent relations, translating English sentences into algebraic equations and making computations. According to Grossman, students find making such transformations difficult. Schecker (1993: 102) observes, "Physics teaching seems to put too much emphasis on solving equations and calculating numbers without securing a qualitative understanding of the key concepts."

To help students cope with mathematical problem solving in physics, Rawy (1999) suggests use of a teaching approach that combines use of heuristics, cooperative group work, reflection and metacognition, bridging and modelling as described in section 2.5.3. The focus topic in this research, nuclear physics, does include some basic calculations like determination of number of neutrons given atomic mass and atomic number. Thus, it was expected that participating teachers would be aware of difficulties associated with such calculations and address them, but it was not known how the teachers would address the difficulties.

2.8.2 Difficulties associated with models and modeling

Coll (2005) argues that models and modelling are key tools for scientists, science teachers and science learners. Harrison and Treagust (2000) contend that models are integral to thinking and working scientifically. Physicists use modelling for the generation and application of scientific theories, so learning physics implies learning to play `the modelling game' (Greca & Moreira, 2000).

However, students find scientific models difficult. Coll (2005) identifies the following seven factors that may impede pupils' effective use of models:

1. Some learners may learn the model rather than the concept being illustrated.
2. Pupils may lack awareness of the boundary between the model and the reality being represented.
3. Unshared attributes are often a cause of misunderstanding for learners.
4. When given a range of models, students may continue to use the least sophisticated one.
5. Some pupils lack the necessary visual imagery.
6. Some pupils may find it difficult to apply the model in different contexts.
7. Pupils may mix their models.

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For analogical models, Harrison and Treagust (2000) identify two problems:

1. Students find it hard to generate or select appropriate analogies for a given situation
2. Students find comparing the analogy and the target phenomenon difficult.

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Greca and Moreira (2000) identify the following difficulties that students meet with scientific models:

1. Students do not have the knowledge to interpret conceptual models.
2. Students often do not understand that a conceptual model is a simplified and idealized representation of phenomena or situations.

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Authors reviewed here seem to agree that students have difficulties in interpreting models correctly, which in turn tends to lead to problems of confusing models for reality and students' failure to generate their own models. Thus, when using models, teachers need to remember the potential learning difficulties and plan to address them accordingly. Harrison and Treagust (2000) suggest that a teacher should assess carefully the conceptual demands that the models presented place on students and consider using the FAR approach described in section 2.5.4. Schecker (1993) recommends engaging students in modelling using computers so that the computers can take over mathematical computations and students can concentrate on structuring the problem, assessing or looking up realistic parameters, and in testing their hypotheses. Nuclear physics, the focus topic of this research, does include some scientific models like model of the atomic nucleus and it was expected that the participating teachers would be aware of difficulties associated with models and address them accordingly. However, it was not clear how the teachers would address the difficulties.

2.8.3 Difficulties associated with teaching about physics

Crowe (1999) points out that in teaching physics, one teaches not only the content of physics but also about physics. He argues that what the student learns *about* physics may play a very large role in the conception of physics he or she carries away from a course. According to Newton (1987), physics teaching should aim at educating in physics, through physics and about physics. However, Newton observes that educating in physics is what consumes a teacher's energy traditionally, while the other two are largely ignored. Why do teachers ignore teaching about physics?

Lederman (1992) reviewed research on the nature of science and found that science teachers did not possess adequate conceptions of the nature of science, irrespective of the instrument used to assess understandings. This, I feel, is one of the difficulties of teaching physics because, as Lederman argues, teachers cannot be expected to purposefully teach what they do not understand.

2.8.4 Student conceptions and pre-conceptions

Duit and Treagust (2003) assert that findings from many studies over the past three decades show that students come into science instruction with deeply rooted conceptions and ideas that are not in harmony with the science views. These conceptions and ideas manifest even when the students have received no systematic instruction whatsoever (Driver et al., 1989). One cause of learning difficulties in science generally and physics in particular are these ideas that students bring to lessons (Jimoyiannis & Komis, 2001; McDermott, 1998) . Jimoyiannis and Komis (2001) and Driver et al. (1989) point out the following about student conceptions:

1. Students possess a system of beliefs and intuitions about physical phenomena mainly derived from their everyday experience.
2. Such systems of beliefs and intuitions are usually incompatible with scientific theories and knowledge, hence are called misconceptions or alternative conceptions.
3. Research findings also suggest that conventional instruction is ineffective in dealing with misconceptions.

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Schecker and Niedderer (1996) hypothesise that if students are not aware of their intuitive notions, they will hardly be able to learn a related concept, so they recommend that considerable teaching effort is needed to help students notice the difference between their intuitive views derived from everyday experience and the scientific view based on theory-laden experiments.

As for nuclear physics, the literature shows that students tend to have the following ideas about the topic:

1. A tendency not to differentiate terms like radiation, radioactivity and radioactive materials (Alsop, 2001; Cooper, Yeo, & Zadnik, 2003;

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Millar & Gill, 1996; Millar et al., 1990). Also, X-rays and nuclear radiation are not differentiated (Cooper et al., 2003) .

2. Nuclear radiation is thought of as manmade (not natural) and hence is linked with technological advancement, such as lasers (Cooper et al., 2003; Henrikssen & Jorde, 2001)
3. The process by which radioisotopes work in medicine is largely unknown, resulting in various alternative understandings about medical uses of nuclear radiation (Cooper et al., 2003).
4. There is a tendency to think that radiation can be absorbed, accumulate in things and be released later (Alsop, 2001; Millar & Gill, 1996; Millar et al., 1990). Thus, ideas of 'contamination' and 'irradiation' may not be properly distinguished (Millar et al., 1990).
5. Radiation is often associated with danger and tends to generate fear, which is reinforced by the media (Alsop, 2001; Henrikssen & Jorde, 2001; Millar et al., 1990).

The students' ideas about phenomena are highly resistant to change, especially when the a student does not see the relevance of adapting his or her ideas (Gomez-Zwiep, 2008). For instance, Cooper et al. (2003) investigated the effect of instruction on Australian high school students' ideas about nuclear physics concepts using a pre-test and post-test design, they found that some of the students' ideas did not change. Students expressed a limited conceptual understanding about the processes by which ionising radiation affects human tissue before and after instruction. Driver et al. (1989) also point out that students' ideas are stable and often appear even after instruction. Therefore, it seems plausible to classify students' conceptions as teaching difficulties.

In this study, the participating teachers' awareness of some of the conceptions discussed here was determined from their teaching practices and interview data as one way of characterising the teachers' PCK. Also, the possible students' conceptions about nuclear physics informed the video and interview transcript coding process.

2.8.5 Complexity of learning in physics

Learning in physics is complex as it consists of a number of components and these components are: acquisition of experiences with natural phenomena, development of concepts, development of epistemological awareness and development of scientific and reasoning skills (Constantinou & Papadouris, 2004). Real learning, according to Constantinou and Papadouris, can only emerge when all these components are promoted in unison, which might not be easy for teachers to achieve. One way of helping students to gain experience with phenomena is through experiments, but for nuclear physics concepts such as atomic structure, nuclear structure and radioactivity, this is difficult in a high school (Norman, Larimer, Rech, Lee, Vue, Leubane et al., 2004). Norman et al. have developed a web site that contains experimental data on nuclear physics concepts, which they suggest students can analyse in order to gain understanding of the concepts involved like half-life.

Demand and complexity of a learning task in terms of the information-processing requirements compared with the student's information-handling capacity can be a source of learning difficulties, and hence can cause teaching difficulties (Ben-Zvi & Hofstein, 1996). Ben-Zvi and Hofstein reached this conclusion after studying for eight months the sort of learning difficulties that grade 11 Israeli chemistry students faced with the subject. They observed that most students could correctly give the symbol for one molecule of an element, but not for a molecule of a compound. The students also had difficulties representing the gaseous or solid state of an element or a compound. Actually, Hurd et al. (1993) assert that learning processes that include inferences and abstract reasoning are more difficult for students. Ben-Zvi and Hofstein reason that students may have experienced information overload as they attempted to coordinate two aspects: transition from element to compound and transition from one molecule to many molecules. One could also argue that the students may not have developed scientific and reasoning skills for understanding of many molecules. Although this example is from chemistry, it also applies to physics because to understand radioactivity, one has to focus on a single nucleus, while to understand effects of radioactivity, one has to focus on many nuclei. The change of focus from one to many can be a source of teaching difficulties.

Children have difficulties with the atomic and sub-atomic level explanation of radioactive phenomena that is prominent in most treatments of the topic because they do not have a secure understanding of the particulate model of matter (Millar et al., 1990). The difficulties with particulate nature of matter could be explained in terms of the components of learning: students do not have the necessary experience with the phenomenon of particles for effective development of their conceptual understanding.

In this study, participating teachers were asked to identify aspects of nuclear physics that would be difficult for students to learn. I was therefore able to compare those aspects with the ones identified by literature like particulate nature of matter, difficulties of performing experiments and the many components of learning required in order to determine how the participating teachers used them in their teaching strategies.

2.8.6 Language problems

One hindrance to student understanding of physics can be difficult language (Ben-Zvi & Hofstein, 1996; Giancoli, 1998). For example, the physics terms of electricity, current, voltage and resistance are also used in everyday talk, but with significantly different meanings than in physics (Duit & von Rhöneck, 1998). Ben-Zvi and Hofstein (1996) highlighted language difficulties associated with chemistry, which should also apply to physics because these two disciplines share some common characteristics like use of technical terms. They point out that communication problems arise from language use especially in relation to "… technical terms, general terms with context-specific specialized meanings and the complexity of the sentence structure and syntax used by the teacher compared with the student's own language" (Page110). Students are frustrated by scientific terms because the words are alien to them, are usually difficult to pronounce and are hard to remember (Hurd et al., 1993). Also, students tend to make sense of scientific statements by using everyday interpretations (Gilbert, Osborne, & Fensham, 1986). For instance, when reading or listening to statements on particulate nature of matter, students might think in terms of small visible objects instead of of atoms, ions or molecules. Furthermore, students need to learn the appropriate meanings of science (arguments, terminology, logical operators, etc) and how they are expressed in English (Strevens, 1976). In learning these, students might encounter difficulties.

In nuclear physics, too, difficult terms exist like radioactivity, radiation, and radioactive material. It has been found that students tend to confuse these concepts (Alsop, 2001; Cooper et al., 2003; Millar et al., 1990); hence they pose a potential teaching difficulty. In addition, nuclear physics deals with beta and alpha particles, so there is a chance that students might interpret these particles to be dust-like particles.

Hurd et al. suggest some or all of the following strategies to address language difficulty:

1. Identifying the key concepts and words in a topic.
2. Pronouncing all new words that students might have trouble with.
3. Defining all new and potentially difficult terms.
4. Drawing students' attention to charts, drawings and photographs that might help students understand new words and concepts.

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Evidence of how the participating teachers may have used some, all or none of these strategies was sought as one way of characterizing their PCK about nuclear physics. Transcripts were also coded for potentially difficult terms as one way of characterizing language-related teaching difficulties.

2.8.7 Summary of teaching difficulties

In this section, it has been assumed that a teaching difficulty arises where there is a potential learning difficulty. This assumption seems plausible in that where there is a potential learning difficulty, the teacher has to carefully select and implement teaching strategies so as to address the learning difficulty and some of the difficulties are not easy to address like students' preconceptions.

The teaching difficulties identified in this review include:

1. Difficulties arising from mathematical computations.
2. Difficulties associated with models and modelling.
3. Difficulties associated with teaching about physics.
4. Student conceptions and pre-conceptions.
5. Complexity of learning in physics.
6. Language problems.

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These difficulties guided the transcript coding process by throwing light on possible categories of teaching difficulties. It was then possible to relate the difficulties to teaching strategies used. I could then theorise about the participating teachers' awareness of teaching and learning difficulties, as an aspect of PCK.

2.9 Research Paradigms

2.9.1 Categories of research paradigms

A researcher's paradigm is a set of abstract principles that combine beliefs about ontology, epistemology and methodology (Denzin & Lincoln, 2000). According to Denzin and Lincoln, ontology relates to the nature of human beings and reality; epistemology relates to the nature of the relationship between the inquirer and the known; and methodology concerns how human beings know the world or gain knowledge of it. One can also refer to a research paradigm as traditions consisting of assumptions, commitments, procedures and theories (Walker & Evers, 1988).

There are different types of paradigms that can be identified. Some of these are:

1. Pragmatic paradigm (Mertens, 2005)
2. Positivism (Lincoln & Guba, 2000; Walker & Evers, 1988)
3. Postpositivism (Lincoln & Guba, 2000)
4. Critical theory (Lincoln & Guba, 2000; Walker & Evers, 1988)

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5. Constructivism (Lincoln & Guba, 2000) or interpretive paradigm (Walker & Evers, 1988)
6. Participatory paradigm (Lincoln & Guba, 2000)

Mertens (2005) describes the pragmatic paradigm as one based on the view that what is useful determines what is true and that mixed methods can be used. Positivists are guided by *naïve realism* in that they believe in 'real' reality that can be objectively apprehended through empirical observation (Lincoln & Guba, 2000; Walker & Evers, 1988). Postpositivists are guided by *critical realism,* as they believe that real reality exists but can only be apprehended imperfectly through falsification of hypotheses (Lincoln & Guba, 2000). Those who are for critical theory are guided by *historical realism,* the belief that virtue reality is shaped by social, political, cultural, economic and gender values and that reality can only be subjectively comprehended through value mediated findings (Lincoln & Guba, 2000). According to Walker and Evers (1988), supporters of the critical theory paradigm contend that educational research must contribute to human betterment. Proponents of constructivism or the interpretivist paradigm believe in *relativism* whose main tenet is that reality is local and can only be subjectively constructed (Lincoln & Guba, 2000). As Walker and Evers (1988) point out, interpretivists argue that reality is something that researchers construct in their minds as a product of theorising.

2.9.2 The research paradigm for my study

This research was guided by tenets of the interpretivist paradigm as outlined in some literature (Denscombe, 2002; Eisenhart, 1988; Mertens, 2005). These tenets are:

1. Reality is a social construction, created in the minds of people and reinforced through the interaction with each other, not an objective reality that can be known.
2. The goal of research, in this paradigm is to understand multiple constructions of meaning and knowledge.

3. When humans become aware that they are the focus of attention for research there is a possibility that they will act differently from normal.
4. The knowledge produced can feed back into the situation and interfere with the explanations or predictions initially made from the investigation.
5. Observations and explanations of the social world are inevitably affected by observations and predispositions that are brought to the research through observation. Thus, the values that influence the researcher are made explicit.
6. The researcher influences explanations, thus a claim about objectivity cannot be made, as alternative versions of the truth are possible. So, the concept of objectivity is replaced by confirmability.
7. Qualitative methods like interviews, observations and document reviews are predominant in line with the assumption that research is an interaction between the researcher and the researched.

In this study, I interacted with participating teachers through interviews, class observations and other informal meetings. I assumed that such interactions had potential to influence the reality created. It was also assumed that interactions between a particular teacher and his or her students had potential to affect the way a lesson could unfold, regardless of the teacher's plans. Therefore the possibility of multiple realities, in terms of how the participating teachers helped students understand concepts related to nuclear physics, was a major assumption of this study. In light of these assumptions, it seemed appropriate to locate this study in the interpretivist paradigm.

The goal of this research was to understand the realities that would unfold and understanding is a major aim of inquiry in the interpretivist paradigm (Denscombe, 2002; Mertens, 2005). Such understanding would be achieved by constructing meaning from interviews, observations and document analyses carried out.

2.10 Theoretical framework of the study

2.10.1 Definition of theoretical framework

A conceptual framework is a system of concepts, assumptions, expectations, beliefs and theories that supports and informs a particular research (Maxwell, 1998). Maxwell's view seems to emphasise components of a conceptual framework and its general function. Another view emphasises the specific functions and how these are achieved: a conceptual framework describes and explains the major facets of an investigation by identifying the key factors and the assumed relationships between them (Sowden & Keeves, 1988). Sowden and Keeves argue that such relationships need not be causal; they might simply involve sequences that occur over time or merely be a pattern in the events or between the factors being observed. These definitions, as well as the research paradigm, helped in choosing an appropriate framework to guide this study: the framework had to be in tandem with the assumption of multiple realities and be able to explain complexities associated with teaching of specific physics topics such as nuclear physics. Pedagogical content knowledge (Shulman, 1986, 1987) was deemed to be an appropriate theoretical framework, as it meets these criteria.

2.10.2 Pedagogical content knowledge

This study investigated teaching strategies in nuclear physics through the theoretical framework of pedagogical content knowledge (PCK) first proposed by Shulman (1986, 1987). PCK is one of the seven categories of the knowledge base for teachers. The other categories are: content knowledge; general pedagogical knowledge; curriculum knowledge; knowledge of learners and their characteristics; knowledge of educational contexts; and knowledge of educational purposes, ends and values (Shulman, 1987; Wilson et al., 1987). Shulman contends that PCK:

1. "Goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching" (Shulman, 1986: 9)
2. "Embodies the aspects of content most germane to its teachability" (Shulman, 1986: 9)

3. “Is of special interest because it identifies the distinctive bodies of knowledge for teaching” (Shulman, 1987: 8).

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Figure 2.1 shows the three components of PCK that Shulman (1986) identifies. Those components are: knowledge of the most useful forms of representing ideas of most regularly taught topics, knowledge of strategies likely to be fruitful in organising the understanding of learners and understanding of what makes learning of topics easy or difficult.

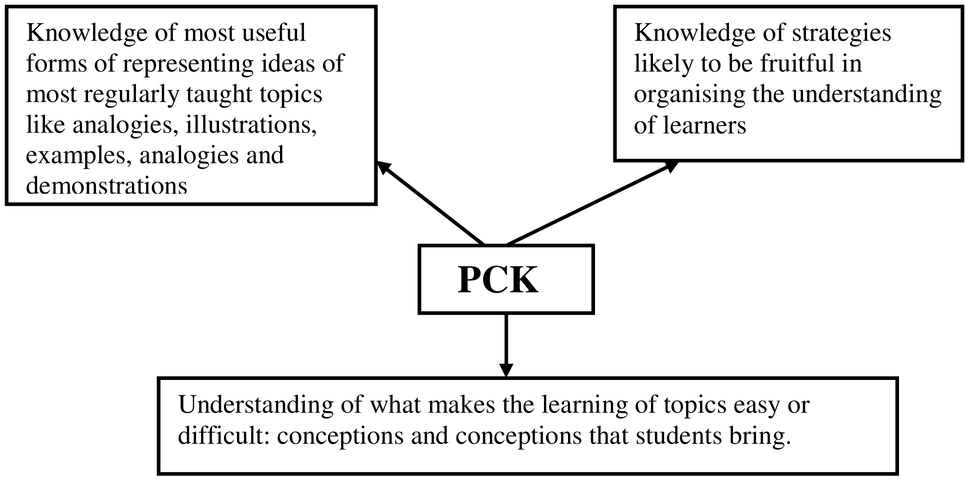

Figure 2.1: The components of PCK based on Shulman’s (1986) view

Some authors and researchers have subsequently also identified some or all of the components of PCK in Figure 2.1. For instance, Loughran et al. (2006) mention the following components: important ideas for students to know, difficult aspects of a topic, students’ alternative conceptions, and teaching procedures. It could be argued that the important ideas or key ideas are equivalent to Shulman’s (1986) view of content most germane to the teachability of a subject (Deng, 2001). Deng (2001) contends that knowledge of key ideas and the ability to analyse how content of the discipline could be transformed into subject matter for teaching high school physics represent an essential feature of PCK. In addition to student misconceptions, strategies for altering misconceptions and alternative representations, Geddis et al. (1993) also include transformation of subject matter as an important aspect of PCK.

Sometimes scholars have expanded Shulman's conception of PCK to include some components that are different from those reflected in Figure 2.1. One group of scholars have adopted the following as components of PCK: knowledge of subject matter, knowledge about students, knowledge about instructional strategies, knowledge about the teaching context and knowledge about one's teaching purposes (Fernández-Balboa & Stiehl, 1995). Apart from subject matter knowledge and instructional strategies, which also appear in Figure 2.1, the rest of these components are a new addition.

Another group has modified Shulman's conception of PCK to come up with pedagogical content knowing (PCKg) (Cochran, DeRuiter, & King, 1993), which they define as a teacher's integrated understanding of four components of pedagogy, subject matter content, student characteristics, and the environmental context of learning. Cochran et al.'s (1993) modification is based on the constructivist view that knowledge is created by the knower and not passively received in an unmodified form from the environment.

Still other researchers have referred to 'curriculum saliency' as a component of PCK, which refers to the importance of a topic in the curriculum (Barnett & Hodson, 2001; Geddis et al., 1993; Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008). Rollnick et al. (2008: 1367) assert that: "Curricular saliency may be observed, for example, in teachers' decisions to leave out certain aspects of the topic, and in teachers' awareness of how a topic fits into the curriculum." Barnett and Hodson (2001) mention that it is knowledge of curriculum salience that enables a teacher to judge matters such as depth of treatment and contexualisation.

PCK has also been viewed as a specific form of a teacher's craft knowledge (Van Driel et al., 1998). Van Driel et al. explain that PCK implies a transformation of subject matter knowledge, so that it can be used effectively and flexibly in the communication process between teachers and learners during classroom practice. This view seems to be shared with Geddis et al. (1993) who have viewed PCK as knowledge that plays a role in transforming subject matter into forms that are more accessible to students. The notion of transforming subject matter is similar to Ball's (2000: 245) assertion that a teacher should have "the capacity to deconstruct one's own knowledge into a less polished and final form, where critical components are accessible and visible."

This brief review supports the observation that there are differences of opinion and a lack of clarity pertaining to the nature and development of PCK (Hashweh, 2005). According to Van Driel et al. (1998), the elements that scholars include in PCK differ. Despite the various views on what constitutes PCK, there seems to be agreement that teachers need specialized knowledge for teaching. Van Driel et al. (1998) assert that all scholars agree on Shulman's two key elements: knowledge of representations of subject matter and understanding of specific learning difficulties and student conceptions. There is also agreement that PCK refers to particular topics.

In this study, I adopted the way of defining PCK by enumerating the types of knowledge in question (Henze, Van Driel, & Verloop, 2008). I viewed PCK to be an amalgam of content and pedagogy that includes teacher knowledge about: big or key ideas of a lesson or topic, useful forms of representing ideas, what makes learning of a topic/lesson easy or difficult, ways of assessing learners' understanding of a topic/lesson and strategies likely to be fruitful in organizing learners' understanding of a specific topic, lesson or concept. This view expands Shulman's (1986, 1987) conception of PCK by including the concept of big ideas (Loughran et al., 2004) or key ideas (Deng, 2001) and ways of assessing learners' understanding (Henze et al., 2008; Lee & Luft, 2008). Figure 2.2 shows five components of PCK adopted for this study. This view of PCK was embraced because it includes the important aspects of teaching: content, pedagogy and interaction between them. Also, this framework is in line with the interpretive paradigm in that the way content and pedagogy interact to form an amalgam depends on the teaching context (Barnett & Hodson, 2001; Hashweh, 2005).

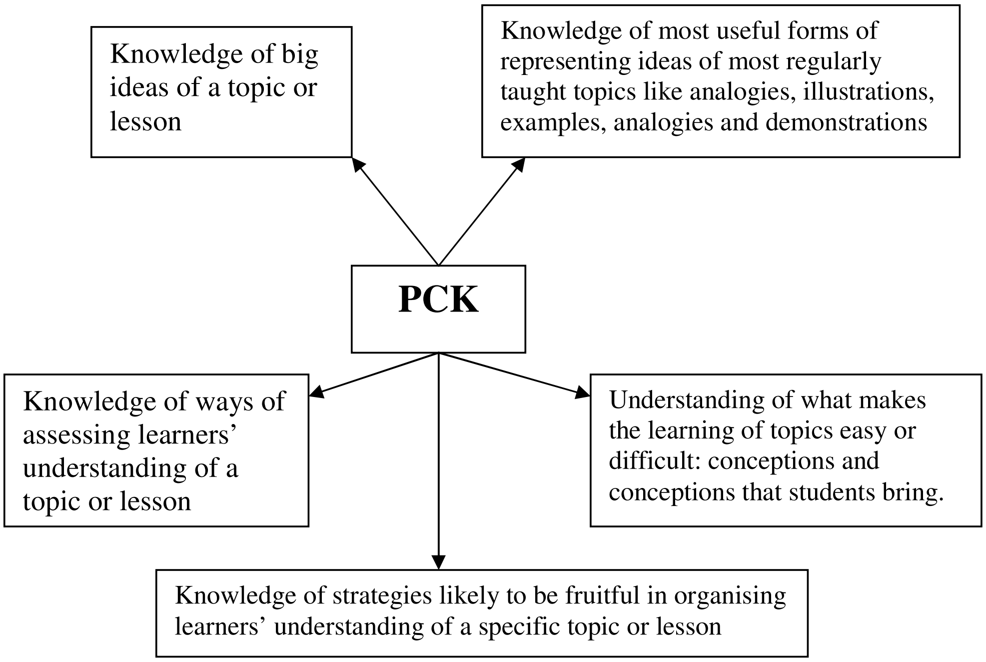

Figure 2.2: Components of PCK adopted for this study

PCK has been referred to as a special amalgam of content and pedagogy that is uniquely the province of teachers (Loughran et al., 2001; Shulman, 1987). In the following excerpt, Loughran et al. (2006: 9) emphasise that PCK is an amalgam of pedagogy and content:

> When teaching outside one's area of teaching expertise, despite having a well-developed knowledge of teaching procedures (e.g. Venn diagrams, concept maps, interpretive discussion, etc.) or strong specialist content knowledge (e.g. specialist of physics or biology or chemistry, etc.) a teacher's skill of combining such knowledge of content and pedagogy in meaningful ways for particular reasons is no longer so readily apparent. Issues associated with difficult aspects of the topic, students' alternative conceptions, important big ideas, conceptual hooks, triggers for learning and so on, are not well-known or understood by the teacher when rich understandings of subject content is lacking and, it is in elements of professional practise such as these that PCK stands out as different and distinct from knowledge of pedagogy or knowledge of content alone.

This excerpt agrees well with what van Driel et al. (1998) found following a study done in the Netherlands in which they designed workshops to enhance teachers'

PCK about chemical equilibrium. The aim was to improve the teachers' ability to recognise specific preconceptions and conceptual difficulties. They found that familiarity with a specific topic in combination with teaching experience, positively contributed to PCK. It would seem the interaction of subject matter knowledge (SMK) and pedagogical knowledge (PK) is critical to the development of PCK. This could be the reason why there has been an argument that SMK, (PK) and PCK remain essential to effective science teaching (Zeidler, 2002). It could also be the reason PCK has been defined in terms of a teacher's ability to convey and explain details of a field of specialisation in a manner that makes it accessible to their students (Geddis et al., 1993; Van Driel et al., 1998; Zeidler, 2002). In this study, I felt that PCK was an appropriate framework for studying teaching strategies because it brings together content and pedagogy. During many teacher preparation programmes (including those in Malawi), content and pedagogy are treated separately, leaving the challenges of integrating them to individual teachers in the contexts of their work (Ball, 2000). No wonder PCK is considered to be knowledge associated with experience that does not seem to develop from studying in traditional pre-service teacher education programmes (Hashweh, 2005). I hoped that by adopting the PCK framework it would be possible to gain insight into how the participating PSTs integrated content and pedagogy.

PCK can be different for different teachers of a given subject area as it is influenced by the teaching content, context and experience (Barnett & Hodson, 2001; Loughran, Berry, & Mulhall, 2006). In the words of Hashweh (2005: 277), it "is personal and private knowledge, rather than public and objective knowledge." For instance, teachers' explanation in science, which are an aspect of teaching strategies (and hence also an aspect of PCK), have been found to be influenced by four factors: content, student, teacher and context factors (Treagust & Harrison, 2000). Therefore, PCK cannot be considered to be a fixed body of knowledge because it develops through reflection and application (Fernández-Balboa & Stiehl, 1995). I argue that for the same subject matter knowledge, PCK will be different for different teachers, different groups of students and different contexts. This is why I felt that by studying some Malawian PSTs' teaching strategies, this research would also shed light on the nature of these teachers' PCK in secondary school nuclear physics. Such a study has not been done in Malawi since the current PSS was introduced in 2002.

2.10.3 Some studies on/guided by PCK

There are a number of studies that have been done in the PCK framework. Some of these have concentrated on documenting PCK of science teachers or professors in specific topics. As an example, *content representations* (CoRes) and *pedagogical and professional-experience repertoires* (PaP-eRs) have been used to document expert science teachers in Australia. (Loughran et al., 2006; Loughran et al., 2001; Loughran et al., 2004). CoRes consist of what these authors have called *big ideas*, which I feel, could also be referred to as *key* or *overarching* ideas. PaP-eRs could be interpreted as descriptions of teaching situations that are clearly linked to the CoRes and help to connect the practice seen and understanding of particular content. (Loughran et al., 2006; Loughran et al., 2001; Loughran et al., 2004). On the benefit of using CoRes and PaP-eRs, Loughran et al. (2001: 292) contend that "Our research has now led us to contend that to see PCK in the classroom, or in a teacher's articulation of their practice, is to see a mixture of interacting elements which, when combined, help to give insights into the PCK informing the practice." In the present study, key concepts of the lessons observed (similar to big ideas) were identified and strategies used to convey them were described and analysed.

Fernández-Balboa and Stiehl (1995) of the University of Colorado in the United States of America explored the kinds of frameworks that university professors use in constructing and implementing PCK with the aim of understanding the nature of PCK among exceptional university-level teachers across a number of subjects. They used phenomenological interviews with ten professors. Through qualitative analysis, they identified components that emerged from the data as knowledge about subject matter, students, numerous instructional strategies, teaching context, and one's teaching purposes. Although this study relied only on interviews, without including observations of actual practice, it does indicate that one research can target the components of PCK that emerge with a particular group of teachers. The instructional strategies that emerged from Fernández-Balboa and Stiehl's (1995) study guided the coding and analysis of video transcripts for teaching strategies in my study.

Some studies have explored the utility of Shulman's (1986, 1987) concept of PCK in articulating the manner in which teachers transform subject matter content for teaching (Geddis et al., 1993; Geddis & Wood, 1997). Geddis et al. (1993) used two student teachers studying at the University of Western Ontario, Canada and their cooperating teachers and collected data through audio-recorded interviews and field notes from chemistry classroom teaching. These researchers used components of PCK to frame experiences of the four participants. The findings revealed aspects of PCK that could be useful in transforming subject matter knowledge of teachers into forms that are meaningful for students. The findings also revealed concepts that students found difficult and the deficiencies in the novice teachers' knowledge about curriculum saliency. Geddis and Wood (1997) used a single case study design to study teaching as transformation of subject matter in the context of mathematics methods instruction. All lessons were audio taped and transcribed. All transparencies, handouts and black board work were photocopied or recorded in field notes. By looking at transformation of knowledge, the researchers concluded that teaching practice is both complex and messy and that teachers' knowledge is similarly complex. They also claim that student teachers discovered that there is a difference between doing mathematics and teaching mathematics and this, I feel, should also apply to physics because there is a close relationship between these two subjects. It would seem PCK, when applied to study of teaching, leads to better understanding of the teaching of specific subjects and this is why it was adopted in this study.

There have also been studies focusing on the development of science teachers' pedagogical content knowledge (e.g. De Jong, Van Driel, & Verloop, 2005; Henze et al., 2008; Loughran, Mulhall, & Berry, 2008; Van Driel et al., 1998).

Van Driel et al. (1998) organized workshops for upper secondary school teachers in the Netherlands as a way of developing the teachers' PCK. The workshops involved discussing practical experiments and assignments. There were two major findings. Firstly, the teachers lacked theoretical arguments to promote student understanding of chemical equilibrium. Secondly, the teachers gained knowledge of specific types of reasoning and learning difficulties in the context of chemical equilibrium. De Jong et al. (2005) run a module with pre-service chemistry teachers at two universities in the Netherlands that emphasized learning from teaching using particle models. The aim of the module was to help the pre-service teachers develop their PCK pertaining to learning difficulties and teaching strategies. At the end of the module it was claimed that the PCK of the pre-service teachers developed. Loughran et al. (2008) studied how a teacher education programme informed by the PCK lens influenced pre-service science teachers' conception of science teaching. They observed that the pre-service teachers began to explore the influence of PCK on their developing knowledge of practice through paying careful attention to their students' learning. It should be clear that one thrust of research guided by the PCK framework has been development of PCK among pre-service or practicing science teachers.

2.10.4 Framework for conceptual analysis of knowledge for teachers

The study also attempted to characterise the participating teacher's PCK by interrogating relevant portions of the data using questions. Those questions were adapted from some of the statements that Loughran et al. (2004) used in constructing content representations as a way of capturing and portraying the participating teachers' PCK. Loughran et al. (2004) used the statements shown below.

1. What you intend the students to learn about this idea.
2. Why is it important for students to know this.
3. What else you know about this idea (that you do not intend students to know yet).
4. Difficulties/limitations connected with teaching this idea.
5. Knowledge about students' thinking which influences your teaching of this idea.
6. Other factors that influence your teaching of this idea.
7. Teaching procedures (and particular reasons for using these to engage with this idea).

> 8. Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).
>
> (Page 376)

Statements 2 and 3 were deemed irrelevant for this study, as there was no data where they could be applied. The rest were converted into questions that were used to interrogate the data. The questions are shown below:

1. From the content covered, what would be the main ideas that the teachers intended the students to learn?
2. What do the results on difficulties reveal about the teachers' knowledge of difficulties associated with learning of those ideas?
3. What knowledge about students' thinking may have influenced the choice of teaching strategies?
4. What other factors may have influenced the teachers' choice of teaching strategies?
5. What do results on teaching strategies reveal about the teachers' knowledge of strategies that could aid understanding of those main ideas?
6. How did the teachers ascertain students' understanding?

I used these questions because I felt they covered the important aspects of PCK. Also the statements from which they were derived worked well in capturing and portraying participating teachers' PCK with Rollnick et al. (2008) and Loughran et al. (2004).

2.10.5 Summary on the research paradigm and theoretical framework

Section 2.10 has been dedicated to describing the research paradigm and framework. This research was set in the interpretivist paradigm, whose major tenet is that reality is a social construction, created in the minds of people and reinforced through the interaction with each other, not an objective reality that can be known. The framework of pedagogical content knowledge was adopted whose major argument is that teachers need specialized knowledge for teaching, which is an amalgam of content and pedagogy. It has been shown that research on PCK has involved some of the following: documenting science teacher's PCK, analyzing components of PCK with aim of describing nature of science teachers' PCK about a specific topic, and utilizing PCK to understand teaching of different subjects in different contexts. None of such studies has been done in Malawi with respect to teaching of secondary school nuclear physics. This study was conceived because of this knowledge gap.

PCK has guided this research in documenting the teaching strategies and representations employed to achieve student understanding of concepts. There is also an attempt to determine the participating teachers' awareness of possible learning difficulties and how these affect choice of teaching strategies. This framework guided me in directing attention to subject matter, teaching strategies and their interaction at the same time. It is hoped that by adopting this framework, I should be able to contribute to the debate about how teachers transform subject matter knowledge to knowledge for teaching using the case of nuclear physics.

CHAPTER 3
RESEARCH DESIGN

3.1 Introduction

A qualitative research design employing a case study approach was used because it was deemed appropriate for studying teaching strategies in depth. Purposive sampling was used to select participating teachers as it enabled me to target those I thought could provide desired data. Ethical issues were considered in terms of negotiating access, confidentiality and informed consent of the participants. Interviews, observations using a video camera and analysis of documents were some of the methods used to collect data. Research trustworthiness was established mainly through triangulation.

3.2 Schematic representation of the research design

Table 3.1 shows a schematic representation of the design. The first column shows the main aspects of the study, which included: subject matter (nuclear physics in this study), learning difficulties and the teaching strategies used to attempt to address those difficulties. The second aspect shows the research methods used to obtain data related to the main aspects. The methods included: a questionnaire, interviews, video recording of lessons and discussion of the video-recordings. The third column shows the demarcation in the main aspects studied.

In Figure 3.1, I have tried to capture the sequence of events and the relationship of those events to the data produced. The figure shows that the process of data collection started with negotiating access and then the questionnaire was administered. It then shows that for each lesson a series of events followed ending with discussion of the video recording. The figure also shows the data that resulted from activities related to lesson observation: main ideas of the lessons, difficulties associated with learning of those ideas, teaching strategies used and reasons for the chosen strategies. Next the data obtained was used to theorise about the case teachers' PCK. The documents analysed are also shown and there is an indication that the results obtained were compared with those obtained with the teachers.

Table 3.1: Schematic representation of the research design

Main aspect of the study	**Research method**	**Demarcation**
Subject matter	Analysis of PSS for depth and breadth Analysis of textbooks Questionnaire (Appendix 6) Interviews (See Appendix 16) Video recordings of lessons	Subject objectives Main ideas of lessons Difficult aspects
Learning difficulties	Questionnaire (Appendix 6) Interviews (See Appendix 16) Video recordings of lessons Literature review Analysis of MANEB Examiners' reports	In nuclear physics Anticipated difficulties for lessons observed Observed difficulties for the lessons observed
Teaching strategies	Case study approach Video recording of lessons Discussion of video recording Interviews (See Appendix 16)	PSTs who rate nuclear physics as difficult Four case teachers

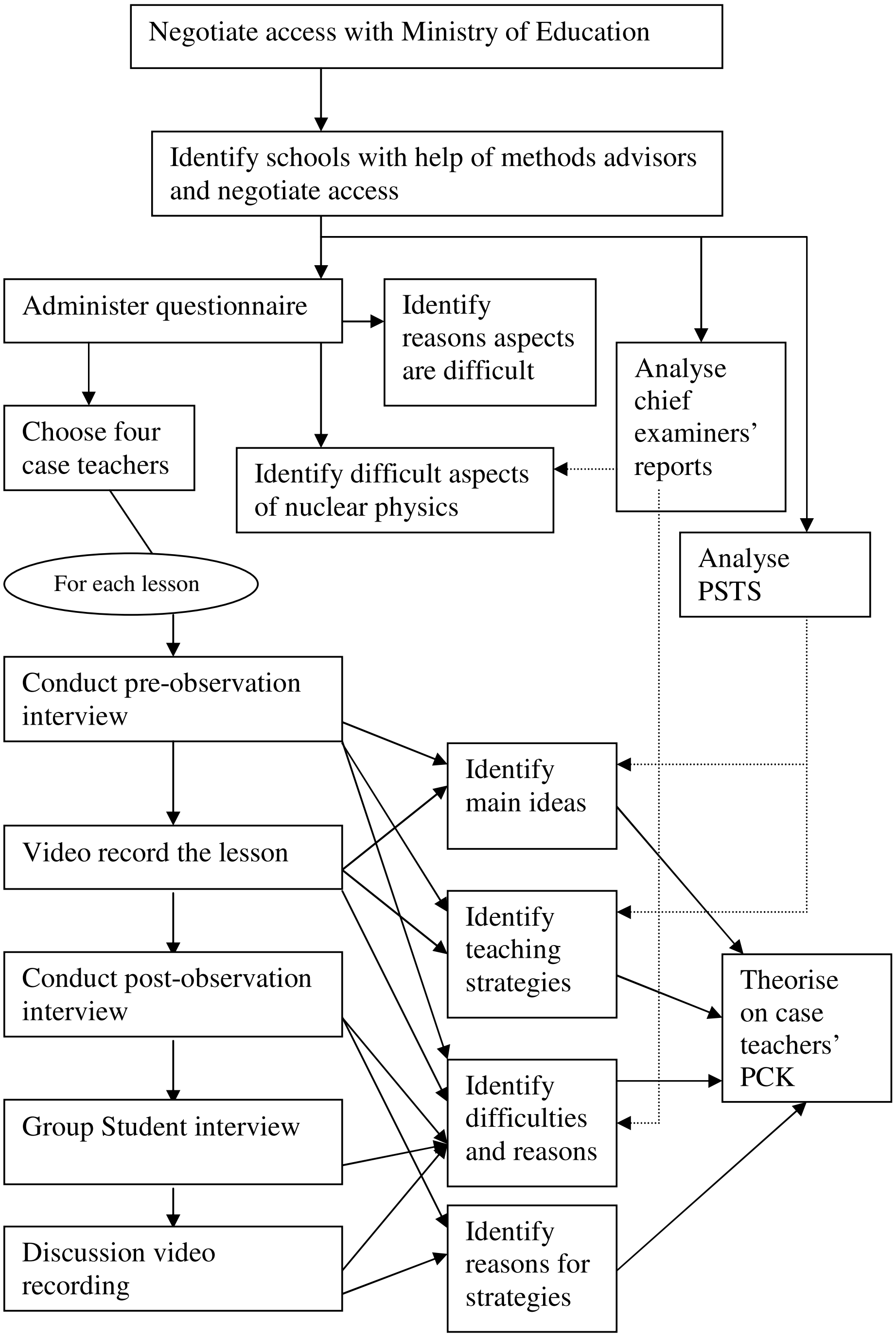

Figure 3.1: Sequence of activities and their relationship to results obtained

Note: Dotted arrows indicate results of the analysis were compared with results from teachers

3.3 Type of study

3.3.1 Qualitative research approach

This study fits into the qualitative research category. One of the assumptions of qualitative research is that multiple realities are socially constructed through individual and collective definitions of a situation (McMillan & Schumacher, 1993). The present study assumed that the PSTs constructed realities in their classrooms individually and through interactions with students. In so doing, they adapted, transformed or interpreted a curriculum to suit their situation. Also qualitative research could be described as an interpretive and naturalistic approach to the world (Denzin & Lincoln, 2000). This study satisfies these descriptions in that I collected data in the natural setting and engaged in interpretation in order to construct meaning from the data.

Among the strengths of qualitative research is its ability to illuminate the particulars of human experience in the context of a common phenomenon (Ayres, Kavanaugh, & Knafl, 2003). It enables collection of multiple accounts of a common experience across participants as well as individual accounts in specific contexts. Thus, qualitative researchers are able to seek illumination, understanding and extrapolation to similar situations (Hoepfl, 1997). Regarding classroom studies, it could be argued that prolonged engagement and extensive observation are central to gaining an in-depth understanding, which calls for qualitative methodology (Fasse & Kolodner, 2000). The aims of this study were to: explore the reasons PSTs would give for choosing nuclear physics as the most difficult topic to teach; describe the nature of teaching strategies that the PSTs would use to deal with learning difficulties; explore the differences in the reasons that Malawian PSTs give for choosing a particular teaching strategy; and understand the nature of Malawian PSTs' pedagogical content knowledge (PCK) with respect to teaching and learning of concepts perceived as difficult. I felt that these aims were consistent with those of the qualitative research approach.

3.3.2 A collective case study approach

This study used a case study approach, using the ethnographic methodology. In a *case study,* a single case is studied in depth, which could be an individual, a group, an institution, a programme or a concept (McMillan & Schumacher, 1993). The strength of this design lies in its potential to enable the study of things in detail (Denscombe, 2003; Patton, 1987). With case studies, it is possible to gain a unique perspective of a single individual or group (Libarkin & Kurdziel, 2002). It can also explain why certain things happen. In this study I used multiple cases in that four teachers were studied in depth. The use of multiple cases created opportunities for within- case and across-case approaches of data analysis (Ayres et al., 2003) to be done. Stake refers to a study extending to several cases as a *collective case study* (Stake, 2000). Stake (2000: 437) further argues that in a collective case study, individual cases are selected because "it is believed that understanding them will lead to better understanding, perhaps better theorising about a still larger collection of cases."

Case studies are faulted for questionable credibility of generalisations. There is a perception that there is a general lack of rigour, difficulties in defining boundaries of the cases, problems of negotiating access to study settings and the effect of the observer on the natural setting (Denscombe, 2003). However, this is a simplistic way of looking at case studies based on some misunderstandings (Flyvbjerg, 2001, 2004). I feel one such misunderstanding could be the belief that all research should always aim at generalisable findings. Such a belief negates the important role that specific information about particular cases plays in understanding phenomena. The conception of 'generalisation' itself may also be problematic by being limited in scope to the positivistic sense. Stake (2000: 439) argues, "In intrinsic case studies, researchers do not avoid generalisation – they cannot. Certainly, they generalise to happenings of their cases at times yet to come and in other situations." Another misunderstanding seems to be that there is no rigour in case studies. My view is that it requires deliberate effort to achieve rigour in all types of designs and case studies are not an exception. By carefully choosing the cases and by paying careful attention to detail and ethical issues, I feel rigour was achieved in this research.

3.3.3 Ethnographic methodology

The term ethnography could refer to a research process or the product of a research effort (LeCompte & Goetz, 1982). As a product of research effort, ethnography refers to a kind of qualitative research that seeks to describe culture or parts of culture from the point of view of cultural insiders (Hatch, 2002). Such research delineates the shared beliefs, practices, artifacts, folk knowledge, and behaviours of a group of people so as to achieve a holistic reconstruction of the culture or phenomena investigated (LeCompte & Goetz, 1982). Eisenhart (1988) describes the following characteristics of ethnography:

1. It derives its tenets from 'interpretivism', so the idea that all human activity is a social and meaning-making experience is central. A further assumption is that "identifiable social groups construct coherent systems of belief and action from intersubjective meanings … which are essentially modes of social relation, of mutual action." (Eisenhart, 1988: 103).
2. In line with goals of interpretivistic research, ethnography aims to make sense of the world from the perspective of participants.
3. Employs the following methods together to gain perspective: various levels of participant observation, ethnographic (open-ended) interviews, search of artifacts like documents and researcher reflecting on the research activities and context.
4. To contribute to triangulation, methods such as surveys, observation schedules and quasi-experiments may be used.
5. Analysis generally involves defining units of the material that are meaningful to participant or researcher and comparing the units to other units, grouping like units into categories, comparing the categories and analysing relationships between the categories.

I do not claim that my research is ethnography. In ethnography the researcher spends long periods watching people and talking to them about what they are doing, thinking and saying in order to see how they understand their world (Delamont, 2004; Mertens, 2005). The period of data collection for my study (nine months) may not be long enough. However it shares a lot of the characteristics given above. For instance, I studied a specific group of people (PSTs) in their natural settings (classrooms). I assumed that classrooms form social units that interact in unique ways as they construct meaning from events. For instance, one aim of this study was to understand how the participating PSTs facilitated student understanding of a topic perceived as difficult. To achieve this aim it was important to observe the interactions that took place between a particular teacher and his/her students and among students themselves. I also had to talk to teachers to understand why they employed certain strategies or how they interpreted certain scenes.

Because of the similarities between my study and ethnography, I employed some methods that are widely used in ethnographic research. I adopted the descriptions of ethnography as a research method designed to describe and analyse practices and beliefs of cultures and communities (Mertens, 2005). I interpreted 'culture' to mean the practices and interactions in the observed physical science classrooms in Malawi and communities to refer to the participating PSTs and their classrooms. In this study I used a combination of participant observation, open-ended interviews and collection of documents, which are key methods of data collection in ethnography (Nasir & Saxe, 2003). I also administered a short questionnaire, which is in line with suggestion that ethnography includes use of surveys and questionnaires for some types of data (Eisenhart, 1988; Nasir & Saxe, 2003). Examples of other studies that have employed ethnography in educational settings exist (e.g. Crawford, Kelly, & Brown, 2000; Kelly & Crawford, 1997; Reed & Lave, 1979). The common aspect of these studies is the use of observations, interviews and collection of documents. One of the strengths of the ethnographic methodology is that it utilises direct observations (Mertens, 2005). As Eisenhart (1988) argues, direct researcher involvement increases chances that constructs and procedures make sense in the social reality of the group studied.

Another strengths is the use of multiple sources of data, which contributes to triangulation and, in turn, to the credibility of the findings (Eisenhart, 1988; LeCompte & Goetz, 1982). The major criticism of ethnographic research is that it is not suitable for coming up with findings that are generalisable (Eisenhart, 1988). However, in the interpretivist paradigm, research is evaluated in terms of trustworthiness, the extent to which the findings are compelling to a researcher's audience (Lincoln and Guba, 1985). I discuss how trustworthiness was established in section 3.9.2.

3.4 Negotiating access to schools

3.4.1 Letters of introduction and permission to conduct research

I got letters of introduction from the University of the Witwatersrand where I am a student and Mzuzu University, my employer. The letter from the University of the Witwatersrand is shown in Appendix 1, while the one from Mzuzu University is shown in Appendix 2. These two letters were presented to the Ministry of Education and Vocational Training, together with a letter requesting for permission to conduct the study in some Malawian schools (Appendix 3). I also included an information letter (Appendix 4) to guide the Ministry of Education in making the decision whether to grant me permission to conduct the study or not.

I sent the documents mentioned in the above paragraph to the Ministry of Education and Vocational Training by fax. When I enquired the following day if the fax had reached him, the principal secretary for education said no. He gave me another number and he confirmed receipt thereafter. Permission was granted in writing in mid-February 2007 (Appendix 5), almost five weeks later.

3.4.2 Permission from head teachers

After getting permission from the Ministry of Education to conduct research in Malawian schools (see Appendix 5), I had to negotiate with the head teachers of the target schools for access. At first I visited the Division Education Managers for the Centre and North to get permission to access schools in their divisions. However, they told me that with permission of the Ministry of Education, I could go straight to the schools and talk to the head teachers. To save time, the first visits to schools had two purposes: to negotiate access and if granted to administer a questionnaire (Appendix 6).

During the first visit at each school, I called at the head teacher's office and introduced myself. I then explained the purpose of my visit. I also handed an A4 envelope to the head teacher containing the following documents: a letter requesting for permission to involve some of the physical science teachers (Appendix 7), an information letter for the head teacher (Appendix 8), two copies of an information letter for PSTs (Appendix 9) and two copies of the questionnaire (Appendix 6). Once access was granted, the head teacher would take the two questionnaires, together with copies of the information letter for teachers, to two PSTs considered best in physical science. If the teachers were not busy I could also then meet them. From then on, each visit I made to the school started with meeting the head teacher or the deputy head teacher, if the head teacher was unavailable.

3.4.3 Ethical issues

3.4.3.1 Preamble on ethics

Negotiating access to schools was closely linked to issues of ethics as decisions to grant permission or not would be influenced by whether the participants would be disadvantaged or not.

The nature of the research process raises ethical issues that are difficult to reconcile (Pring, 2000). For example a researcher's absolute *right to know* would conflict with the respondents' *right to confidentiality*. Despite such difficulties, there is still need to follow ethical principles for carrying out research in order to avoid potential harm to those researched (K. R. Howe & Moses, 1999; Pring, 2000). However, there are no internationally agreed upon regulations on ethical standards in research (Ryen, 2004). Nevertheless, the three main issues frequently raised in ethical research discourse on ethics are informed consent, confidentiality and trust (Howe & Moses, 1999; Ryen, 2004). Informed consent requires that the participants are informed about the nature and consequences of the research in which they are to be involved (Christian, 2000; Henning, 2004). Babbie (2005) contrasts anonymity and confidentiality by pointing out that with anonymity readers of the research, including the researcher do not know the identities of the participants. On the other hand, with confidentiality, the researcher knows the participants' identities but commits to protect those identities. The issue of trust refers to the extent to which the research keeps the commitments made with participants. However, sometimes the researcher may not reveal the true intentions of a study if there are compelling scientific or administrative concerns (Babbie, 2005). In this research there was no compelling reason to hide anything. In the subsections that follow I describe how these three aspects and other requirements were handled.

3.4.3.2 Submission and approval of an ethics proposal

The University of Witwatersrand requires that an ethics proposal be submitted to an ethics committee. For this study, an ethics proposal was submitted to the Wits School of Education Ethics Committee. The committee approved the proposal (see Appendix 10). The process of preparing the proposal made me think seriously about issues of informed consent, confidentiality and full declaration of intentions of the study.

3.4.3.3 Issues of informed consent

One of the main ethics issues frequently pointed out is that of informed consent (Christian, 2000; Ryen, 2004). For this study, the informed consent issue was at different levels. The first was when requesting for permission from the Ministry of Education in Malawi to access the schools. The ministry had to make the decision fully aware of what the study was about and how teachers would participate. Thus, the request was accompanied with an information sheet (Appendix 4) for the principal secretary. In the information sheet, I made it clear that: the teachers' participation would be entirely voluntary, all the information gained from the study will be treated with confidentiality, the teachers' identities would be preserved and that none of the participants would be forced to answer any question during interviews and discussions. Permission was granted (Appendix 5), hopefully basing on the information provided.

The second level of informed consent was with head teachers, who were also given an information sheet (Appendix 8). In addition, I explain to the head teachers the purpose of the study and how their teachers would participate. Those with questions were free to ask and I could answer them as honestly as possible. The only problem here with some schools is that the head teachers granted permission just after I had explained, so they may not have understood some of the ethical issues involved.

The third level was with the participating teachers. These too were given an information sheet. In addition, I had a chance to explain to them about the purpose of my research, issues of confidentiality and that their participation is voluntary. For the PSTs I insisted that they read the information sheet (Appendix 9), as they were required to sign consent forms agreeing to participate (Appendix 11) and to be video/audio-recorded (Appendix 12). Even on the questionnaire (Appendix 6), the PSTs were supposed to indicate if they were willing to participate in the study.

The fourth level concerned students who would be part of the case teachers' observed lessons. Apart from verbal explanation, the students too were each given an information sheet (Appendix 13). They also had to consent to participate in the study, including being video recorded. Parents of the students were also given information sheets through the students (Appendix 14). The parents were asked to sign a consent form (Appendix 15). Some parents returned signed forms, while others did not. However, the students opted to attend lessons, even if their parents had not signed a consent form. The students were assured that no one would have access to the video recordings, except their teacher and myself. Therefore, their identity was protected.

3.4.3.4 The issue of confidentiality

Confidentiality is a theme that appears in most codes of research ethics (Adams & Schvaneveldt, 1991). In all the information sheets discussed above, be it for teachers, students, head teachers or Ministry of Education officials, there was assurance of confidentiality. Here I dwell on how the assurance was implemented.

At the school level, the head teacher and other teachers knew whom I was working with and I could not control the participating teachers and students from discussing their involvement with others. This confirms the observation that issues of ethics are sometimes difficult to reconcile (Babbie, 2005; Christian, 2000; Pring, 2000). However, from my part, confidentiality meant the following:

1. Not revealing the identities of teachers or schools to anyone throughout the research process and beyond. Instead of names, codes have been used in the write up. Also, no one else apart from the concerned teacher and myself, have had or will have access to video and audio-recordings. No photographs have been used in this study to protect identities.
2. Not making any judgemental comments about the participating teachers to the head teacher or any other persons, even if they insisted. This was to avoid disadvantaging the teachers for their participation in the study.

3.4.3.5 The issue of trust

According to Ryen (2004: 234), "Trust refers to the relationship between the researcher and the participants, and to the researcher's responsibility not to 'spoil' the field for others in the sense that potential research subjects become reluctant to research." According to Howe and Moses (1999), trust and accountability are central to the research enterprise as knowledge and truth are sought. Howe and Moses further argue that any breach of trust and accountability is research misconduct. Christian (2000) contends that the researcher should avoid deliberate misrepresentation, which amounts to deception. Ryen (2004) argues that trust is the traditional magic key to building good field relations and offers the following ways of building intense field relations:

1. Carefully balancing the need to declare intentions of the study and deliberately misrepresenting oneself to obtain greater and deeper understanding, depending on the nature of an issue under study.
2. Shared understanding of a respondent's experiences, in the case of interviews, which demands an empathetic orientation from the interviewer.
3. Fidelity during the write up phase, which is the obligation for truth telling.

In this study, I felt there was no need to hide my intentions because of the nature of the study. This is the reason information sheets were given to all participants and concerned authorities. However, much as I declared my intentions in most cases there were times when this would not be appropriate. For instance, while observing one of the case teachers, I felt the teacher presented scientifically incorrect content. My real intention would have been to intervene and say it, but I felt this would embarrass the teacher and jeopardise our relationship. On building trust by being empathetic, I tried to be polite and non-judgement in all interactions with the teachers. This freed the case teachers to such an extent that they were not afraid or ashamed to admit where they did not know an aspect of content. The third way involves presenting the truth during write up. I have tried to do this by backing any claims about the teachers with extracts from the data.

3.5 Selection of participants

3.5.1 Selection of schools

One aspect of this study was to ascertain if practising teachers would also rate nuclear physics as the most difficult topic in the PSS. To do this, I developed a questionnaire (Appendix 6) to be administered to 30 PSTs in selected schools. The schools had to have 'best' PSTs in their category (conventional or community day secondary schools). They also had to be easily accessible to me. I stay in Northern Malawi in a town called Mzuzu, so the selected schools from the Northern Region had to be within 50 kilometres radius of this town. To have teachers from a different context, I also involved schools in the Central Region. For easy accessibility, only schools from Lilongwe (400 km south of Mzuzu), which is the capital city of Malawi, were considered.

Also, Malawi has two types of secondary schools: conventional secondary schools (CSS) and community day secondary schools (CDSSs). CSSs are mainly owned by the government, though there are some run by religious organisations - also supported by the government in terms of teachers and some grants. Local communities run CDSSs. In most cases, CSSs are better equipped than CDSSs in terms of teaching materials, infrastructure and quality and quantity of teachers. In the past CDSSs could not offer physical science because of lack of teachers and learning materials. Even now it is not all CDSSs that offer physical science. In this study, both CDSSs and CSSs had to participate as they both teach the same curriculum and to the same Malawian learners as far as they offered senior secondary school physical science.

To select which schools to involve, I visited offices of the Division Education Managers for the northern and central divisions on separate days to meet the education methods advisors responsible for physical science. I visited each of these offices twice: the first visit was to request the advisors to supply me with information about who they thought were 'best' physical science teachers at CSSs and CDSSs. In both places the advisors found this difficult to do and instead said they would give me information about which schools performed well in physical science. Thus, I worked with the assumption that schools with best performance in physical science on national examinations had best physical science teachers. I would then give the advisors time to compile the information and collect it on another day. There were very few CDSSs that offered senior physical science; so all those mentioned were selected. With CSSs, I had to select because all of these schools offered the subject. Thus, I selected those that were most accessible. It should be pointed out that the best performing CDSSs still performed worse than the worst performing CSSs. This means the phrase 'best teacher' here only makes sense if teachers from CSSs are compared among themselves and similarly those from CDSSs.

Eight schools were selected from the Mzuzu area. Four of these schools were CDSSs. From the Lilongwe area, also eight schools participated, but only two were CDSSs as most of the CDSSs had just started introducing physical science at junior level.

3.5.2 Selection of case teachers

From the 30 PSTs who completed the questionnaire (Appendix 6), I had to select four (hereafter called case teachers) to study in depth. The criteria for selecting the case teachers were as follows: they had to have a minimum of two years' teaching experience, they must have chosen nuclear physics as the most difficult physics topic from the list in item six of the questionnaire and they must have been willing to participate in the study. The two years' teaching experience was based on the assumption that during that time, they should have had a chance to take students through the whole of the senior physical science course. The selected teachers should have mentioned nuclear physics to be the most difficult physics topic because this study was about how the case teachers would try to address learning difficulties in a topic perceived as difficult.

Of the thirty PSTs requested to complete the questionnaire (Appendix 6), 28 of these did so and returned the questionnaire and 14 out of these 28 chose nuclear physics as the most difficult physics topic to teach. Out of the 14, 12 (hereafter referred to as 12 PSTs) also chose nuclear physics as the most difficult to learn.

To choose four case teachers from the 12 PSTs, *stratified purposeful sampling* was used. In stratified purposeful sampling, a subgroup is chosen based on specific criteria and on the fact that it can provide rich information (Mertens, 2005). This type of sampling was necessary because there were two groups of PSTs (those from CSSs and those from CDSSs), hence the need for stratification because two had to be selected from each group. From the Mzuzu area no teacher from a CDSS chose nuclear physics as both most difficult to teach and to learn. So one of the two (identified by code T10) who had chosen nuclear physics as the most difficult to teach and was willing to continue in the study was selected. This, I feel was in order because where the best case cannot be obtained, the next best could be selected in line with the assertion that case studies are opportunistic, a matter of seeing interest to which one has access (Stenhouse, 1988).

Also those who gave more detailed reasons for rating nuclear physics as the most difficult to teach and/or learn were preferred, justifying the use of purposeful sampling. In other words, the case teachers qualify to be called critical cases. Flyvbjerg (2001) defines a critical case as one that has strategic importance in relation to the problem. A critical case allows generalisations like 'if it is valid for this case then it is valid for all and vice versa.' Use of critical cases is appealing because the cases could also serve as models to others.

As expected, those from CSSs were qualified to degree in education level whereas those from CDSSs had lower qualifications. Table 3.2 shows the characteristics of the case teachers. The codes T10, T12, T23 and T25 correspond with those used to identify the teachers when they returned the questionnaire and have been used throughout this write up to shield the teachers' identity. All the case teachers had a minimum of two years' teaching experience at secondary school level, which means they should have developed some PCK for teaching at this level.

Table 3.2: Characteristics of the case teachers

Case Teacher	**Qualification**	**Teaching experience (yrs)**	**Category of school**
T10	Primary teaching certificate	2*	CDSS
T12	Bachelor of Education	11	CSS
T23	Diploma in Education	7*	CDSS
T25	Bachelor of Education	7	CSS

** These teachers had more experience at primary level, but I have just indicated the one at secondary school level.*

To ensure that the study is politically and culturally sensitive, two of the four teachers were drawn from schools in the Northern Region and another two from schools in the Central Region. There was supposed to be a school from the Southern Region, but this was dropped, after getting the go ahead from my supervisors because of long distances involved. The town where I stay is 650 km from the Southern Region's Blantyre City.

3.6 Data collection methods

3.6.1 Description of sites

3.6.1.1 The country

This study was done in Malawi, a developing country located in South East Africa. Its secondary education system is small compared to the number of pupils who qualify. According to the *Malawi Poverty Reduction Strategy Paper* (MPRSP), only 18 percent of those who successfully complete primary school proceed to secondary school (Malawi Government, 2002). An attempt to increase secondary enrolment has lead to over-crowded classrooms and shortage of teaching resources.

3.6.1.2 The case teachers' schools

As already mentioned four case teachers were involved in this study. They were from four schools. Two of the schools were CSSs and the other two were CDSSs. The CSSs were better resourced than the CDSSs in terms of teaching materials, infrastructure and quality and quantity of the teachers. For instance, both CSSs had physical science laboratories with running water and power points, while the CDSSs did not.

Even when comparing the CSSs amongst themselves, differences do exist. One of the CSSs was a boarding school, which allowed teachers to have access to students even during weekends or in the evenings. The other was a day school where students operated from their homes and operated a double-shift system, with one cohort coming in the morning and the other in the afternoon. It was like two schools using the same facilities.

The CDSSs were also different from each other. One was a completely day school with all students operating from their homes, while the other was partly boarding and partly day. Even the infrastructure was different in that at one school there were more classroom blocks than at the other. Although both CDSSs did not have laboratories, at the one with more classroom blocks a new block was being built and I learnt from the head teacher that there would be a laboratory once completed.

Detailed descriptions of each of these schools are given in relevant sections in chapter 5.

3.6.2 Instruments for data collection

3.6.2.1 The teachers' questionnaire

One of the instruments I used in this study for data collection was a short questionnaire (Appendix 6). Construction of the questionnaire was guided by the research design itself. It had to enable collection of biographical information, which was important for selection of cases (see subsection 3.5.2). It also had to enable collection of information about the topic teachers thought was most difficult and the reasons for their choice. Thus, questions to elicit such information were included.

A number of people looked at the questionnaire, which helped to ascertain if it would elicit desired information. . First were my supervisors, who thought it was appropriate for the task. Next, were the audience at the presentations I made at various forums like the "PhD weekends" organised by the Marang Centre for Mathematics and Science Education of the University of Witwatersrand where science educators and fellow PhD students commented on it. Two science educators were specifically requested to look at the questionnaire and they thought it was appropriate for the task. The research ethics committee of the Wits School of Education also looked at the questionnaire when considering the ethics proposal and they made an observation that respondents had to indicate their consent on it and this was done. Finally, before administering it, I piloted the questionnaire on five PSTs and these did not form part of the 30 described earlier. The pilot results made me refine the questionnaire. For instance, at first the items were not numbered, but the pilot results indicated that numbering them would facilitate capturing of the results. Also, item seven simply said '*Give reasons for* *your choice'*. This was improved to read '*Give as many reasons as possible for choosing this topic as the most difficult to teach'*.

To check if the questionnaire gave consistent results, it was administered twice to the 30 teachers. There was a space of at least three weeks between the first and second administration. I then compared the responses each teacher gave during the first and second administrations. The comparison revealed that there was good agreement. For instance, among the 14 who chose nuclear physics as the most difficult to teach during the first administration, 12 of them made the same choice during the second administration.

A questionnaire was chosen because I needed to survey the views of more teachers than the four case teachers on the most difficult topic. Soliciting responses from more teachers enabled a pattern to emerge concerning which topic is most difficult and the reasons given for choosing a particular topic as the most difficult.

However, questionnaires do have weaknesses in that the response rate can be low and the responses can lack depth. To ensure a good response rate, I physically visited the schools to administer the questionnaire and where possible collect it on the same day. In most cases it was not possible to collect them on the same day, so I made arrangements with the teachers to pick them on an agreed date. For Lilongwe schools, I spared a whole week to this because of the long distance. So it was possible to pick them up on an agreed date within the same week. This helped to improve the response rate as 28 of the 30 questionnaires were returned.

Another weakness with questionnaires is that the responses may lack depth, especially if closed questions are used (Patton, 1987). To prevent this weakness, I included open questions that allowed the teachers to explain their responses. Such questions might have 'forced' the teachers to think deeper than they would with closed questions only.

3.6.2.2 The video camera

Another instrument I used was a video camera. I used it to record lessons and discussions I had with some students at the end of lessons. One advantage of the video camera was its ability to capture and preserve more detail than would be possible if unaided (LeCompte & Goetz, 1982). I utilised this advantage to capture class conversations, some student written tasks, work written on the chalkboard and classroom settings. It was also easy to play a video recording and discuss the lesson reflectively with a concerned case teacher. I could also play the video recording several times on my own to gain deeper in sight from the classroom interactions.

After access to the schools and teachers had been granted (see sections 3.3.1 and 3.3.2), the following conditions had to be met to record a lesson:

1. The concerned teacher must have signed two consent forms: one agreeing to participate in the study and the other agreeing to audio and video recordings.
2. The head teacher and the teacher concerned must have explained to students about my research and their role before the day of the first recording.
3. A day before the first recording, I should have left information sheets for students (Appendix 13) and the students' parents (Appendix 14) together with a consent form for parents (Appendix 15).
4. On my arrival to a class for the first time either the case teacher or myself had to explain again to the students why I was attending and recording the lesson. The students were told clearly that they could opt out and none did so.

In spite of strengths of using the video camera as an observational tool, I had two problems with its use: I could only capture a portion of a class at a time, voices of those far from the camera were sometimes inaudible and transcription of video is difficult and time consuming as it becomes necessary to add notes to describe certain actions. In addition, observation methods could be intrusive and indeed one of the case teacher at some point admitted that the camera affected his presentation. By explaining to the teachers the use of the camera and assuring them that it was for research purposes only it might have reduced anxieties. In spite of these difficulties, I feel the amount of data collected per lesson was immense.

3.6.2.3 The digital voice recorder

In this study I used a digital voice recorder to capture and preserve interviews and discussions of the video recording. Interviews and video discussions enabled me collect data about why teachers did certain things, especially reasons for choosing certain strategies. I could probe decisions made before and during the lesson. There were two types of interviews: those conducted just before a lesson was observed (pre-observation interviews) and those conducted soon after the lessons (post-observation interviews). Both pre-observation and post-observation interviews were conducted in a place the teacher offered. At one school it was in the laboratory, at another in the library, yet at another in the preparation room of a laboratory and then there was one school at which the interviews were held under a tree. I could sit next to a case teacher, with the recorder put on a desk or held in my hands in the case of where we sat under a tree, and ask questions. The case teacher would then answer. The setting was similar for the video discussion. The only exception was at the school where interviews were held under a tree, the video discussions were held in a storeroom attached to the classroom. I could run a portion of the tape and discuss its contents and if necessary a replay could be done. Before I could do any recording, issues of ethics described earlier had to be explained (see section 3.3). I discuss the types of questions asked during the interviews or discussion of the video under types of data collected in section 3.7.

This recorder was chosen because it was: sensitive enough to capture even low voices, possible to transfer the recordings to a computer and it was small, light and easy to carry. One of the weaknesses was that it had small memory size, so there was need to transfer recordings to a computer regularly. In one instance this was not possible and the memory was full, so I just took notes. Another weakness was that batteries needed replacing regularly to avoid poor quality of voice resulting from low power and this carried a cost with it.

3.7 Types of data collected

3.7.1 Responses to the questionnaire

As already explained a questionnaire was administered to some PSTs (Appendix 6) and much has already been said about the questionnaire. Here I just state the types of data that this instrument allowed me to collect and how that data related to this study. It was as follows:

1. Biographical data, which was used in selection of case teachers.
2. Information about the most difficult physics topic in the PSS, which was used in selection of case teachers and to confirm that practising teachers also rate nuclear physics as the most difficult physics topic.
3. PSTs' reasons for rating nuclear physics as the most difficult physic topic in the PSS. Such information was then used to shed light on one aspect of teachers' PCK in nuclear physics: knowledge about what makes learning of topics difficult.

3.7.2 Pre-observation interviews

As mentioned earlier, I interviewed the case teachers before each lesson observed. This enabled me to collect audio-recorded interview data. Pre-observation interviews took between 10 and 15 minutes. I preferred the interviews because they allowed me to follow up on responses. The interviews were semi-structured in nature, so I could only bring in guiding questions (Appendix 16). Formulation of the guiding questions was influenced by the model of pedagogical reasoning and action (Shulman, 1987; Wilson et al., 1987). It enabled me to find out whether the case teachers:

1. Comprehended the purposes and ideas of their lessons.
2. Engaged in critical interpretation and analysis, so they could identify difficult aspects.
3. Possessed an instructional repertoire from which they chose strategies to use in their lessons.

The question on main ideas was influenced by Loughran et al.'s (2004) concept of 'big ideas' used in developing what they called teachers' content representations (CoRes).

Pre-observation interviews enabled me to collect data about what a case teacher had planned to do in a particular lesson, difficulties the teacher anticipated students would have with the topic, the strategies the teacher would use and reasons behind choice of those strategies. These data contributed to answering questions on difficult aspects, teaching strategies used and to shed light on the following aspects of the teachers' PCK in nuclear physics: knowledge of main ideas, learning difficulties, strategies to address learning difficulties.

3.7.3 Video recordings

One aspect of this study was to investigate how the case teachers tried to address learning difficulties in nuclear physics. I felt use of a video camera to record some lessons and some students' views about those lessons was appropriate for this purpose. As mentioned already, the case teachers' lessons were recorded using the video camera described in section 3.5.2.2.

Also, this study was set in the constructivist paradigm and naturalistic qualitative methods (like use of a video camera) are appropriate in such a paradigm (Hatch, 2002). Participant observation, in which the researcher is main instrument of data collection, was used to observe the lessons. The video camera was the instrument for observation.

There are three levels of participation with this method: total participation, participation in the normal setting and participations as an observer (Denscombe, 2003). For total participation, the researcher's role is kept secret and he or she assumes the role of someone who normally participates in the setting. There is participation in the normal setting if the researcher's role is known to certain people, but hidden to others in the setting. As for participation as an observer, the researcher's identity is openly recognised. Since the other two raise ethical concerns, in this study I participated as an observer.

With participant observation, the researcher participates in the daily life of the people under study. Strengths of participant observation include: covering events in real time, covering contexts of events and taking into consideration interpersonal behaviour and motives (Yin, 1998). It is because of these strengths that participant observation was used to study teaching strategies.

I operated the camera myself. To practise with use of a video camera, I used one of the PSTs, who also chose nuclear physics as the most difficult topic, but was not among the four case teachers, as a pilot case teacher. I recorded one of his lessons on nuclear physics. At first I was shaky with tasks such as dismounting a camera from the stand, zooming in or out and to keep the camera stable when held in the hands. By the end of the lesson I had gained some dexterity in handling the camera and focusing it on what I deemed important. The pilot recording also gave me experience with transcribing video data.

Two lessons were recorded per teacher. Originally, four lessons should have been recorded per teacher, but scheduling difficulties forced me to reduce. The teachers were not obliged to teach lessons on same aspects of nuclear physics, as this would have defeated requirements of naturalistic enquiry.

The video recordings of lessons formed the main data concerning teaching strategies. This data contributed to answering questions related to:

1. Main ideas covered and learning difficulties associated with them.
2. Teaching strategies employed to try to address the difficulties.
3. Ways in which the teachers assessed student understanding.

3.7.4 Post-observation interviews

After observing each lesson I interviewed the teachers again. Each interview took anything between 10 and 30 minutes. These interviews were also audio-recorded.

These interviews were also semi-structured in nature, so only guiding questions were brought in (Appendix 16). Here too, Shulman's (1987) and Wilson's et al.'s (1987) model of pedagogical reasoning and action influenced the formulation of guiding questions. It enabled me to assume that the case teachers could engage in reflection over their practice and that the teachers could come up with new understanding and learning from experience.

Post-observation interviews generated data that contributed to the following aspects of this study:

1. Deeper understanding of the strategies that the teachers used through answers to questions such as '*How did you think this strategy would help students understand better*?'
2. Teachers' knowledge about learning difficulties, which is a PCK aspect. This was the case where I asked the teachers to explain some of the observed learning difficulties.

Also, during post-observation interviews, the case teachers were given a chance to elaborate and clarify some points made during the lesson. This interview data was analysed to provide insight into the teachers' knowledge of content, learning difficulties, assessment and teaching strategies.

3.7.5 Group interviews with students

Group interviews with students (hereafter called student interviews) were not part of the original plan. However, feedback from presentations I made during one PhD weekend at the University of the Witwatersrand strongly recommended that I talk to some students and I felt the recommendation had merit. Individual interviews were going to be time-consuming and would have diverted my focus on teaching strategies. Thus, group interviews were preferred.

At the end of a lesson, the teacher would ask five volunteer students to take part in the interview. The first five to come forward were considered. In all cases more students wanted to participate in the interviews, so finding volunteers was not a problem. At one school, the teacher just asked the whole class to remain behind, so I just asked questions to the whole class. These interviews were short: five to 10 minutes long, as they took up part of break time. The interviews were recorded using the video camera. Three of the four case teachers did not attend the student interview. Although I did not ask them to do so, they left me on my own with students who had volunteered and remained in class. One attended the interview and since the questions had nothing to do with evaluation of the teacher, the students were still free to speak. The questions were centred on two things: what the students had learnt from the lesson and where they felt they did not understand and would need the teacher to clarify. Specific examples of questions include:

1. Tell me, what aspects of this lesson did you understand most?
2. Were there any aspects where you still have doubts and you would want them may be re-taught or you would want to go back to the teacher and say sir could you please assist me here?
3. Is there any other area where you feel you would want to get clarification?

Responses to questions like these revealed where and what the students had understood or not. They also brought to light student thinking about certain phenomena. Data from student interviews proved invaluable in bringing to light some of the hidden difficulties; for instance, one teacher used a diagram that students did not show that they had difficulties with during the lesson. But during the student interview, as one student was explaining what he had learnt, he mentioned a statement that revealed that he had interpreted the source of radiation as the sun. Student interview data could also be related to the strategies that were used and give an indication of the effectiveness of those strategies.

3.7.6 Video discussion

Each case teacher and I discussed the video recording of that teacher's lessons. Ideally this should have been done after I had viewed the video on my own. However, I realised that teachers were busy people and if time allowed it was better to discuss the video on the same day directly from the camera screen. It also became difficult to make more trips to schools in Lilongwe because of the distance involved and the costs. So, where possible the video discussion took place soon after the post-observation interview. The advantage of this was that the lesson was still fresh in the minds of both the teacher and myself and in many respects it built on what had been discussed during the post-observation interview. In other cases, the concerned case teacher and I agreed to meet on a specified day and time for the discussion. All the discussions were audio-recorded using the digital voice recorder. To achieve efficient use of video discussion time, I could play the video for sometime, say three minutes and discuss the contents. Where an aspect of the lesson was already sufficiently discussed during the post-observation interview, I could fast forward the video and where necessary I could rewind. These discussions took anything between 40 and 60 minutes per lesson. The discussion focused on:

1. Teaching strategies and why they were used.
2. Learning difficulties and the strategies used to try to address them.
3. Factors that may have influenced certain activities.

Data from discussion of the video recording contributed to answering of the research questions in the same way as that from the post-observation interviews.

3.7.7 Collection of documents

The following documents were collected: the PSS, chief examiners reports in physical science and copies of the relevant chapters of two commonly used books for the topic. Charts used and notes written on the board were captured on the video camera and formed part of the video transcripts for the lesson.

Content analysis of the PSS revealed the depth and breadth that lessons in nuclear physics should achieve. From the objectives given in the PSS I was able to comment on the teachers' knowledge of the curriculum and major concepts, which is a PCK aspect. Content analysis of the chief examiner's reports revealed the topics deemed as difficult and the sort of difficulties associated with them. The difficulties identified for the topic on nuclear physics were then used as benchmarks for assessing the case teachers' knowledge about difficulties in this topic and for justifying credibility of the difficulties identified. The textbooks were mainly used to identify the main concepts of the topic.

3.8 Analysis of results obtained

3.8.1 Approach to the section on analysis

Here I describe the general approach to data analysis. Details of what exactly was done with the data are given in the section where a particular type of data is presented. This is the case because the processes of data organisation, analysis and write-up were interrelated. Patton (1987: 144), writing about analysing and interpreting qualitative data, put this point across as follows: “There is typically not a precise point at which data collection ends and begins. Nor, in practice are the analysis and interpretation neatly separated.”

I have also organised description of how analysis was done in sections because the different types of data collected meant different types of analyses would be appropriate. However, where similar types of analysis are used, I describe them in one section.

3.8.2 Content analysis of data from the questionnaire

Content analysis was applied to data obtained through the questionnaire. I use the phrase ‘content analysis’ in line with Patton’s (1987) description that content analysis involves:

1. Identifying examples, themes and patterns in the data.
2. The analyst looking for quotations or observations that go together and are examples of the same underlying idea, issue or concept.
3. Classifying contents of the data.

All responses from the questionnaires were summarised in a master table, which consisted of a number of rows and columns. All responses from each teacher were entered in a separate row of the master table. Also, all responses to each item of the questionnaire were entered in separate columns of the table. The questionnaire items were constructed in such a way that responses to each item already form a class. Thus, from the master table I was able to extract two tables: the first giving biographical information and the second showing what each PST thought was the most difficult topic, the difficult aspects of the topic, the reasons those aspects were deemed difficult from both a teaching and learning perspective. From the second table it was easy to see who had chosen nuclear physics and select case teachers from them. The second table also allowed me to identify aspects of nuclear physics mentioned as difficult, the reasons given for labelling them so and to capture these in a table shown in Appendix 17. The table in Appendix 17 formed a basis for discussion of what the PSTs thought were difficult aspects of nuclear physics.

The technique of content analysis was also used with documents. For instance with chief examiners' reports, I first identified the relevant sections of each report (e.g. comments on a question on nuclear physics in a particular paper), read through to classify the difficulty, if any, highlighted and then looked for patterns across papers from different years.

3.8.3 Analysis of interviews, video recordings and video discussions

3.8.3.1 Transcription of all recordings

I transcribed all audio and video recordings into text. To facilitate easy replaying of segments, all audio recordings were transferred and saved into a computer. I could then listen to a segment of a recording and type straight into the computer. I could replay the segment a number of times to make sure I got it right before moving forward to another segment. For video recordings, I viewed them straight from the screen of the video camera. Again, I could view a segment of the tape, type straight into a computer and replay a number of times to get it right if necessary. All transcriptions were done in, either my bedroom (those done when I was in Malawi) or in my room (those done when I was in South Africa). My bedroom (or my room in South Africa) provided a conducive and quiet environment for this difficult task. Doing this task in the solitude of my bedroom (or room) also meant no one else could have access to the recordings, which had ethical implications. While transcribing, any insights that came to mind, in the form of possible interpretations, were noted in italics in brackets.

Some conventions were used while transcribing and these were as follows:

…. Indicated that something had been left out because it was inaudible.

… Indicated that something meant to complete a statement was not uttered

(t) Indicated that there was a pause of about t seconds, where t could be any number.

// Indicated preceding word(s) had been said emphatically.

||| Indicated preceding words had been said hesitantly.

3.8.3.2 Analysis of transcripts

Inductive analysis of qualitative data (Hatch, 2002) was used to analyse the transcripts. Hatch gives the following steps in inductive analysis:

1. Read the data and identify frames of analysis, segments of text that contain one idea, episode or piece of information.
2. Create domains based on semantic relationships discovered within frames of analysis. Nine semantic relationships are useful for accomplishing domain analysis and these are: strict inclusion (X is a kind of Y); spatial: (X is a place in Y); cause-effect (X is a result of Y); rational (X is a reason for doing Y); location for action (X is a place for doing Y); function (X is used for Y); means ends (X is a way to do Y); sequence (X is a step in Y); and attribution (X is a characteristic of Y).
3. Identify salient domains, assign them a code, and put others aside.
4. Reread data refining salient domains and keeping a record of where relationships are found in the data.
5. Decide if the domains are supported by data and search data for examples that do not fit with or run counter to the relationships in domains.
6. Complete an analysis within domains.
7. Search for themes across domains.
8. Create a master outline expressing relationships within and among domains.
9. Select data excerpts to support the elements of your outline.

This approach is similar to the steps described by Denscombe (2003) and McMillan and Schumacher (1993) that qualitative data analysis involves. Miles and Huberman also propose a similar approach to qualitative data analysis that is composed of three concurrent activities: data reduction, data display and drawing conclusions (Miles & Huberman, 1984). However, Hatch's (2002) approach is more detailed, so it was preferred.

Inductive analysis as described by Hatch (2002) fitted with requirements of this study. Firstly, it applies to the constructivist assumptions, which apply to this study, in that codes emerge from the data and are not predetermined. Next, it is powerful in getting meaning from complex data. And, lastly, it is a systematic approach to processing data.

To facilitate inductive analysis, the transcripts were converted to rich text format and loaded on to the *Atlas.ti 5.2* software. A set of transcripts related to one lesson (pre-observation interview, video recording, post-observation interview and video discussion transcripts) was loaded as a single file. Thus, for the eight lessons, there were eight files (called primary documents in the language of *Atlas.ti 5.2* software) each consisting of four transcripts.

In line with the above nine steps in inductive qualitative analysis, I read through each primary document (PD). Then I read through again slowly, while creating frames of reference (quotations in the language of *Atlas.ti 5.2*) and assigning codes to them. The codes defined the applicable domains. However, not all the semantic relationships were used in this study, as others were not applicable like the one that gives a spatial relationship. The following relationships were widely used: strict inclusion (X is a kind of Y), cause-effect (X is a result of Y), rational (X is a reason for doing Y), function (X is used for Y), means-ends (X is a way to do Y), sequence (X is a step in Y) and attribution (X is a characteristic of Y). The codes were revised several times to come up with the salient ones. Evidence for the domains was also sought and this is why a lot of quotations have been used in the results chapters. Lastly, themes (supported by the data as much as possible) were generated. Detailed descriptions of how specific data was handled have been provided in the results chapters close to where particular results are presented.

The benefits of using *Atlas.ti 5.2* in this study were as follows:

1. I could combine some of the steps in inductive analysis like the processes of identifying frames of reference, identifying domains and coding.
2. It was easy to navigate within or across the primary documents (PDs)
3. It allowed me flexibility. I could change code names and quotation (the equivalent of frames of analysis) boundaries easily. I could also delete unwanted codes or combine them. Adding notes to what I was doing was also made easy through the edit functions. I also had the option of coding by using the existing list of codes (coding by list), creating new codes (open coding) or using portions of selected text from the PDs (in vivo coding). In this study, though, I did not use in vivo coding.
4. Tracking quotations to which a certain code or group of codes applied was easy.

Other approaches to qualitative data also exist; for example, Panayiotis describes the method of using critical incidents (Panayiotis, 2001). In this research it was felt such an approach would be difficult to implement because of difficulties in identifying what would count as a critical incident. Hatch (2002) describes other approaches like typological analysis, interpretive analysis, political analysis and poly-vocal analysis. Typological analysis requires predetermined typologies, which is not consistent with constructivist assumptions of this study. Interpretive analysis requires pre-determined impressions written in research journals, which was not done. Political analysis was not used because it suits critical/feminist epistemological assumptions, which was not adopted for this study. Poly-vocal analysis was not applied because this study did not focus on voices, but on how teachers actually address teaching problems.

3.9 Research trustworthiness

3.9.1 Credibility of the questionnaire

Credibility of the questionnaire has already been discussed in section 3.6.2.1. Other colleagues and science educators looked at the questionnaire and attested that it was appropriate for the task. The questionnaire was also piloted to ascertain that it would give desired results. I administered the questionnaire twice and compared responses from the two administrations in order to check consistency of the questionnaire results.

3.9.2 Criteria for trustworthiness

For quantitative research, internal validity, external validity, reliability and objectivity are the measures for research quality (Anfara, Brown, & Mangione, 2002). However, these criteria are difficult to apply to qualitative research. In qualitative research, the issue is that of trustworthiness (Lincoln & Guba, 1985). Lincoln and Guba (1985: 290) argue, "The basic issue is simple: How can an inquirer persuade his or her audiences (including self) that the findings of an inquiry are worth paying attention to, worth taking account of?" As a result, as Hoepfl (1997) points out, Lincoln and Guba identified an alternative set of criteria that correspond to those typically employed to judge quantitative work. These criteria are: credibility, transferability, dependability and confirmability (Lincoln & Guba, 1985). Credibility is the equivalent of internal validity, transferability that of internal validity, dependability that of reliability and confirmability that of objectivity. These criteria could be explained as follows:

1. Credibility is the extent to which the researcher has portrayed the multiple constructions adequately (Lincoln & Guba, 1985)
2. Transferability refers to the process in which the researcher and the readers infer how the findings might relate to other situations (Denscombe, 2002; Lincoln & Guba, 1985).
3. Dependability is a careful review of the process of data collection and the research product (Libarkin & Kurdziel, 2002).

4. Confirmability is the extent to which the interpretations and recommendations are supported by the data and are coherent (Lincoln & Guba, 1985)

Hoepfl (1997) points out that these criteria are criticised because they look little different from those used with quantitative studies. However, they are still useful for assessing quality of qualitative research (Libarkin & Kurdziel, 2002). Thus, in this study I adopted them for improving trustworthiness of the research. Table 3.3 shows the criteria for assessing quality of quantitative (first column) and qualitative (second column) research. The table also shows the strategies employed to ensure criteria for assessing quality of qualitative research are met.

Table 3.3: Criteria for assessing research quality

Quantitative term	**Qualitative term**	**Strategy employed**
Internal validity	Credibility	Prolonged engagement in field Use of peer debriefing Triangulation Member checks Time sampling
External validity	Transferability	Provide thick description Purposive sampling
Reliability	Dependability	Create an audit trail Code-recode strategy Triangulation Peer examination
Objectivity	Confirmability	Triangulation Practice reflexivity

This table was adapted from Anfara et al. (2002: 30)

In this research, only triangulation and peer debriefing were used to achieve research credibility. Triangulation was achieved by using multiple sources of data. For instance, information on difficult aspects of nuclear physics was collected in three ways: the questionnaire (Appendix 6), pre-observation interviews and from the video recording of lessons. Peer debriefing is a process where a disinterested peer discusses the findings, conclusions, hypotheses and analyses to explore aspects of the inquiry that might otherwise remain only implicit within the inquirer’s mind (Lincoln & Guba, 1985). This too was done as a way of achieving credibility. For instance, a colleague looked at my coding system and ascertained that it was done consistently (Appendix 18)

With transferability, I used purposive sampling and I have tried to provide as much description of what was observed and what I did with it. This should enable anyone to assess the findings of this research and decide if they would apply to their setting.

To Lincoln and Guba (1985), the best way to establish dependability is to carry out an inquiry audit to attest the quality and appropriateness of the inquiry process. This was done in a number of ways. Firstly the research process was presented and discussed in a number of academic forums like the 2008 Southern African Association for Research in Mathematics, Science and Technology Education conference in Lesotho by means of a roundtable discussion and presentations during “PhD weekends” at the Wits School of Education (Marang Centre for Mathematics and Science Education). Secondly, fellow PhD students at Marang had chances to go through my research and offer constructive criticism, a typical example being the coding system that a colleague attested that it was consistent. I also personally made sure I crosschecked information and processes. For instance, I had to review the codes several times to remove duplications and add new codes where a salient domain was not captured. Thirdly, my supervisors also played a big and critical role by evaluating my ideas, activities and write-ups. Triangulation, as explained under credibility, was employed and this should have added to dependability as well.

As for confirmability, triangulation was used as the main strategy for achieving it. The use of different sources of data meant that interpretations and conclusions were based on solid evidence. I have also tried to back up any interpretations with quotations from the PDs. I have also described in detail what I did to arrive at those interpretations

CHAPTER 4

DIFFICULT ASPECTS OF NUCLEAR PHYSICS

4.1 Introduction

This chapter addresses the question: What reasons do Malawian PSTs give for rating *nuclear physics* as the most difficult topic? To address this question, a questionnaire (Appendix 6) was administered to PSTs. The questionnaire required the teachers to: choose a topic that they deemed most difficult to teach and/or learn from a list of physics topics contained in the PSS, give reasons why they thought the topic is difficult and to identify the aspects that made the chosen topic difficult. It was hoped that the aspects teachers would identify might shed more light on the reasons for choosing nuclear physics as difficult. To triangulate the data, the four teachers who continued in the study were interviewed before each observed lesson to state and explain the difficulties they anticipated. Also during discussion of video and post-observation interviews, teachers were asked to explain difficulties noted during the lessons. This chapter presents the results obtained through these data collection methods. It also presents difficulties on nuclear physics identified from chief examiners' reports for further triangulation.

The chapter has been arranged into the following sections: difficult aspects to teach – questionnaire results, reasons nuclear physics is difficult to teach – questionnaire results, learning difficulties from pre-observation interviews, observed learning difficulties and learning difficulties from external examiners' reports. Difficulties actually observed during lessons and those identified from examiners' reports have been included here so that they can act as benchmarks against which to judge the credibility and confirmability (Anfara et al., 2002) of the teachers' responses. Tables are used to present the difficult aspects and reasons they are difficult.

4.2 Difficult aspects of nuclear physics: questionnaire

4.2.1 Aspects identified as difficult to teach

Thirty PSTs were requested to complete a questionnaire (Appendix 6) and 28 of these did so and returned the questionnaire. All responses to the questionnaire were summarised in a master table. The summary revealed that 14 out of the 28 chose nuclear physics as the most difficult physics topic. Out of the 14, 12 (hereafter referred to as 12 PSTs) also chose nuclear physics as the most difficult to learn. The reasons that each of these 12 gave for choosing nuclear physics as both most difficult to teach and learn were extracted from the master table and are presented in Appendix 17. From Appendix 17, Table 4.1, which shows frequencies of aspects that make nuclear physics difficult, was constructed. Some of the aspects mentioned in Appendix 17 have not been reflected in Table 4.1 because they were considered inapplicable as they did not directly relate to subject matter itself. These include: teachers' lack of understanding of subject matter, lack of teaching approaches, lack of apparatus, and the topic is very scientific. The first two were left out because they apply to the teacher, not the subject. The third one was left out because it is an aspect of the teaching environment. The last one was ignored because it relates to what counts as scientific and what does not.

Table 4.1 below shows that the teachers were able to identify ten aspects of nuclear physics that are difficult to teach. An examination of the PSS revealed that under half-life the major activity suggested is calculation of half-lives of radioactive substances. Balancing nuclear equations also involves calculation of atomic masses and numbers of the parent nucleus, daughter nucleus and the released particle. Thus, half life (frequency of 2), nuclear calculations (frequency of 5) and balancing equations (frequency of 1) could be collapsed into one aspect (calculations) with a frequency of eight (2 + 5 + 1). The decay process (frequency of 8) and fusion and fission (frequency of 2) are similar in that they are all processes involving nuclei and could also be considered into one aspect (nuclear processes), with a total frequency of 10. Similarly, aspects 7 and 8 relate to the nature of elements involved and could be placed into one category with a frequency of two: nature of radioisotopes. The last aspect in Table 4.1 has a connotation of application of nuclear physics to other fields

Table 4.1: Aspects of nuclear physics that are difficult to teach

Aspect	**Frequency**
Radioactive decay process	8
Nuclear calculations	5
Nature of gamma rays, beta & alpha particles	4
Nuclear fission & fusion	2
Half life	2
Detectors of radioactivity	2
Elements involved are outside the first 20 in the periodic table that are recommended	1
Balancing nuclear reactions	1
Forms or isotopes of elements	1
Transfer nuclear energy to various working field	1

With these refinements, the difficult aspects now look as shown in Table 4.2. Table 4.2 shows that a majority of those teachers who chose nuclear physics as the most difficult to teach and learn (10 out of 12) identified nuclear processes - which include the decay process, fission and fusion – as the difficult aspects. Still a majority (eight out of 12) identified calculations as another difficult aspect. Four out of the 12 respondents mentioned nature of the three types of radiation as difficult. Detectors of radioactivity and nature of radioisotopes were mentioned by two respondents each. Only one teacher mentioned application of nuclear physics to other fields. In section 4.2.2 reasons the 12 PSTs gave for choosing nuclear physics, hence the difficult aspects, as the most difficult to teach have been explored.

Table 4.2: Refined aspects that make nuclear physics difficult to teach

Aspect	**Frequency**
Nuclear processes	10
Calculations	8
Nature of gamma rays, beta & alpha particles	4
Detectors of radioactivity	2
Nature of radioisotopes	2
Application of nuclear physics to other fields	1

4.2.2 Reasons for choosing nuclear physics as most difficult to teach

The PSTs were asked to give as many reasons as possible for the topic they chose as most difficult to teach (Appendix 6, item 7). The reasons given by each of the 12 PSTs who chose nuclear physics as the most difficult to teach and learn were noted (Appendix 17). Table 4.3 is an extract from Appendix 17, which summarises the reasons given for choosing nuclear physics as the most difficult to teach. It also shows the number of respondents (frequency) for each reason.

A closer examination of Table 4.3 shows that some of the reasons given could be combined into one. Reason 6 (frequency of 2) has been combined with reason 1 (frequency of 8) to give a total frequency of 10, as they both relate to lack of teaching materials. Reason 2 (frequency of seven) and reason 9 (frequency of one) have also been combined to give total frequency of eight, since abstractness of concepts is related to how easy it is to apply them to daily life. Reason 5 has been interpreted to be a possible explanation for difficulty to perform experiments at secondary school level as it relates to issues of safety. Hence, reason 5 (frequency of two) has been incorporated into reason 4 (frequency of three) to give a total frequency of five. In light of these combinations, Table 4.3 was modified accordingly to give Table 4.4.

Table 4.3: Reasons nuclear physics is most difficult to teach

Reason	**Frequency**
1. Lack of teaching materials	8
2. Most concepts are abstract	7
3. The topic is new	5
4. Difficult to do experiments at this level	3
5. Deals with dangerous substances	2
6. Lack of relevant textbooks	2
7. It is complex for students	2
8. Teacher inadequacies	2
9. Difficult to apply to real life situation	1

Table 4.4: Categories of reasons nuclear physics is difficult to teach

Reason	**Frequency**
Lack of teaching materials	10
Most concepts are abstract	8
The topic is new	5
Difficult to do experiments at this level	5
It is complex for students	2
Teacher inadequacies	2

Assuming a reason with a higher frequency is more compelling than one with a lower frequency, Table 4.4 shows that lack of teaching materials was the most compelling reason (10 out of 12 PSTs mentioned it) for labelling nuclear physics as the most difficult to teach. Examples of materials mentioned as lacking are textbooks. Many teachers would need textbooks as basic teaching tools during preparation, instruction or for assigning homework. Experimentation and illustrations also form an integral part of science teaching and learning. So, where basic resources like these are not available, teachers are likely to find it difficult to teach the relevant topic or part of it.

The next most compelling reason was ‘concepts involved are abstract’ (8 out of 12 PSTs mentioned it). According to Constantinou and Papadouris (2004) acquisition of experiences with natural phenomena is an important aspect of physics teaching and learning. With abstract ideas, it is not easy for teachers to help students experience the phenomenon under consideration, especially through the senses. So, the difficulties PSTs meet in explaining the abstract concepts may have influenced them in labeling nuclear physics as the most difficult to teach.

Two reasons followed abstract concepts in level of ‘compellingness’: the topic is new and it is difficult to do experiments (5 out of 12 PSTs mentioned each of these). Nuclear physics has been in PSS for six years now, so it is not necessarily new. However, the fact that teachers mentioned it shows the importance of actual teaching experience with a topic. Although the questionnaire did not ask the teachers to specify number of years they have actually taught the topic, it is possible that a majority of them have taught it for about three years. This should be the case because teachers are not always allocated to teach senior secondary physical science. In some years they could be allocated junior classes, for example. It would seem the longer a teacher handles a topic, the more familiar it becomes and perhaps the easier it becomes to teach for those teachers who are able to engage in pedagogical reasoning as described by Shulman (1987).

The teachers also reasoned that it is difficult to do experiments. This reason is related to abstract concepts, which are hard to demonstrate or experiment with. Those who gave this reason seem to have assumed that ability to experiment would make teaching the topic easy. This assumption has merit to an extent because, as Gollub and Spital (2002) assert, effective instruction should engage students in inquiry by providing opportunities to experiment. It is possible the teachers may have been driven by such a view. However, Gollub and Spital (2002) also include the following as means of engaging students in inquiry: critically analysing information, making conjectures and arguing about their validity, and solving problems both individually and in collaboration. Therefore, experimentation alone may not necessarily simplify teaching.

The least compelling reasons were ‘the topic is complex for students’ and ‘teacher inadequacies’ (each given by two of the 12 PSTs). These two are rather general in nature and do not reveal much. To say the topic is complex for students begs the question *What about the topic is complex?* One possibility is that this may have been a reference to the abstract nature of concepts or the reasoning skills required to understand such concepts. It is also related to teacher inadequacies. May be the PSTs do not have the necessary skills to explain abstract concepts, hence a feeling of inadequacy.

4.2.3 Reasons nuclear physics is difficult to learn

In the questionnaire, PSTs were asked to identify the topic their students would find difficult to learn and to explain their choice (Appendix 6, item 9). As pointed out already, 12 PSTs chose nuclear physics as the most difficult to learn. These 12 teachers had also chosen nuclear physics as the most difficult to teach, which indicates that these teachers were consistent with the view that nuclear physics is the most difficult physics topic in the PSS. It could be argued that if students, instead of teachers, had been asked to mention the topic they found most difficult to learn, a different topic would have been chosen. Such an argument is, however, weakened if it is assumed that the PSTs based their responses on experience. It is further weakened by comments in the 2003 and 2005 chief examiners’ reports that, among other topics, students had difficulties with nuclear physics (Malawi National Examinations Board, 2003, 2005).

The explanations that each of the 12 PSTs gave for choosing nuclear physics as the most difficult to learn were noted (Appendix 17). Table 4.5 is an extract from Appendix 17, which summarises the explanations. The table also shows the number of respondents (frequency) for each explanation.

Table 4.5 shows that eight PSTs explained why nuclear physics is difficult to learn by arguing that the ‘ideas are hard to understand’. Explanation 5 (the topic needs high class reasoning) is also related to the first one, hence has been interpreted to mean ‘ideas are hard to understand’. This was the most compelling explanation since it has the highest frequency of nine (eight for explanation 1 and 1 for explanation five) and it focuses on the topic itself. However, the teachers did not give examples of the concrete ideas. In this study it has been assumed that a teaching difficulty arises where there is a learning difficulty. Hence, Table 4.4, which captures the reasons given for labelling nuclear physics as the most difficult to teach, could also indicate the ideas that are hard to learn. It appears 'ideas are hard to understand' relates to 'most concepts are abstract' mentioned in Table 4.4. The literature too mentions that students find the subatomic explanations in nuclear physics difficult (Millar et al., 1990).

The next most compelling explanation given for nuclear physics being the most difficult to learn was 'lack of teaching materials like detectors' (frequency of 4), which relates to the teaching and learning environment. Teaching materials are provided to facilitate learning, so where these are not available or are in short supply, learning is likely to be compromised. This may be the reason PSTs thought lack of teaching materials is responsible for the difficulties in learning.

In Table 4.5 there are four explanations each with a frequency of one. I consider these four explanations to be the least compelling. Three of these of these pertain to students and they are: preconceived ideas from periodic table, students take the topic as irrelevant and lack of basic knowledge from forms 1 and 2. One of these pertains to teachers and it is 'poor teacher presentation'.

The result that only one teacher ascribed difficulties in learning nuclear physics to teacher presentation could be interpreted in two ways. Firstly, it might be that the 12 PSTs did not see the connection between teaching and learning. Secondly, it might be that the 12 PSTs took it that their teaching is so good that any learning problems could only be due to something else. The second interpretation probably carries more merit because all the PSTs involved in this study were considered as some of the best in physical science by education methods advisors.

In the literature students' ideas or preconceived ideas are identified as one of the major causes of learning difficulties in physics (e.g. Jimoyiannis & Komis, 2001; McDermott, 1998; Schecker & Niedderer, 1996; Shulman & Shulman, 2004). Yet, preconceived ideas were not a compelling reason for labelling nuclear physics as the most difficult to learn. This shows the 12 PSTs may not have been aware that students' preconceptions are one of the major causes of learning difficulties in nuclear physics.

'Students take the topic as irrelevant' is an explanation that relates to students' motivation. It could be argued that students' learning is facilitated where there is high motivation and no student can be motivated to learn what they consider irrelevant. However, only one teacher gave this explanation, which focuses on a student's preparedness to learn. This just shows the emphasis placed on other factors like hardness of the topic and the learning environment and not the learner.

Learning difficulties in nuclear physics have also been explained in terms of poor prerequisite knowledge from lower classes (Table 4.5, explanation seven). This explanation is related to conceptions that students bring to classrooms. If prerequisite knowledge is poor, students are likely to hold knowledge that is incomplete or inconsistent with that of scientists. So I argue that 'lack of basic knowledge' about a topic leads to conceptions that are inconsistent with those of science, which in turn make learning of the topic difficult.

Table 4.5: Reasons nuclear physics is most difficult to learn

Explanation	**Frequency**
1. Some ideas are hard to understand	8
2. Lack of teaching materials like detectors	4
3. Preconceived ideas from periodic table	1
4. Students take the topic as irrelevant	1
5. Needs high class reasoning	1
6. Poor teacher presentation	1
7. Lack of basic knowledge from forms 1 and 2	1

4.3 Case teachers' anticipation of learning difficulties in nuclear physics

Four of the 12 PSTs were selected to continue in this study (referred to as case teachers). For each case teacher, data was collected from two lessons on nuclear physics. One of the types of data collected before each lesson was audio-recorded interviews (referred to as pre-observation interviews). These interviews were open-ended in nature and focussed on the content the case teachers would cover in those lessons, the difficulties they expected students to face with the lessons and the methods they would use in teaching. Like other data that I collected, the pre-observation interviews were transcribed verbatim, loaded on to *Atlas.ti 5.2* software and coded for content to be covered, anticipated learning difficulties and possible explanations for the difficulties. There were other codes associated with the pre-observation interviews, like those concerned with planned teaching strategies, and these are discussed in the relevant sections later.

Table 4.6 is an extract from an *Atlas.ti 5.2* output of codes and the frequencies with which the codes appear in the primary documents. In this study a primary document (PD) is a file composed of five transcripts about a single lesson loaded into *Atlas.ti 5.2* for analysis. The four transcripts are the pre-observation interview, video recording, an interview with students, post-observation interview and the video discussion. In Table 4.6, numbers in the top row (10, 11, …, 17) identify PDs. The first column lists the names of codes in question. The columns to the right (PD columns) show the frequencies of codes, the number of quotations (segments of a PD) associated with a particular code. The naming of the codes was systematic in that the suffix 'Pre' indicates that the codes apply to the pre-observation interview transcript. Also the names themselves are descriptive. For instance, code 'Diff abstract Pre' identifies text in the pre-observation interview where there is reference to a learning difficulty arising from abstract concepts.

Appendix 19 was used to construct Table 4.6 by focusing on one PD column at a time and noting all the codes that apply. From the relevant codes, it was then possible to work backwards to identify and capture in Table 4.6 the content to be covered, aspects associated with learning difficulties and possible explanations why those aspects of the topic pose difficulties.

Table 4.6 shows that T25's first lesson (PD 10) would cover types of radiation and deflection of those types in electric and magnetic fields. It also shows that T25 felt no aspect of the first lesson would pose difficulties to student's learning. However, difficulties did arise during the lesson (captured in section 4.4). For the second lesson (PD 11), Table 4.6 shows that it was supposed to cover the processes of alpha, beta and gamma decay. The lesson would also cover nuclear reactions and equations. T25 anticipated students to have difficulties with decay of a neutron to a proton and an electron and the explanation given for anticipating this difficulty was that this idea has always been a problem as the following excerpt from PD 11 shows:

> **25 I:** I don't know if there are some may be challenges that you expect students will meet, as the lesson progresses, with some of the concepts that you will be covering today?
>
> **26 T25:** Ah probably on the beta decay just from experience. Ah if you noticed yesterday's lesson when we were talking about the splitting of the neutron into a proton and an electron, I think I still feel that some will have problems with understanding beta decay because that point, which we mentioned yesterday, where the neutron breaks down into a proton and an electron, will still come in this lesson.
>
> …
>
> **29 I:** Okay. Are there any specific reasons why alpha decay tends to be problematic for the students?
>
> **30 T25:** Ah, it's beta decay.
>
> **31 I:** Oh! Beta decay. Okay. Yes.
>
> **32 T:** Yah, it's an issue which ah really ah I could say probably because of the idea of saying that the neutron breaks down. I don't know, but it's always been a problem. I don't know, but it has been a problem really.

In the above extract, the use of the qualifier 'always' in paragraph 32 indicates that the problem is a prevalent one. There is also repeated reference to previous experience in paragraphs 26 and 32, which indicates that T25 could not think of another reason for anticipating the difficulty in understanding of decay of a neutron into a proton and an electron. Actually, in paragraph 32 he admits, “I don’t know, but it has been a problem really.”

For T12, Table 4.6 shows that the two lessons (PDs 12 and 13) would cover atomic structure, isotopes and radioactivity (definitions, detection, types and properties). It also shows that T12 felt abstract concepts, how disintegration happens (perhaps of nuclei) and details about types of radioactivity would be the difficult aspects of the lessons. T12 thought these difficulties would arise because he had no ‘physical things’ to show the students. Apparently, there is an assumption that teaching with physical objects facilitates learning. Unfortunately, not all concepts are amenable to use of objects. It is possible to bring in models, but these have their own complications (Coll, 2005).

Concerning T23, Table 4.6 shows that the first lesson (PD 14) would cover particles of an atom and properties of sub-atomic particles. Difficulties associated with this content include abstract concepts and scarcity of learning aids. The teacher explained these difficulties in terms of having ‘nothing to bring for students to see’. So, the view that teaching with objects facilitates learning appears here as well. In the second lesson (PD 17), T23 intended to cover isotopes (definition and examples) and calculation of relative atomic masses and only one difficult aspect was identified: definition of isotopes. No explanation was given for the difficulty, so it is not clear why the teacher thought the definition of isotopes would be problematic.

T10’s first lesson (PD 15) was supposed to centre on nuclear particles, nuclear notation, definition of isotopes and relative atomic masses. The second lesson (PD 16) was on nuclear stability, guidelines for stability and neutron to proton ratio. The teacher could not identify any difficult aspect, arguing that he could only do so after the lesson, as the following extract from PD 16 shows:

> **33 I:** Any specific difficulties that you expect students will face with the lesson?

> **34 T10:** I hope I will comment after the lesson. It is then that I can say I think the preparation has met these difficulties. But I feel ….
>
> **35 I:** Okay, so you don't expect any difficulties?
>
> **36 T10:** I don't.
>
> **37 I:** As of now?
>
> **38 T10:** As of now we don't expect any challenges.

Failure to mention difficulties may be due to a number of reasons. Firstly, the teacher may not have thought seriously about difficulties during preparation. Secondly, the teacher may not have enough experience actually teaching the topic. Thirdly and lastly, the teacher's subject matter knowledge may be too weak to enable the teacher analyse the teaching and learning demands of a topic sufficiently. T10 had a minimum of two years' teaching experience at secondary school level and more at primary. However, he was under-qualified in that he did not possess the minimum qualification of a diploma in education for one to teach at secondary school level. Thus, the first and the third explanations above are possible causes for the failure to identify any difficulties.

Globally, Table 4.6 reveals a number of patterns. Firstly, the difficulties identified fall into the following categories: abstract concepts (identified by T12 and T14) and decay processes (identified by T12 and T25). Results from the questionnaire responses also showed that these aspects are difficult (Section 4.2), which shows that there is a certain degree of corroboration in the results. However, fewer difficulties per individual case teacher were mentioned in pre-observation interviews compared with those from the questionnaires. Secondly, in three of the eight lessons (PDs 10, 15 and 16) concerned case teachers did not identify difficulties. Yet, the difficulties mentioned in other lessons also applied to these, like the one on difficult concepts. This could indicate that case teachers did not take students' learning difficulties into account in those lessons or indeed the case teachers may not have been aware of the difficulties. Thirdly, only two reasons for labelling certain aspects as difficult emerged: the reason that decay has always been a problem and that there are no teaching resources to demonstrate the ideas. These two reasons also appeared in section 4.2 where I discussed difficult aspects of nuclear physics from questionnaire results, which adds to the credibility of the results. Fourthly, the content under consideration is associated with a number of learning difficulties in the literature and chief examiner's reports (Sections 2.8 and 4.6). The case teachers mentioned very few of those difficulties. It appears the case teachers were not sufficiently aware of such difficulties, which might explain why the teachers could hardly anticipate difficulties in some lessons.

Table 4.6: Content of lessons and anticipated learning difficulties

PD*	Content to be covered	Difficult Aspects	Explanations for the difficulties
10 T25	Types of radiation Behaviour of radiation in magnetic and electric fields	None	None
11 T25	Radioactive decay: alpha, beta and gamma Nuclear equations	Decay of a neutron to a proton and an electron	The idea has always been a problem
12 & 13 T12	Atomic structure Isotopes Radioactivity definitions Detection of radioactivity Types of radioactivity Properties of radiation	Abstract concepts How disintegration happens Details about types of radioactivity	There is nothing to show students
14 T23	Particles of the atom Properties of subatomic particles	Abstract concepts Scarcity of learning aids	Nothing to bring for students to see
15 T10	Nuclear particles Nuclear notation Definition of isotopes Relative atomic masses	None. Teacher said would comment on difficulties after the lesson	None
16 T10	Nuclear stability Guidelines for stability Neutron: proton ratio	None	None
17 T23	Definition of isotopes Examples of isotopes	To define isotopes	None

	Calculating atomic masses		

* PDs 12 and 13 relate to two lessons held on the same day. So, the pre-observation interview for PD 12 also applies to PD 13. T10, T12, … identify the teachers

4.4 Observed learning difficulties in nuclear physics

Observed learning difficulties are those noted from the video recordings of lessons and group interviews with students (student interviews) soon after each lesson. The recordings were transcribed and coded for learning difficulties using *Atlas.ti 5.2* software. 'Diff' at the beginning of a code name indicates that the code identifies a difficulty. A 'Vi' at the end of a code name identifies all codes that apply to the video transcript, while 'St', again at the end of a code name, identifies codes that apply to student interviews. From the lesson recordings, learning difficulties were identified where a learning outcome inconsistent with the teachers' expectations was noted. During student interviews, students were asked about what they found interesting, difficult and about where they would need the teacher to clarify. The students' responses to such questions revealed the difficult aspects and such aspects were coded as learning difficulties. The content covered in each of the lessons was the same as shown in the second column of Table 4. 6.

Appendix 20 is an extract from an *Atlas.ti 5.2* output of codes and the frequencies with which the codes appeared in the PDs. It shows the codes that identified learning difficulties in all the lesson and student interview transcripts, and hence it displays codes of difficulties actually observed. The frequency of each code refers to the number of quotations where that code applies. The first column shows the codes, while the columns on the right give frequencies of the codes. By focusing on one PD at a time, and working backwards and forwards between a particular code and the relevant quotations in the PDs, information in Appendix 20 has been used to identify aspects of each lesson where learners faced difficulties. These aspects have been captured in Table 4.7. To allow comparison with anticipated difficulties, Table 4.7 also captures the difficult aspects identified in Table 4.6.

Table 4.7: Content covered observed learning difficulties

PD	Content covered	Anticipated difficulties	Observed difficulties
10 T25	Types of radiation Behaviour of radiation in magnetic and electric fields	None	Students’ conceptions Diagrams used Behaviour in fields Mass number Decay of a neutron Effects of radiation Calculations
11 T25	Radioactive decay: alpha, beta and gamma Nuclear equations	Decay of a neutron to a proton and an electron	Calculations Students’ conceptions Mass number Decay of a neutron to a proton and an electron Effects of radiation Use of symbols
12 T12	Atomic structure Isotopes Radioactivity definitions Detection of radioactivity Types of radioactivity Properties of radiation	Abstract concepts How disintegration happens Details about types of radioactivity	Calculations Students’ conceptions Scientific explanations Isotope No experiments Mass number Principle on number of electrons Relative atomic masses
13 T12			Splitting of an atom Calculations Students’ conceptions Isotope New topic
14	Particles of the atom Properties of subatomic particles	Abstract concepts Scarcity of learning aids	Students’ conceptions Mass number

T23			Use of symbols No experiments
15 T10	Nuclear particles Nuclear notation Definition of isotopes Relative atomic masses	None	Calculations Students’ conceptions Use of symbols
16 T10	Nuclear stability Guidelines for stability Neutron: proton ratio	None	Students’ conceptions Guidelines for stability Concept of limit for nucleon number Concept of stability
17 T23	Definition of isotopes Examples of isotopes Calculating average atomic masses	To define isotopes	Calculations Students’ conceptions Definition of isotope Isotopes Mass number Proton number Use of symbols

Patterns that emerge from Table 4.7 are firstly, the observed difficulties are far more than the anticipated ones. For instance, T25 did not anticipate any difficulty for the first lesson and he anticipated only one difficulty for the second lesson. However, there were seven difficult aspects associated with the first lesson and six with the second one. The other case teachers also anticipated far fewer difficulties than were actually observed. From this, it could be concluded that all the case teachers had limited awareness of learning difficulties.

A second pattern is that a majority of the anticipated difficulties also were actually observed in the lessons or during student interviews. For example, T25 predicted that the decay of a neutron to a proton and a beta particle would pose difficulties to students and this was observed both in the lesson and during student interviews. The following excerpt from the video transcript (PD 11) shows how students struggled with the idea of beta emission:

> **483 T25:** The question is it's produced in the nucleus; why does it not stay there?
>
> **484 S25:** Because it's …. because …. *[Teacher laughs other students continue to raise hands]*
>
> **485 T25:** She is saying because it's going to become another particle that's why it cannot remain there.
>
> **486 S26:** It's by nature. Electrons are not supposed to be in the nucleus so they are rejected. That's why they will move out. And for the nucleus, it got to be stable because in the nucleus there are only protons and neutrons that stay there. So the electron is rejected.
>
> **487 T25:** He is saying by nature electrons cannot stay in the nucleus. Do you see some sense in that? *[The class laughs]* Yes.
>
> **488 S27:** I think it's simply because the electron is very light. In terms of its choice, it is easy for an electron … to go out of the nucleus.
>
> **489 T25:** Okay, so he is talking about in terms of lightness, he said it is light.
>
> **490 S27:** *[Nods head in agreement]*
>
> **491 T25:** Yes
>
> **492 S28:** Yah …
>
> **493 T25:** Mr Hiri you have withdrawn your hand, okay.
>
> **494 S28:** I have withdrawn.

The above excerpt was chosen because a number of students had a chance to contribute to the debate involving decay of a neutron into a proton and a beta particle. It also clearly shows how students grappled with the idea of beta emission. From the above excerpt, the following ideas about why a beta particle is emitted from the nucleus emerged: because the beta particle is to become another particle, it is by nature and the electron (beta particle) is light. During student interviews, the problem of beta emission also came up and this corroborated what was observed in class. The following portion of the student interview transcript supports this (PD 11):

> **530 S4:** In fact I understood. But now there is a certain point where I was not convinced because the way the answer was just, when asked "How come the neutron is producing a proton and an electron?" he said its by nature, so that was not … to me. We wanted something further.

Another example, which illustrates that some predicted difficulties were actually observed, is with T23 who predicted that students would face difficulties with the definition of an isotope in his second lesson (PD 17). During the lesson some students had difficulties as indicated by the following excerpt:

> **313 T23:** Now let's look at it together. The first definition says it is an element having the same number of protons but different number of neutrons. How do you look at that definition?
>
> **314 S11:** I think that definition is right because … it is showing us that ….
>
> **315 T23:** Anybody?
>
> **316 S12:** Actually if you look at the table *[Pointing to a table on the board]*, realising element number two which has got, you can see that there is a proton number of one and neutron number of one as well which means that the first one isn't really true.

Two students, S11 and S12, interpreted the following student definition of an isotope differently: 'an element having the same number of protons but different number of neutrons'. S11 thought it was right, while S12 thought it "isn't really true". S11 was a member of the group that came up with this definition, which means the other group members also shared his view. According to the teacher, the definition was "not right". This shows the definition posed difficulties, as the teacher had predicted.

T23 also expected difficulties to arise from scarcity of learning aids. This was confirmed during the student interview where one student indicated that they learn better if they see things. An excerpt of the student interview transcript (PD 14) that supports this is given below:

> **380 S1:** Also, it's not a comment but just a supplication that if it is possible, for us to learn much better, we have to have some, some elements in hand. May be saying, we have to learn while the elements are there. We have to look that this element is lithium, so how it is really look like. May be we can understand better.
>
> **381 I:** Okay. Okay.

> **382 S1:** Yah, just, rather than just learning theoretically *[Smiles again after making the point clear]*.

Table 4.7 shows that T12 anticipated that students would find abstract concepts difficult. An example of a difficulty observed which related to abstract concepts was in T12's first lesson where a student could not understand the relationship between particles that make up a substance (which are abstract) and the substance itself. The following excerpt of the lesson transcript (PD 12) illustrates this:

> **399 T12:** If you take a sample of chlorine, that is you have got a sample of chlorine, maybe chlorine in a gas bottle like this one *[Picks a bottle which was on the front bench and shows it to the class]* Chlorine gas, you have chlorine gas there, so you have got particles of chlorine there.
>
> **400 S27:** Is it one sample or one atom where …?
>
> **401 T12:** Ah, you take a sample of chlorine and analyse it, so you will look at atoms in there, atoms of chlorine in that. You will find that for every one chlorine that you have, …
>
> **402 S27:** A sample or atom?
>
> **403 T12:** Ha!
>
> **404 S27:** A sample or atom?
>
> **405 T12:** Okay, a sample of chlorine contains atoms. You understand? A sample of chlorine will contain chlorine atoms.
>
> **406 S27:** Eh.
>
> **407 T12:** Yes. So in that sample which has got chlorine atoms, if you a look at that, if you analyse those atoms, you find that for every one atom in that sample, because that sample is made up of chlorine atoms. So every one atom of chlorine thirty-five ah of chlorine thirty-seven, you have three chlorine ah thirty-five. That's what I mean.
>
> **408 S27:** *[Still seemed not to have understood]*
>
> **409 T12:** You are confused.
>
> **410 S27:** I have somehow *[Class and teacher laugh]*.

The above excerpt shows that at least one student had difficulties understanding abstract concepts, which the teacher had predicted. The difficulty may have arisen because of the tendency among students to confuse bulk properties of matter to the particles themselves (Driver, 1989). In the case of chemistry, there are three levels of understanding: the macrosopic (experiments and experiences), symbolic (models, formulae, equations) and sub-microscopic (electrons, molecules, atoms) (Treagust, Chittleborough, & Mamiala, 2003). These levels should apply to physics as this subject also utilises experiements, models, formulae and equations. Like chemistry, physics also discusses electrons, atoms and other sub-atomic particles. I argue that the student who confused the bulk properties of matter and the particles believed to consitute it may have had difficulties to think at the macrosopic and sub-microsopic levels simultaneously.

T12 also anticipated that students would have difficulties with 'how disintegration happens.' When introducing the first lesson (PD 12), T12 asked students to define an atom and their responses showed that they believed an atom cannot be split as the following portion of the lesson transcript (PD 12) show:

> **145 T12:** So let's start our topic. We'll look at nuclear physics. That is our topic ah this morning …, but I just want to find out how much you know, what you know about an atom, you know about an atom. What is an atom? What is an atom? Yes ah
>
> **146 S1:** An atom is a small indivisible particle of which matter is made up.
>
> **147 T12:** Sorry.
>
> **148 S1:** A small indivisible particle of which matter is made up.
>
> **149 T12:** Okay, so ah a small, I like *[Looks and points to S1]* this word here, indivisible particle *[Writes on the board: "Atom - a small indivisible particle"]*. Can you continue eh?
>
> **150 S1:** of which matter is made up of.
>
> **151 T12:** of which matter is made up of *[Looks to the student to confirm it. Teacher also completed statement started earlier: "of which matter is made up"]*
>
> **152 S1:** Yah.
>
> **153 T12:** Something like that. So she says an atom is a small, I will underline this word *[Underlines "indivisible"]* particle of which matter is made up. That is a definition we all know, isn't it?
>
> **154 Small student minority:** Yes.

Although a small minority agreed with S1's definition, no other alternative was given. It might be that the other students did not have an alternative definition or they silently agreed with S1's. So, the view that an atom cannot be split was a potential difficulty to learning about radioactive decay or disintegration of atoms because the two were contradicting views.

T12 also thought that students would have difficulties with 'details about radioactivity.' He did not specify what details and no detail directly related to radioactivity was observed as a difficulty in both of T12's lessons or during student interviews. This does not mean that students did not have difficulties but it only shows that the nature of the lessons did not allow such difficulties to surface. However, some evidence that students have difficulties with details were noted and this is exemplified in the extract from the student interview transcript of PD 12 below:

> **476 I:** So what aspects have you learnt in today's lesson? Actually we had two lessons: the first one and the second one. Ah so let's may be begin with the first one, which centred on the atom.
>
> **477 S5:** Me I learnt about the atom … things are found inside the nucleus when it changes …
>
> **478 I:** Uh, anything else?
>
> **479 S2:** We have also learnt about the an atom it consists of two, it consist of an electron is actually consist of; an atom consist of two electrons in the first shell and eight electrons in the second shell as well as eight electrons in the third shell.
>
> **480 I:** Okay, anything else?
>
> **481 S1:** We have also learnt that an atom can be identified by looking at the atomic number.
>
> **482 I:** Okay and what does that stand for?
>
> **483 S1:** It stands for; if you want to identify an atom by just looking at its atomic number you can easily identify it.

In paragraph 477, S5 failed to mention contents of the nucleus (protons and neutrons) and just referred to them as 'things'. Paragraph 479 shows that S2 attempted to explain well but missed minor details of 'maximum number of' to qualify the number of electrons in shells. In paragraph 482, the interviewer asked S1 to explain what 'atomic number' stands for. S1 then responded by explaining that atomic number can be used to identify an atom, which shows the student missed the key phrase ‘stands for’. Similarly, there is a chance that students may have missed some details associated with the concept of radioactivity, like the difference between radiation, radioactive substance and radioactivity.

A third pattern from Table 4.7 is that some of the difficulties anticipated or observed are more prevalent than others. To see which is more prevalent than the other, Table 4.8 has been constructed from the observed difficulties column of Table 4.7. All learning difficulties were noted from Table 4.7 and listed in the left column of Table 4.8. ‘Average atomic mass’, ‘mass number’, ‘concept of nucleon limit’ and ‘proton number’ have been combined into one group of observed difficulties: mathematical concepts. Similarly, ‘definition of isotopes’ has been incorporated into ‘isotopes’ because the two are closely related. ‘Concept of stability’ and ‘guidelines for stability’ have also been combined into one: stability of nuclei. Then all PDs associated with a particular difficulty have been noted and indicated in the column to the right. The observed difficulties have been listed starting with one that appears in most PDs and ending with one that appears in the least. Anticipated difficulties have not been included because, as already pointed out, the observed ones include these as well.

Table 4.8 shows clearly that students’ conceptions were associated with difficulties in all PDs, and hence lessons, except one. Next were calculations and mathematical concepts (each in six PDs), isotopes (in three PDs). Decay of a neutron, effects of radiation and no experiments were noted in two PDs each. The rest of the difficulties were observed in one PD each. I do not claim that those observed in fewer lessons are less important because the lessons were not the same. I would like to just argue that focusing on those difficulties that cut across more lessons made sense for this research because it facilitated comparison of teaching strategies. Also the result that some difficulties occur in more lessons than others has implications for teacher improvement efforts (see later).

Table 4.8: Prevalence of observed difficulties across PDs

Observed difficulties	**Applicable PDs**
Students' conceptions	10, 11, 12, 13, 14, 15, 16, 17
Calculations	10, 11, 12, 13, 15, 17
Mathematical concepts	10, 11, 12, 14, 16, 17
Use of symbols	11, 14, 15, 17
Isotopes	12, 13, 17
Decay of a neutron to a proton and an electron	10, 11
Effects of radiation	10, 11
No experiments	12, 14
Diagrams used	10
Behaviour of radiation in fields	10
Scientific explanations	12
Principles on electron number of electrons	12
Splitting of an atom	13
New topic	13
Stability of nuclei	16

In this section learning difficulties actually observed from the lesson or student interviews have been identified and compared with anticipated ones. Three patterns and relationships have emerged: the observed difficulties are far more than the anticipated ones, almost all difficulties anticipated were also actually observed and some of the difficulties are more likely to occur than others. From these patterns, one could conclude that the case teachers were aware of learning difficulties associated with the lessons under consideration only to a limited extent; the fact that the anticipated difficulties were actually observed renders credibility to the case teachers' predictions; and that some difficulties are more likely than others to occur.

4.5 Case teachers' explanations for observed difficulties

In this section I present some of the explanations that the case teachers gave for the observed difficulties during discussion of the post-observation interview and discussion of the video, as a way of triangulating the reasons identified earlier in sections 4.2 and 4.3. No PD was specifically coded for such explanations. Thus, quotations from post-observation interview and video discussion transcripts of PDs coded for the difficult aspects or any concept associated with difficulties were reread and explanations that emerged noted. Other quotations read were those where code 'Teacher underst Po' applied, which is a code that identifies text in the post-observation interviews and video discussion transcripts containing information about teacher understanding of content, teaching and learning difficulties, and teaching strategies. Since there were 105 quotations with this code, only every fifth quotation was read to cut on the number of quotations read and also to ensure that the selection was as objective as possible. I also read, all the six quotations for code 'Teach reflection Po', which identifies quotations where the teacher reflected on a lesson. Those explanations are captured in Table 4.9. The first column captures the difficulty concerned, while the second one captures the explanations given and the PDs (given in square brackets) from which those reasons were noted. The excerpt below illustrates how this was done and is taken from the video discussion transcript of PD 12 to which code 'Teacher reflection Po' applied:

> **87 I:** Okay, Mr. Lenjama I see that in this lesson right from the beginning you tried to find out from the students what they knew about an atom.
>
> **88 T12:** Yes.
>
> **89 I:** Yes, why did you think that was good to do?
>
> **90 T12:** Ah, the fact that that was good to do because this whole topic, nuclear physics, you see it centres on an atom. Basically we are talking about the particles ah in an atom. We talk about the neutrons, we talk about the protons, so if a student doesn't have a good background of what an atom is, then it will be very difficult for him or for her to understand the subsequent concepts ah that will basically be built upon ah the concept of an atom.
>
> **91 I:** Uh.
>
> **92 T12:** Yes.

In paragraph 90 of the excerpt, in the course of explaining the approach that he adopted, T12 mentions that nuclear physics centres on an atom. T12 goes on to explain that 'if a student doesn't have a good background of what an atom is then it will be very difficult for him or her to understand the subsequent concepts'. This explanation has been interpreted to relate to the observation that concepts are difficult to understand and one of the reasons for this is poor knowledge about the atom (Table 4.9, row 11)

Table 4.9 shows that my discussions with the four case teachers yielded a total of about 40 explanations for the observed difficulties. These explanations could be classified into nine categories as shown in Table 4.10, first column. The category to which each of these 40 explanations fits is shown in column two of Table 4.10. The categories have been arranged in order of decreasing number of members in order to facilitate viewing of the patterns that might emerge.

Table 4.9: Case teacher explanations for the observed difficulties

Observed difficulty	**Explanations given for the difficulties**
Abstract concepts	1. Difficult to understand [PD 12]
	2. Difficult to visualise the concepts [PD 12, PD 13]
	3. There are no experiments to conduct [PD 13]
Calculations	4. Poor understanding of basic concept [PD 12]
	5. Poor coverage by teacher [15]
	6. There is need for a lot of activities [15]
Student conceptions	7. Confusing concepts like sample and atoms [PD 12]
	8. Misunderstanding what is read from a book [PD 14]
	9. Wrong concepts held by students [PD 14]
	10. Previous lessons that have similar concepts [PD 16]
Diagrams	11. Could be misleading [PD 10]
	12. Difficult to interpret [PD 13]
	13. Weak pre-requisite knowledge [PD 13]
Difficult to do experiments	14. Nature of radioactive substances [PD 10]
	15. Understanding is limited without them [PD 10]
	16. Resources constraints [PD 14]
Deflection in electric and magnetic fields	17. Difficult to show differences in deflection [PD 10]
	18. Known the difficulty from experience [PD 10]
	19. Need to know magnetic and electric fields [PD 13]

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Stability of nuclei	20. Too many guidelines for students' thinking [PD 16] 21. Complexity of the guidelines [PD 16] 22. Students tended to use guesswork [PD 16] 23. Problems with calculations involved [PD 16]
Composition of matter	24. Weak pre-requisite knowledge [PD 15] 25. Students forget work already done [P 12]
Principle on number of electrons	26. Students do not understand [PD 12]
Isotope	27. Attributed to student as slow learner [PD 16] 28. Requires integrating information on atomic and mass number [PD 17]
Use of symbols	29. Some students weak in algebra [PD 12] 30. Improper use [PD 14] 31. Interpretation can be difficult [PD 14] 32. Periodic tables use different notations [PD 14]
Mathematical concepts*	33. Different notations used to represent them [PD 14] 34. Finding average mass using simple average [PD 17]
The concepts are difficult to understand	35. Poor knowledge about what atom is [PD 12] 36. Poor student attitudes towards science [PD 15]
Decay of a neutron to proton and electron	37. Insufficient teacher explanation [PD 11] 38. Difficult is coming up now and then [PD 10, PD 11] 39. Teacher's insecure content knowledge [PD 11]
Ionising effect of radiation	40. Language used by the teacher [PD 10]

*Mathematical concepts include mass number, protons number, average atomic mass, neutron number and limit for nucleons per nucleus

The explanation categories of Table 4.10 could also be looked at, as was done with those of Table 4.5, by assuming that the explanation category that appears most was the most 'compelling' to the case teacher. Arranged starting with the most compelling, Table 4.10 shows that the teachers felt the difficulties observed were due to: difficulty of the concepts, need for sound prerequisite knowledge, difficulties with representations used, difficulty to 'experience' the concepts teacher inadequacies, complexity of the learning tasks, likelihood to confuse

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concepts, student preparedness for the topic and difficulties with calculations. Close examination of the categories reveals that one could use one category to explain another. For instance, the fact that concepts are difficult could be explained in terms of difficulties to experience the concepts (because they are abstract). Another example is with teacher inadequacies where it could be argued that teachers too find the concept difficult and these difficult concepts lead to teachers feeling inadequate. In short, the categories are not independent of one another: one influences the other directly or indirectly.

Table 4.10: Categories of case teachers' explanations for difficulties

Category of explanations based	**Explanations from Table 4.9**
Difficulty of the concepts	1, 4, 8, 12, 15, 17, 18, 21, 22, 26, 31 and 38
Need for sound prerequisite knowledge	9, 13, 19, 24, 25, 29 and 35
Difficulties with representations used	11, 30, 32 and 33
Difficulty to 'experience' the concepts	2, 3, 14 and 16
Teacher inadequacies were also noted	5, 37, 39 and 40
Complexity of the learning tasks	6, 21 and 28
Likelihood to confuse concepts	7, 10 and 34
Student preparedness for the topic	27 and 36
Difficulties with calculations	23

Comparing explanations from the questionnaire results (Table 4.5) and from discussion with case teachers (Table 4.10) reveals similarities between the explanations given. For example, in both sets of results the explanation that concepts are difficult was the most compelling. Although not necessarily in the same order in terms of which is more compelling, the following explanations apply to both sets of results: difficult to experience the concepts (related to lack of teaching materials), insecure prerequisite knowledge (related to preconceived ideas or student conceptions), teacher inadequacies, complexity of learning tasks (related to high class reasoning needed), and students' preparedness for the topic (partly related to attitudes). So, all the explanations from the questionnaire also appear in Tables 4.9 and 4.10, which apply to observed difficulties. The explanations that appear only in Tables 4.9 and 4.10 are difficulties with representations used, calculations and likelihood to confuse the concepts. I argue that such good agreement indicates that these findings could be taken to have good confirmability and credibility (Anfara et al., 2002).

4.6 Difficulties reported in chief examiners' reports

In this section I present difficulties in nuclear physics identified from Chief Examiners' Reports (CERs) in physical science with the aim of further triangulating the difficulties that were identified by the case teachers. The Malawi National Examinations Board (MANEB) is a government body that sets and administers all national examinations in Malawi (including MSCE examinations). For MSCE examinations, MANEB issues reports in all subjects to secondary schools about how the candidates had performed. These reports are prepared by Chief Examiners, hence the name Chief Examiners' Reports. The reports comment on student performance by highlighting difficulties on each question.

The current PSS was introduced in 2002 and first examined in 2003. Also, at the time of data collection in 2007, the 2006 report was not yet released, while the 2007 one was supposed to be released in 2008. Thus, the CERs analysed here are only those from 2003, 2004 and 2005. The CERs contain two parts: one on general comments applicable to the whole paper and another on specific, question-by-question comments. To analyse each report, the following steps were followed for the first part: summarised all general comments in a table (Table 4.11), read through all the comments, then read through each general comment again to note its content, and then the comments which applied to nuclear physics were noted and examined to determine if they supported the other findings on difficulties or not. For the second part of CERs, a similar approach was followed but only with comments on nuclear physics questions. Table 4.11 shows the general comments and the CER to which a particular comment applies, while Table 4.12 shows the specific comments on nuclear physics questions. A tick (√) indicates that a particular comment applies to a particular CER.

Table 4.11 shows that the following difficulties were noted in all the three CERs:

1. Generally poor responses, deficient of knowledge of course material.
2. Poor drawings and graphs.
3. Great problems with calculation questions.

Although these difficulties are general, they also apply to nuclear physics specifically because this topic also involves some calculations, use of drawings and graphs. Difficulties with drawings and calculations could lead to poor responses, which are a symptom of deficiency in knowledge.

Table 4.11 also shows that the following difficulties were noted in two of the three CERs analysed:

1. Candidates have problems with nuclear physics, among other topics.
2. Candidates have problems with explanation and description questions, showing lack of organisation.
3. Poor reasoning ability.
4. Failure to interpret diagrams and graphs.

Again, these comments also apply to nuclear physics. Actually, one of these specifically singles out nuclear physics to be among the difficult topics, which supports the 12 PSTs' view that nuclear physics is difficult. Problems requiring students to describe and explain should also apply to nuclear physics because some aspects of this topic involve description and explanation. For instance, students are supposed to be able to describe detection of alpha particles, beta particles and gamma rays and to explain the meaning of radioactive decay (Ministry of Education Science and Technology, 2001). The CERs analysed show that there were questions on these aspects of the topic (see Table 4.12). Use of diagrams and graphs applies to nuclear physics as well. For example, students are supposed to interpret a diagram showing the behaviour (deflection) of each of the three types of radiation in electric and magnetic fields and graphs showing the decay of a substance with time. In 2004, there was a question asked on deflection of radiation in electric fields. However, for the CERs analysed, no question on graphs showing decay curves was asked. For students to describe, explain or interpret, they need good reasoning abilities.

Finally, Table 4.11 shows that failure to conclude correctly from essays and lack of ability to design experiments were noted in only one CER. The difficulty of “failure to conclude correctly from essays” should also apply to nuclear physics because the PSS states that students should be able to discuss, for instance differences between induced and natural radioactivity. The difficulty of “ability to design experiments” may not apply to nuclear physics since the PSS does not expect students to be able to do this.

Table 4.11: Chief Examiners’ general comments on student performance

Difficulty	**CERs**		
	2005	**2004**	**2003**
1. Candidates gave generally poor responses, deficient of knowledge of course material	√	√	√
2. Candidates had problems with topics electricity, vibrations & waves, gas laws, nuclear physics	√		
3. Candidates had problems with magnetism, gas laws, nuclear physics among physics topics			√
4. Poor drawings and graphs	√	√	√
5. Great problems with calculation questions	√	√	√
6. Explanation and description questions were generally poorly done showing lack of organisation	√		√
7. Poor reasoning ability noted		√	√
8. Low level of vocabulary, with serious problems noted with definition of terms and failure to express themselves clearly		√	√
9. Non-use of diagrams in essays		√	
10. Failure to interpret diagrams and graphs		√	√
11. Failure to conclude correctly from essays		√	
12. Acute lack of ability to design experiments			√

From Table 4.11 and the preceding discussion, I conclude that all the general comments, with the exception of only one (ability to design experiments), apply to nuclear physics. Comparing the applicable comments in Table 4.11 with the difficulties identified in other sections of this chapter shows good agreement. For instance, some of the explanations the 12 PSTs gave (captured in Table 4.5) for nuclear physics being difficult to learn were: some ideas are hard to understand, the topic needs high class reasoning, existence of pre-conceived ideas, there is lack of basic knowledge from forms one and two. These explanations are supported by comments 1, 2, 3 and 7 of Table 4.11 and this I take it renders credibility to the teachers' explanations. Another illustration of agreement is with the explanations case teachers gave for the observed difficulties during post-observation interviews or discussions of the video (captured in Table 4.10) some of which are: the concepts are difficult, there is need for sound prerequisite knowledge, difficulties with representations used, complexity of the learning tasks and difficulties with calculations. Comments 1, 2, 3, 4, 5, 7, and 10 in Table 4.11 supports the case teachers' explanations.

The specific comments on nuclear physics questions are given in Table 4.12 can be summarised as follows:

I. The topic is generally unfamiliar to many candidates (2005 & 2004).
II. Problems with calculations on half-life and average mass (2005 & 2003).
III. Failure to explain answers on radioactivity (2005, 2004 & 2003), especially with respect to application to industry.
IV. Problems with equations of nuclear decay (2004 & 2003).
V. Problems with definitions and description associated with radioactivity (2004, 2003).
VI. Failure to interpret diagrams (2004)

Formatted: Indent: Left: 1.27 cm, Hanging: 0.63 cm, Numbered + Level: 1 + Numbering Style: I, II, III, … + Start at: 1 + Alignment: Right + Aligned at: -1.59 cm + Tab after: -1.27 cm + Indent at: -1.27 cm

Again comparing the difficulties identified in Table 4.12 with those mentioned by the 12 PSTs (Table 4.1), the case teachers and those observed from lessons reveals good agreement and I illustrate this by comparing comments in Table 4.12 with those in Table 4.1.

Table 4.12: Chief Examiners' comments - performance in nuclear physics

Difficulty	**CERs**		
	2005	**2004**	**2003**
1. Topic generally unfamiliar to many candidates	√	√	
2. Failure to calculate mass left using half life	√		
3. Failure to explain importance of using a substance with short half life in agriculture tracers	√		
4. Failure to explain why fission is a useful process in industry	√		
5. Failure to describe beta and alpha particles		√	
6. Failure to explain why gamma radiation is used in medical equipment sterilisation		√	
7. Question on nuclear equation of decay of radium-226 to radon-222 proved exceptionally difficult		√	√
8. Interpretation of the diagram on gamma rays in an electric field proved difficult		√	
9. Failure to explain how gamma rays are emitted			√
10. Failure to correctly define radioactivity			√
11. Failure to give the name of an alpha particle as helium			√
12. Failure to calculate the average mass of chlorine given ratio of the isotopes			√

The difficulties in Table 4.1, numbered 1 to 9, are reproduced below for easy comparison. The numbers in square brackets are those corresponding comments in Table 4.12.

1. Radioactive decay process [7 and 9]
2. Nuclear calculations [2 and 12]
3. Nature of gamma rays, beta & alpha particles [5, 8 and 11]
4. Nuclear fission & fusion [4]
5. Half life [3]
6. Detectors of radioactivity
7. Forms or isotopes of elements [12]
8. The elements involved are out side the first 20 in the periodic table that are recommended

9. Balancing nuclear reactions [7]

The above comparison clearly shows that out of the nine difficulties identified by the 12 PSTs (Table 4.1) only two are unmatched. Even these, it could be argued, may not be matched because the comments are specific to the questions asked. Thus, the conclusion that the difficulties the 12 PSTs mentioned agree with those identified in CERs is plausible.

4.7 Conclusion

In this chapter, results from the questionnaire PSTs completed have been presented. The results show that a majority of the teacher rate nuclear physics as the most difficult topic in the PSS. Questionnaire results from the 12 PSTs have revealed that the following are the difficult aspects of the topic:

1. Nuclear processes
2. Calculations
3. Nature of gamma rays, beta & alpha particles
4. Detectors of radioactivity
5. Nature of radioisotopes
6. Application of nuclear physics to other fields

The chapter has also presented some results from the lessons observed with the case teachers. These results have corroborated those from the 12 PSTs. These results were observed during lessons or student interviews, and there was a lot of student input. Actually, student interviews revealed that the difficulties mentioned by teachers and those that students really experience agree, rendering credibility to the teachers' views. Comparing with comments from CERs has further strengthened the credibility of the results.

Finally, this chapter's gist was to explore the reasons, or explanations that the 12 PSTs for labelling nuclear physics as the most difficult to teach and learn. The reasons are mainly from questionnaire results, but have been supported with explanations gleaned from interactions with the four case teachers through pre-and post-observation interviews and discussions of the video. The reasons the topic is difficult to teach fall into the following groups:

1. Lack of teaching materials
2. Most concepts are abstract
3. The topic is new
4. Difficult to do experiments at this level
5. It is complex for students
6. Teacher inadequacies

The reasons the topic is difficult to learn fall into the following categories:

1. Some ideas are hard to understand
2. Lack of teaching materials like detectors
3. Preconceived ideas from periodic table
4. Students take the topic as irrelevant
5. Needs high class reasoning
6. Poor teacher presentation
7. Lack of basic knowledge from forms 1 and 2

In the next chapter, I present results on teaching strategies with emphasis on how the teachers tried to address the identified difficulties.

CHAPTER 5

CASE TEACHERS' TEACHING STRATEGIES

5.1 Introduction

This chapter addresses the following research questions:

1. What teaching strategies do Malawian PSTs use to address difficulties students face in learning *nuclear physics* concepts?
2. What reasons do the teachers give for choosing some teaching strategies over others?

Results on the nature of teaching strategies were drawn from data collected through the pre-observation interviews and video recorded lessons. Examples of questions asked during the pre-observation interview to identify their teaching strategies are:

1. Any specific methods that you will be using?
2. What strategies are you going to use?
3. So how do you intend to help them with the problems?

Reasons for the methods chosen were obtained through pre-observation interviews, post-observation interviews and discussion of videos. Examples of questions asked during the pre-observation interviews for this purpose are:

1. I see that you have included a bit of aspects of history. What is the significance of that?
2. Okay, are there any reasons why you have chosen the lecture, then charts?
3. Would you explain why you have chosen those strategies?

Examples of questions asked during the post-observation interviews and/or discussion of the video are (copied verbatim from audio recorded voice of the interviews or discussions):

1. I saw that at some points you also called some students, at least I have seen one student you called to the board to complete a table. Why did you think that was a useful thing to do?
2. Then, after group work you indicated the groups on the board by name, by student name, say so so's group can you come. What value of r did you find, what value of q and the like? Why did you find that a better way of presenting, should I say, the answers from the groups?
3. Okay, okay thanks. Now, here I see that you brought in some five diagrams that I can see. Now the notation that has been used, I think, is different from the one you used earlier on for the atom and the one you used for the standard notation. Yes, I don't know if you have a comment on this one?

The pre- and post-observation interviews and video recordings of lessons were then transcribed and coded using the *Atlas.ti 5.2* software for content under consideration and teaching strategies planned to be used or actually used and the reasons given for those strategies.

The chapter has been arranged into the following sections. Firstly, I present extracts from an *Atlas.ti 5.2* of codes pertaining to teaching strategies and their distribution in the PDs because they apply to all case teachers. Then codes applying to each case teacher have been extracted and used to identify the relevant strategies and reasons pertaining to that case teacher in separate sections. Next, the individual case teachers' results have been integrated in another section to facilitate comparisons. Finally, the results from all the four case teachers have been discussed in another section to enable comparison with what the literature says about teaching of nuclear physics. The case teachers have been identified by their codes (T25, T12, T23 and T10) for confidentiality reasons.

5.2 Teaching strategies codes across primary documents

Appendix 21 is an extract from an *Atlas.ti 5.2* output of distribution of codes in all the PDs. The extract shows codes pertaining to teaching strategies. Names of codes identifying teaching strategies start with 'Meth' (for method), while those that identify reasons start with 'Reason'. Names of codes associated with the pre-observation interview transcript end with 'Pre'; those associated with the video transcript end with 'Vi' and the codes associated with the post-observation or video discussion transcript end with 'Po'.

Appendix 21 reveals a number of patterns and relationships. For example, some strategies like use of exposition (identified by code ' Meth expose Vi') were more prevalent than others such as use of role-play (identified by code 'Meth roleplay Vi'). Another example is the relationship between strategies mentioned in the pre-observation interview and those actually observed: some observed strategies were not mentioned during the pre-observation interviews, showing some constant decision making in the course of instruction. Similarly, patterns could be identified in reasons for the strategies used. I argue that by examining the patterns in each case teacher's strategies, it is possible to get in-depth understanding of that teacher's overall teaching strategies.

5.3 T25's teaching strategies

5.3.1 Teaching context

T25 teaches at a government conventional school. Conventional schools tend are better equipped than what are called community day secondary schools (CDSSs). The school at which T25 taught had sufficient classrooms, three laboratories (one for physical science, the other for biology and the last for home economics), furniture and qualified teachers in physical science. The laboratories are fitted with power points, benches, sinks and water taps. They also have football, netball and basketball pitches. The school has two shifts: one coming in the morning and the other in the afternoon. It is like having two schools utilising the same facilities.

Thirty-eight students and forty-one students attended T25's first lesson and second lesson respectively. Forty students is the normal class size for the majority of conventional schools in Malawi. Both of the lessons observed with T25 were held in the physical science laboratory. Each lesson was two periods long, with each period being 40 minutes in duration. Students sat along the fixed laboratory benches facing the front of the room, where a chalkboard was fitted.

According to the head teacher, their school was one of the best performing schools on MSCE examinations, including in physical science. This explains why one of the methods advisors contacted recommended the school as one having the best teachers in physical science.

5.3.2 Content covered in T25's lessons

The content covered in T25's lessons has already been identified in the previous chapter (Table 4.9, PDs 10 & 11). The first lesson (PD 10) covered types of radiation and deflection of each type of radiation in magnetic and electric fields. The second lesson (PD 11) covered radioactive decay and nuclear equations. Here I give details of what was covered under this content and such details are important because they provide a context in which the teaching strategies are used. To do this, I identified codes related to the content under consideration from the code manager of *Atlas.ti 5.2*. The code manager lists all the codes for the loaded and coded PDs. It also allows the analyst to select a particular code and, with a simple double click, to create a list of all the quotations in the PD to which the selected code applies. So, by selecting relevant codes, creating a list of the requisite quotations and reading through those quotations, it was possible to identify details covered under each content area. For instance, by double clicking on code 'Magnetic field Vi', a list showing the PD in which a particular quotation is located, paragraph number(s), and the first few words of the quotation was created. Clicking on each item of the list highlighted the quotation in question in a relevant PD. Table 5.1, summarises the details covered under each of the content areas.

While reading through the quotations for details of content, all codes for that quotation were also looked at in order to identify examples of difficulties associated with the particular content in question. These too have been presented in Table 5.1 because it was felt they might be useful in discussing teaching strategies used with difficult content in the following section.

The first column of Table 5.1 shows the relevant lesson and the PD for that lesson; the second column shows the content area, which is the major idea under consideration; the third column shows content in a more detailed way; and the fourth column shows the difficulties related to the content.

Table 5.1 shows that T25's first lesson centred on types and characteristics of radiation. The details covered under types of radiation included: the three types of radiation, an alpha particle as a nucleus of a helium atom, a beta particle as an electron, gamma radiation as an electromagnetic wave, charge of each type of radiation, calculating the mass and charge of an alpha particle, and the notations used to represent each type of radiation. For this content, the table shows that the following learning difficulties were observed: some conceptions inconsistent with scientific views, difficulties in understanding mass number and decay of a neutron into a proton and an electron.

Under characteristics of radiation, Table 5.1 shows that the lesson concentrated on ionising effect, penetrating power, deflection in an electric field, deflection in a magnetic field and penetrating power of each type of radiation. The table shows that the following were associated with learning difficulties: effects of radiation, behaviour of radiation in magnetic and electric fields, existence of students' conceptions and the diagrams used.

From Table 5.1, it is clear that T25's second lesson covered the radioactive decay processes and the equations used to represent such processes. Specifically, the lesson covered the following: definition of radioactivity, process of each type of decay, concepts of parent and daughter nuclei, and changes in atomic and mass numbers during each decay. It also covered: general equations for alpha, beta and gamma decay; calculation of missing values in given nuclear equations; and equation for decay of a neutron into a proton and an electron. T25 did not first define radioactivity before looking at characteristics of different types of radiation. He may have assumed that students would still follow the lesson. However, such an omission may have made difficult for students to understand the characteristics of radiation. Aspects associated with learning difficulties included: existence of students' conceptions, concept of mass number, decay of a neutron into a protons and an electron, effects of radiation, calculations and use of symbols.

Table 5.1: Content covered in T25's lessons and the related difficulties

	Content area	**Details of content covered**	**Observed difficulties**
First lesson (PD 10)	Types of radiation	Types: alpha, beta, gamma Alpha particle as helium nucleus Beta particle as an electron Gamma radiation as electromagnetic wave Charge of each type Calculating charge and mass of alpha particle Notations for each type	Student conception: decay of neutron Mass number
	Characteristics of radiation	Ionising effect of each type Penetrating power Deflection in electric fields Deflection in magnetic fields	Effects of radiation Behaviour in fields Students' conceptions: ionisation Diagrams used
Second lesson (PD	Radioactive decay: alpha, beta and gamma	Definition of radioactivity Processes of alpha, beta and gamma decay Parent and daughter nuclei Changes in atomic and mass numbers during each decay	Students' conceptions Mass number Decay of a neutron to a proton and an electron Effects of radiation

	Nuclear equations	General equations for alpha, beta and gamma decay Calculating missing values in given nuclear equations Equation for decay of a neutron into a proton and an electron	Calculations Mass number Use of symbols

In the next sub-section, I present the strategies that T25 used to try to address the identified difficult aspects.

5.3.3 T25's teaching strategies used to address learning difficulties

5.3.3.1 Identification of T25's strategies

To identify the strategies T25 used to attempt to address the relevant difficulties, I used the code manager of *Atlas.ti 5.2* to isolate quotations in PDs 10 and 11 associated with those difficulties. I then read through those quotations at least twice, noting how the teacher handled them. For instance, by double clicking on code 'Diff calculations Vi', all quotations in all the video transcripts for each PD where this code appears were identified. It was then easy to go to a particular quotation from a PD (in this case 10 or 11) of interest by clicking on it. The strategies T25 used for each difficulty are shown in Table 5.2. From Table 5.2 patterns in the strategies used could then be identified. I have also supported the findings in Table 5.2 with some excerpts from the PDs showing typical approaches adopted.

Table 5.2: Learning difficulties and strategies used in T25's lessons

Identified difficult aspect	**Strategy used to try to address it**
1 Conception: As alpha particle ionises air it also becomes ionised.	Asked students if they heard the question Repeated the question Explained Used a diagram in explaining
2 Conception: There must be a cause for the neutron to proton and electron decomposition	Explained meaning of decomposition Used an equation Asked leading questions
3 Conception: There is a reason for an electron to be ejected from	Asked students if they heard the question

the nucleus	Repeated the question Gave other students a chance to answer it Agreed with one of the answers Then went into lengthy explanation, with help of questions and diagrams
4 Mass number: Failure to give mass number of helium	Ask a question Gave one of few students with hands up to answer and answered correctly ‘four’. Teacher explained why it should be four
5 Mass number: Thinking that it could also be used to identify an element	Asked students leading questions Then went on to explain why mass number cannot be an identity for an element
6 Mass number: Failure to explain alpha decay in terms of changes in mass numbers	Used questions to guide students to the expected answer
7 Decay of a neutron: Student surprised how this happens	Guiding question on why decay happens Then throws question back to class Then goes on to explain, with aid of diagrams and questions, in terms of stability Finally offers to meet students outside class to discuss the difficulty
8 Effects of radiation: Thinking that radioactive substances are very dangerous	Actually, reinforced by teacher during explanation.
9 Behaviour in electric and magnetic fields: Students’ failure to show differences in deflection	Used a combination of: explanations, charts, guiding questions, symbolic representations to compare masses of alpha and beta particles, use of diagrams on the chalkboard to illustrate that extent of deflection depends on mass and T25 also cautioned students not to confuse electric and magnetic field diagrams
10 Diagrams used: Student interpreted source of radiation as the sun	This came up during student interviews, so teacher was not aware of the difficulty. Teacher was surprised when I told him about the difficulty He suggested changing the diagram

11 Calculation: Failure to calculate atomic number in beta decay equation	Ask if other students agree Ask leading questions Explain
12 Calculation: Failure to calculate atomic number in beta decay equation	Ask leading questions Explain Do calculation on the board Then repeat explanation
13 Calculation: Failure to calculate atomic number in alpha decay equation	Ask leading questions Explain, if necessary Do calculation on the board Indicate right and wrong answers

5.3.3.2 Patterns in T25's strategies

To easily identify the patterns and relationships, an important step in qualitative inductive analysis (Hatch, 2002), Table 5.3 has been constructed from Table 5.2. The first column of Table 5.3 indicates all the strategies T25 used in addressing learning difficulties. The columns to the right show the learning difficulties to which a particular strategy applied. A number has been used to represent a particular difficulty, and this number is the same as the one indicated against that difficulty in Table 5.2. Letter 'X' is used to indicate the strategies used with each difficulty. The distribution of 'Xs' revealed how the strategies were combined. Colour coding has been used to depict different combinations. For example, green is used for the 'ask a question then explain' sequence.

From Table 5.3, some patterns are evident. Firstly, the top row shows that T25 used about eight strategies in the two lessons, after allowing for duplications in counting. These included: use of questions, repeating a student question, giving an explanation, use of chalkboard or chart diagrams to illustrate an idea, bringing in symbols and equations into explanations, offering to meet concerned students outside the lesson, indicating if a student's response is right or not and going through calculations on the chalk board. Secondly, T25 tended to use these strategies in combination. In most cases, a combination of three or more strategies was used. The only exceptions were difficulties 5 and 6 where combinations of two or less strategies were used. Thirdly, some combinations were more common than others. For example the combinations containing the ‘ask a question, give students a chance to answer and explain’ sequence of strategies are more common than those containing the ‘explain, ask leading questions and use of symbols’ sequence. Fourthly and lastly, the bottom row of Table 5.3 shows that some strategies belong to more combinations than others. For example, among the 13 difficulties, the teacher attempted to address 10 of them with combinations including use of questions, while he attempted to address only four difficulties through combinations including use of diagrams drawn on the chalkboard.

5.3.3.3 T25’s prevalent combinations of strategies

Table 5.3 shows that the following combinations of teaching strategies were noted with T25, starting with the most prevalent:

1. Combination 1 - colour code red (frequency of four)
    - Begin with a question, either by a student or the teacher.
    - Repeat the question.
    - Let the students attempt to answer the question.
    - Then explain.
    - Use diagrams in explaining
    - Meet concerned students, if the above fail.
2. Combination 2 - colour code green (frequency of two)
    - Begin with a question, either by a student or the teacher.
    - Repeat the question.
    - Then explain.
    - Use diagrams in explaining.
3. Combination 3 - colour code blue (frequency of two).
    - Start by explaining.
    - Use leading questions as much as possible.
    - Use diagrams, symbols and/or equations as much as possible.
    - Then explain again.
4. Combination 4 – colour code pink (frequency of two)
    - Begin with one or more leading question(s).

Then explain if necessary

Then do the calculation on the board.

Indicate where students are wrong or right, if necessary.

Then explain again, if necessary.

5. Combination 5 – colour code grey (frequency of one)

   Just ask leading questions

Table 5.3: T25's combinations of teaching strategies

Strategy	**Difficulty number as in Table 5.2**												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**[p]	**9**[q]	**10**[r]	**11**	**12**	**13**
Ask students question(s)	X		X	X			X				X	X	X
Repeat student questions	X		X										
Give students a chance to answer			X	X			X				X		
Agree with a student answer			X										
Explain	X	X	X	X			X		X			X	X
Ask leading questions		X	X		X	X	X		X		X		
Use diagrams on chalkboard	X		X				X		X				
Use chart diagrams									X				
Use symbols/equations		X							X				
Change diagram										X			
Offer to meet student(s) outside class							X						
Do calculation on the chalkboard												X	X
Indicate if response if right or wrong													X
Explain					X				X		X	X	X

[p] Difficulty 8 only appeared during the student interview and was reinforced by the teacher.
[q] For difficulty 9, the strategies were used more or less simultaneously.
[r] Difficulty 10 was only noted during the student interview, not in class, so the teachers' answer pertains to what he would do in a future lesson.

To illustrate how T25 used the combinations of strategies identified, I present extracts from PDs 10 and 11. The extracts have been chosen because they are typical of how T25 used each combination.

5.3.3.4 T25's use of combination 1 of teaching strategies

Firstly, I present an extract from PD 11, which shows how T25 used combination 1 to attempt to help students who had difficulties calculating the missing atomic number in a given equation. The teacher had written the following question for students to do in groups.

> Work out values of q and r in the following equation
> $^{q}_{r}\mathrm{Na} \quad \rightarrow \quad ^{24}_{12}\mathrm{X} + {}^{0}_{-1}\beta$

The groups were six, with each group having about six students. After giving the students some time to determine values of *q* and *r*, T25 asked group spokespersons to say the values they found. The teacher summarised the values on the chalkboard. The correct values were *q* is equal to 24 and *r* is equal to 11. Five groups found the correct values of both *q* and *r.* One group got the correct value for *q* but the wrong one for *r*. The one group that did not get it right found *r* to be equal to 13. The extract below shows how T25 tried to address the difficulty using combination 1. In paragraph 437 of the extract below, the teacher asked a question to which students are given a chance to answer and this they did (extract below, paragraph 438). After noting that students differed in the way they responded, T25 asked a leading question to the correct response (extract below, paragraph 439). The teacher then goes on to explain in paragraph 441, at the same time doing the calculation on the board. He noted that still some students had not understood, then offered to explain again (paragraphs 441, 443 and 445 of the extract below). Finally, in paragraph 447, T25 indicates whether particular group responses are right or not. Apparently, this approach helped as a majority of students indicated so in paragraph 446.

> **437 T25:** What happens to the atomic number in beta decay?
>
> **438 Some students:** …just the same *[other students]*…it decreases by one.

439 T25: It decreases by one?

440 Majority of students: Yah *[yes]*.

441 T25: So the twelve here, it means this twelve here is just the same as atomic number that is here *[Points to r in equation for question 1]* plus one. The atomic number that we have here is the r eh, so it's like r plus one is just equal to twelve *[Writes the equation r + 1 = 12 and then proceed to solve it; r = 12 – 1= 11]*. And so you are trying to find r, so it's twelve and the one will go this side and you could subtract there, so you get eleven *[some students are heard saying 'Aha', others 'Uhm']*. Let me come again, let me come again. What I'm saying is that this is beta decay. For the mass number you don't have a problem; we are saying it remains unchanged eh.

442 Majority of students: Yah.

443 T25: Yah, but what we said for beta decay, we are saying that the atomic number increases by one. And looking at this *[Points to X in the equation]*, the, the daughter nucleus is this. This is the beta particle eh. So what we are saying is that ah the atomic number of the parent nucleus will increase by what?

444 Majority of students: By one.

445 T25: By one. So what I'm saying is that it's like you are saying this *[Points to r]* is atomic number, without involving that z yah, this should increase by one for us to get the atomic number that we have there *[Writes 'r + 1']*. So this is equal to twelve *[Writes 'r + 1 = 12]*. Therefore r is equal to eleven. You have to subtract there. In other words, you need to have a smaller number there *[Points to r in equation]* for the atomic number and a bigger one there by one eh?

446 Majority of students: Yah *(with emphasis)*

5.3.3.5 T25's use of combination 2 of teaching strategies

An extract from the video transcript of PD 10 of how the teacher used combination 2 to try to address the conception that when an alpha particle ionises air it also becomes ionised is shown below. In the above extract below student 18 (S18) asks a question (paragraphs 384 – 386), which carries the idea that an alpha particle also becomes ionised as it ionises air. This view is scientifically incorrect since an alpha particle is positively charged and does not have electrons, so it cannot lose electrons. An alpha particle could gain electrons. However, the effect of this is to neutralise the positive charge such that if it gained two electrons the alpha particle would become a neutral helium atom. Thus, scientifically, we cannot talk of an alpha particle being ionised. To attempt to address this difficulty, T25 begins by asking the class if they heard the question and then repeats the question in statement form (extract below, paragraph 387). Finally, the teacher goes on to explain, referring to a diagram of an atom drawn on the board and bringing in a bit of vernacular:

> **384 S18, male:** You said an ion is an atom, which has gained or lost …
>
> **385 T25:** Lost electrons, yes.
>
> **386 S18:** You said that an alpha particle ionises air. Which means when it ionises air it can gain or lose electrons. So should we say that it has also been ionised?
>
> **387 T25:** Okay, let's look at this situation. You got his question? Did you get his question? *[Asks whole class and some students say no]*. He is saying we are saying that an alpha particle can ionise eh. I was saying that I think the situation he is looking at is where I was showing that suppose an alpha particle passes through a certain atom and grabs an electron, so he is saying does it also become an …
>
> **388 S18:** Ion.
>
> **389 T25:** So I'm saying, if I can just give you this example. It depends of course …It will remain an ion. In a case where it gains a single electron, if you are referring to my example "eti". "Adutsa apapa eti. Watenga electron iyiyi and electron yabwera ukuku." *[it has passed here and has grabbed this electron and the electron has come to it][Says this while referring to a diagram of an alpha particle passing close to diagram of an atom that he has drawn on the board]*. Okay there are two ways of looking at it. It's like when this one is, it's like this helium there or this alpha particle is just facilitating removal. Because what are we saying, we are not saying it, itself gets ionised. But what we are saying is that it ionises. So what it means, it just facilitates removal of this electron. Just by removing it, yah. So it still remains as it was.

5.3.3.6 T25's use of combination 3 of teaching strategies

In the first lesson, T25 had indicated to students that it is easier to understand deflection of different types of radiation in an electric field than in a magnetic field. During the post-observation interview, I asked the teacher to explain why the one is simpler than another. He explained that from experience students do not show the difference in deflection as the extract from the video transcript of PD 10 below:

> **163 I:** You compared the two diagrams: the one about electric fields and the one about magnetic fields. And you commented on the electric fields one that this one is simpler than this one. So why is the one simpler than the other?
>
> **164 T25:** Okay in actual fact what I meant was ah experience has shown that when you just talk about positive, negative, provided you know that the, this particle is positive and this particle is negative, you can easily tell the direction. And actually because here it's not a question of the way it's been deflected; it's just a question which direction is it taking.
>
> **165 I:** Okay, yah, yah.
>
> **166 T25:** For the electric field. When it comes to magnetic field, students mostly confuse. They, they will not even notice; I mean they will not show the difference in deflection. They will just draw them in the same way, not knowing that or forgetting the fact that the one that is lighter, even when you are drawing the diagram, you should show that it is being deflected more than the one that is heavier. So that's why I was saying that probably, experience has shown "kuti" *[that]* most students will easily get this one.

To deal with the problem of failure to indicate extent of deflection in a magnetic field, T25 used combination 3 of teaching strategies, which is reproduced here for easy reference:

> Start by explaining.
>
> Use leading questions as much as possible.
>
> Use diagrams, symbols and/or equations as much as possible.
>
> Then explain again.

The excerpt below from the video transcript of PD 10 illustrates how T25 used this combination. In paragraph 364 of the extract below, the teacher begins by explaining the chart and while explaining, he brings in symbols for alpha ($^{4}_{2}\alpha$) and beta ($^{0}_{-1}e$) particles. Towards the end of this paragraph, he asks some leading questions, to which students respond in chorus (paragraph 365). Next, in paragraph 366, T25 goes on to explain the masses of these two particles again, this time using a diagrammatic example to illustrate how mass will affect deflection and using leading questions perhaps to guide students' thinking. The teacher ends the episode with an explanation again (paragraph 383)

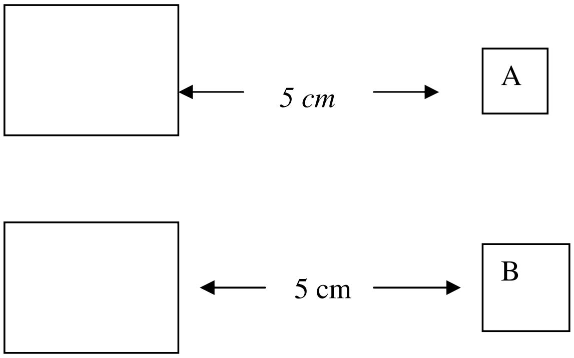
> **364 T25:** Yah, let's put up the last one, which is talking about the behaviour in a magnetic field *[Referring to a chart showing a source of*

radiation drawn like diagram of the sun, a magnetic field represented by crosses and paths for each type of radiation]. Okay so behaviour of the three types of radiations in a magnetic field. So we are also assuming that we have got this source, which is releasing the three types of radiations. And what's the …. Magnetic field. Look at the way they are moving. Let me just go back a bit. If you look at the alpha particle, we have said it appears like this *[Draws this on the board:* $^{4}_{2}\alpha$*]*. For the magnetic field we'll not get concerned with the charge, yah? Just look at the masses. If you look at the electron, it's just this guy here *[Draws this on the board:* $^{0}_{-1}e$ *]*. Between the, between the alpha particle and the beta particle, which one is more massive? Or which one has got a larger mass?

365 Minority of students: Alpha.

366 T25: There is no need for doubting because you can actually see; there is a four there and a zero there. Actually this is almost weightless, eh *[Referring to the beta particle]*. We should say it's weightless, so this one is more massive *[the alpha particle]*. I can give you this example. Lets say we have got a magnet here and a magnet here. These magnets are identical. Then you have got this five centimetres, this five centimetres. And you have this is ah a metal, made of iron and this is a metal made of iron. This is situation A, situation B. In other words, this is metal A, this is metal B. Which metal do you think is going to be easily attracted to the magnet?

[The set up described and drawn by the teacher looks as follows:]



(In the PD, these diagrams constituted paragraphs 367 - 379)

380 Majority of students: A

381 T25: The one that is lighter, "eti" *[isn't it?]*

382 Majority of students: Yah.

383 T25: Because the distance is the same. Ah, so what I'm saying is that if you look at the way the deflection is happening, look at the beta particle, its attracted so easily, its attracted so easily, but this one it's a heavier

> thing. “Attraction yake yikhala” slowish, yikhala slowish *[its attraction will be slowish]*. So basically “osapanga” *[don’t]* confuse this diagram, this diagram. Because this one *[one on electric fields]* I think is simpler than this one *[one on magnetic fields]*. Because this one *[on electric fields]* I just look what is the charge of this, what is the charge of this.

5.3.3.7 T25’s use of combination 4 of teaching strategies

The general sequence of strategies in Combination 4 is as follows:

Begin with one or more leading question(s).

Then explain.

Then do the calculation on the board.

Indicate where students are wrong or right.

Then explain again.

The extract below from the video transcript of PD 11 shows how T25 used this combination to try to address a difficulty in calculating an unknown atomic number in a given alpha decay equation. The teacher had written the following equation on the chalkboard for students to determine values of *r* and *s* in groups.

$${}^{r}_{s}Gd \quad \rightarrow \quad {}^{146}_{62}E + {}^{4}_{2}He$$

All the six groups got the correct value of *r*, which is equal to 150. One group, however, got the wrong value of s, 60 instead of 64. The teacher attempted to address this difficulty as shown in the extract that follows. It shows that through a series of leading questions in paragraphs 450 to 461, T25 lead students to the equations that would help them determine *r* and *s*. Then he explained in paragraphs 462 and 466 what to do with the equations obtained. Next, while engaging students through leading questions, the teacher did the calculations on the chalkboard (paragraphs 468 and 473). Finally, the teacher indicated the correct student answers with a tick (√) and the wrong ones with letter ‘X’ in paragraph 473. Due to the overuse of leading questions, combination 4 of strategies tended to centre on the teacher and to engage students only in giving short answers, as can be seen from the excerpt. Also, the teacher used the same approach to show how to obtain the value for *r* and for *s*, yet the difficulty was observed only with s. So, it is not clear if this combination of strategies was specifically invoked to address the observed student difficulty.

450 T25: And what we said is that an alpha particle if you have got a parent nucleus, the daughter nucleus will have its mass decreased by what?

451 Majority of students: Four *[At this point teacher writes A-4 as mass number for daughter nucleus E]*

452 T25: And the atomic number decreases by what?

453 Majority of students: Two. *[At this point teacher writes 'Z-2' as mass number for daughter nucleus E]*

454 T25: Then you produce this one as well *[Writes symbol for alpha particle]*. That's what we said. So what has happened we have been told this and this *[A and Z for the parent nucleus]*. We see that eh? We have been told this and this. Am I right?

455 Minority of students: No

456 T25: This and this are not known *[A and Z],* but we have been told this and this *[Points to A - 4 and Z - 2]*

457 Minority of students: Yes.

458 T25: So its like what are saying is ah A sorry A minus four they have told us that its equal to what?

459 Minority of students: One forty-six.

460 T25: One forty-six ah? *[Some very few students say yah. The teacher writes on the board 'A - 4 = 146']* And they have also told us z minus two is equal to what?

461 Minority of students: Sixty-two.

462 T25: Sixty-two *[Then writes below the first equation 'Z - 2 = 62']* But this is the guy which is here *[Relates the Z in the equation and the one on the parent nucleus]*. This is the guy, which is there *[Relates the A in the equation and the one on the parent nucleus]*. In this question, the A there is what?

463 Majority of students: r

464 T25: And this here is what?

465 Majority of students: s

466 T25: So you just need to solve these equations. So for this one here what we are saying is r is just equal to one forty-six then four should come here. And what are you getting?

467 Majority of students: One fifty.

468 *[The calculation for r now looks as follows: '$r - 4 = 146 \Rightarrow r = 146 + 4 = 150$']*

469 T25: And this here implies that s is equal to sixty-two plus what?

470 Minority of students: Two

471 T25: Two and this gives us what?

> **472 Minority of students:** Sixty-four.
>
> **473 T25:** Sixty-four. *[The calculation for s looks as follows:* $s - 2 = 62 \Rightarrow s = 62 + 2 = 64$*]*. So there is a problem here. Here its okay, here its okay, here its okay, here its okay, here its okay *[All answers that were deemed okay were ticked by the teacher]*

5.3.3.8 T25's use of combination 5 of teaching strategies

Combination 5 constituted of just leading questions. The extract that follows illustrates how T25 used just leading questions to address a difficulty about failure to explain alpha decay in terms of changes in mass numbers. The teacher had written the following equation on the chalkboard and he asked one student to go to the board to indicate mass and atomic numbers for *Y* in terms of *A* and *Z*.

$$ {}^{A}_{Z}X \longrightarrow Y + {}^{4}_{2}\alpha $$

Parent nucleus *Daughter nucleus* *Alpha particle*

The student who went to the chalkboard indicated mass number to be '*A – 4*' and atomic number to be '*Z – 2*' such that the equation then looked as below.

$$ {}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha $$

Parent nucleus *Daughter nucleus* *Alpha particle*

T25 then asked the class to explain the equation. He paused for about 10 seconds, most probably to wait for one of the students to volunteer to explain. No one did so. The teacher then just picked one student to attempt, and used leading questions to guide students to the explanation, as the excerpt below shows. In paragraph 128, the teacher asked a question, which the students failed to answer. He then points to a student and used leading questions in paragraphs 129 to 141 to try to guide the student to an explanation. Of course the student just used algebraic reasoning and said that taking the alpha particle to the left meant they just needed to subtract. The teacher then repeated the students' response as a way of affirming.

> **128 T25:** So you are saying A minus 4 and A minus two. Anybody who can give an explanation? …. Or do you have explanation why you have

done that? Can anybody explain? Why it's true I'm saying anybody who can give an explanation? Why it's true to say A minus four and atomic number A minus two? (10) You are not sure *[After noting that whole class is quiet]*. Yes Mr. S1

129 S1: In this case it's like X is equal to Y plus beta particle.

130 T25: You said?

131 S11: X.

132 T25: Which X? Okay, that means what you are saying you are saying X …

133 S11: X yah, I hope that is X *[Referring to Greek symbol alpha]*? The one with four. Mass number.

134 T25: This?

135 S11: Yah.

136 T25: Okay, sorry. So you are saying it's like what?

137 S11: X is equal to Y plus the beta particle.

138 T25: Plus the alpha particle?

139 S11: Yah, the alpha particle, so the alpha particle from the X is equal to Y.

140 T25: The alpha particle …

141 S11: From X, subtracting from X is equal to Y.

142 T25: He is saying this $({}^{A}_{Z}X)$ minus this guy $({}^{4}_{2}\alpha)$ will give us this $({}^{A-4}_{Z-2}Y)$. In other words, he saying if you can take this to the left *[Points to the alpha particle]*, then you will have this on the right *[Points to the Y]*.

5.3.4 Reasons given for the strategies used to try to address difficulties

As pointed out already, T25 used a number of strategies in his teaching that were combined in different ways in an attempt to address observed difficulties. During the pre-observation interviews, post-observation interviews and discussion of the video recordings, the teacher was asked to explain the use of certain strategies. This sub-section identifies the reasons associated with teaching strategies that T25 used to try to address learning difficulties. Appendix 21 contains codes that identify portions of the relevant transcripts where the teacher gives the reasons. Such codes have names that start with 'Reason'. Using the code manager of *Atlas.ti 5.2,* it was possible to double click on a code to retrieve the relevant quotations. I could then read through the quotations and note the reasons given for a particular strategy. Table 5.4 gives the reasons identified for T25's use of the teaching strategies. The first column indicates the strategy, the second column contains the reasons T25 gave when asked and the third column gives reasons that I inferred from the transcripts. Since the reasons obtained through inference involved my interpretation, I present one extract below as a way of exemplifying how these reasons were obtained and enhancing their credibility.

The extract pertains to use of questions. However, T25 did not mention that he used questions to guide students' attention. The teacher may have just forgotten to mention that, as this should be clear in the following extract from the video transcript of PD 11. In paragraph 481 of the extract, T25 restated the question a student had asked, setting the context of the difficulty. When S25 attempted to answer the question, the teacher merely repeated the response (paragraph 485) because S25's voice was too low to be heard by the whole class. However, the teacher found S26's response (paragraph 486 of the extract) to be 'sensible' and he directed other students' attention to it by asking the question in paragraph 487 "*Do you see some sense in that?*" This may have influenced S28 (paragraph 494) to withdraw his hand. In PD 11 alone a minimum of five quotations were associated with such use of questions.

> **481 T25:** His question is this electron is produced in the nucleus eh. Why is it that after its production it does not remain there?
>
> **482 S25:** In fact ….
>
> **483 T25:** The question is it's produced in the nucleus; why does it not stay there?
>
> **484 S25:** Because it's … Because … *[Teacher laughs other students continue to raise hands]*
>
> **485 T25:** She is saying because it's going to become another particle that's why it cannot remain there. Mr S26.
>
> **486 S26:** It's by nature; electrons are not to be in the nucleus so they are rejected. That's that's why they will move out. And for the nucleus, it got to be stable because in the nucleus there are only protons and neutrons that stay there. So the electron is rejected.
>
> **487 T25:** He is saying by nature electrons cannot stay in the nucleus. Do you see some sense in that? *[The class laughs]* Yes, S27.

> **488 S27:** I think it's simply because the electron is very light in terms of its choice it is easy for an electron to go out of the nucleus.
>
> **489 T25:** Okay, so he is talking about in terms of lightness, he said it is light.
>
> **490 S27:** *[Nods head in agreement]*
>
> **491 T25:** Yes
>
> **492 S28:** Yah …
>
> **493 T:** Mr S28 you have withdrawn your hand, okay.
>
> **494 S28:** I have withdrawn.

Since the implied reasons are drawn from the data, I take it that they are credible. So, in discussing Table 5.4, I have not differentiated them from the reasons T25 actually mentioned. Also, instead of focussing on each reason at a time, I discuss what I think are the general patterns or themes one could glean from the table.

Firstly, T25 used the strategies as a way of reminding students about what they had covered already or how to do something like calculations. Four strategies were associated with this theme in Table 5.4: use of questions, explanation, use of chart diagrams to summarise ideas and doing calculations on the chalkboard. One could argue that this was one way of preparing students for a particular lesson by targeting prerequisite knowledge. The focus was on work covered, not other ideas that students might hold. Where a student's response or statement contained such an idea the best the teacher could do was simply repeat it, but not follow up on it. For instance, in the above extract, S27 thought that an electron does not stay in nucleus because it is light (paragraph 488), and the teacher did not follow this idea up. Yet, effective science teaching is supposed to build on such ideas, especially where one uses the conceptual change approach (Hewson, 1996).

Secondly, T25 used the strategies to convey information. Strategies associated with this theme are: explanation, use of chalkboard or chart diagrams, use of symbols and/or equations and doing calculations on the chalkboard. The theme of conveying information fits well with the description of traditional physics teaching that focuses on transmission of content (Flores et al., 2000) or telling students the physical rules that seem to guide the universe and demonstrating how to use the rules to solve problems (Van Heuvelen, 1991). Van Heuvelen argues that the only reason the traditional approach persists is because of its efficiency in terms of time, but it has negligible student reception. T25's use of strategies to convey information may have been to save time and this is evidenced by the teacher's suggestion to meet the students outside classroom time if a problem persisted.

Thirdly, the theme of facilitating understanding is evident. Associated with this theme are the following strategies: explanation, use of chalkboard and chart diagrams and use of symbols and/or equations. It is argued that explanations containing metaphors, analogies, and models foster a sense of realism and aid understanding (Geelan, 2003; Treagust & Harrison, 2000). In one instance, T25 did include an analogy of a magnet attracting metals with different masses to help students understand why a beta particle is deflected more than an alpha particle in a magnetic field. This shows T25 did have some knowledge of use of analogies in teaching and maybe if more lessons were observed more of these would have been observed. However, there was no use of metaphors. Also, the only models observed were the standard ones given in books like the standard notation, diagrams used to represent a nucleus and the use of nuclear equations to represent decay processes. It seems the teacher assumed that by presenting standard scientific models, students would understand the topic better. Yet, students may not have the necessary knowledge of the field for interpreting conceptual models and may not understand that a conceptual model is a simplified and idealized representation of phenomena or situations (Greca & Moreira, 2000). Actually, reading through the transcripts revealed that the emphasis of this understanding theme was on knowledge, not nature of the knowledge or how it is generated. This theme confirms the assertion that although physics teaching should aim at educating in physics, through physics and about physics, it is educating in physics that consumes a teacher's energy traditionally (Newton, 1987).

Fourthly, some strategies were selected as a way of guiding students to the accepted scientific view. This mainly concerned the use of leading questions. The use of leading questions meant the teacher was in control of the process and there was no room for alternative views. The extract from PD 11 below illustrates how the teacher maintained control. In paragraph 214 the student wanted to know how a neutron breaks up. In paragraph 217 the teacher does not probe the student's, or other students' understanding. Instead the teacher asks the question in such a way that the student just gives back what is expected in a single word. Such an approach was common throughout both T25's lessons. This is contrary to the assertion that one of the characteristics of teaching for understanding is a negotiated style of interaction (Geelan et al., 2004).

> **214 S17**: I'm just surprised the way how the neutron breaks up to gets nucleus, I mean electron and proton?
>
> **215 T25:** You are wondering how?
>
> **216 S17:** How, exactly
>
> **217 T25:** Okay remember what we said last time. You remember what we said last time eh. We said that if you have got a nucleus and it's undergoing decay, the main reason for it undergoing decay is for it to become what?
>
> Majority of students: Stable.

Table 5.4: T25's reasons for teaching strategies used

Teaching strategy	**T25's reasons for using it**	**Implied reasons**
Asking a question for students to answer	To ask a student to repeat a statement for clarification To check if students could remember what was taught Check if students got what teacher said	Leading questions used to guide students' attention
Repeating question		Repeating student question so that everybody hears it
Explaining	To remind students Help students understand	To convey information

Use of a chalkboard diagram	Facilitate understanding Emphasise a point Illustrate an idea No specific reason	
Use of a chart diagram	Summarise ideas Emphasise ideas Facilitate understanding	
Use of symbols and/or equations	To indicate something Familiarise students with different representations	To convey information Facilitate understanding To illustrate an idea
Doing calculations on the chalkboard	To remind students how to do the calculation	For students to see how it is done
Meet student(s) outside the lesson	Not given as not probed	May be to save time

5.4 T12's teaching strategies

5.4.1 T12's teaching context

T12 also teaches at a government conventional school. It is an old boarding school and is one of the first few government schools put up during the colonial days under British rule, but was recently refurbished. The school has sufficient classrooms, three laboratories (one for physical science, the other for biology and the last for home economics), furniture and qualified teachers in physical science. It also has two workshops: one for metalwork and the other for carpentry and joinery. The laboratories are fitted with power points, benches, sinks and water taps. They also have football and netball pitches. The school has a good track record of good performance on MSCE examinations.

T12 is a qualified and experienced physical science and biology teacher. He holds a Bachelor of Education with 11 years teaching experience at secondary level in Malawi. I also learnt that T12 is responsible for examinations at the school and tends to be busy towards examination time. This became a challenge because nuclear physics is taught towards the end of the year. Because of being busy, with examination arrangements like registering students and preparing them for the national examinations, it was difficult to observe his lessons during normal time as he mainly taught during evenings and weekends. Thus, I observed two lessons on nuclear physics he had on one Saturday. Forty-two students attended the lessons. Each lesson was 40 minutes in duration. Students sat along the fixed laboratory benches facing the front of the room, where a chalkboard was fitted. Charts like the periodic table, diagram of planetary model of an atom and a picture of scientists who contributed to modern physics, were pasted on the laboratory walls. At the corner of the backbench were placed bottles of chemicals. The laboratory had a fume board, as it catered for both the chemistry and physics parts of the physical science curriculum.

5.4.2 Content covered in T12's lessons

The content covered in T12's lessons has already been identified in the previous chapter (Table 4.9, PDs 12 & 13). The first lesson (PD 12) covered atomic structure and isotopes. The second lesson (PD 13) covered types and properties of radiation. Following a similar procedure as described in sub-section 5.3.2, I give details of what was covered under this content to provide context in which the teaching strategies are used. Table 5.5, summarises the details covered under each of the content areas and the difficulties associated with that content, if applicable. The first column of Table 5.5 shows the relevant lesson and the PD for that lesson; the second column shows the content area, which is the major idea under consideration; the third column shows content still, but in a more detailed way; and the fourth column shows the difficulties related to the content.

Table 5.5 shows that T12's lessons centred on structure of the atom and characteristics of the three types of radiation. Under structure of the atom, the following were covered: definition of an atom, characteristics of protons, neutrons and electrons, planetary model of the atom, concept of 'nucleus', atomic and mass numbers, and electron shells and configuration. With isotopes, the focus was on definition, examples and calculation of average atomic masses. For types of radiation, the following were covered: comparison of nuclear change with chemical change, definitions of radioisotopes, radioactivity, radioactive decay and unstable nuclei, the three types of radiation and detection of radiation. Properties of radiation covered were: penetrating power and deflection in magnetic fields.

One interesting aspect of the content covered is that T12 included some content that would normally be covered in the chemistry part of PSS. These include: electron shells, electron configuration and discussion of chemical change. This could be explained in two ways. Firstly, it could be a sign that T12 is aware of the relationship nuclear physics has with some chemistry topics. Secondly, it could reveal that T12 is not sufficiently aware of what exactly to cover and not to cover. The second interpretation is more compelling because the teacher did admit that it is a long time since he taught the topic.

Learning difficulties were noted in both lessons. Student conceptions manifested themselves in both lessons. Students had difficulties with scientific explanations, determination of mass number, the principle that the number of electrons is equal to the number of protons in a neutral atom and the calculation of average mass numbers during the first lesson. In the second lesson, students had difficulties with: the idea of an atom splitting, the fact that there are no experiments to perform and they found the topic to be new. These difficulties seem to be associated with the fact that the topic is treated at symbolic and sub-microscopic levels. According to Treagust et al. (2003) students may not find it easy to understand at these levels.

In the next sub-section, I present the strategies that T12 used to try to address the identified difficult aspects.

Table 5.5: Content covered in T12’s lessons and the related difficulties

	Content area	**Details of content covered**	**Observed difficulties**
First lesson (PD 12)	Atomic structure	Definition of an atom Characteristics of protons, neutrons and electrons Planetary model of the atom Concept of ‘nucleus’ Atomic and mass number Electron shells and configuration	Students’ conceptions Scientific explanations Mass number Principle on number of electrons
	Isotopes	Definition Examples Calculating average atomic mass	Calculating average atomic mass Students’ conceptions
Second lesson (PD 13) lesson	Types of radiation	Compare radioactivity with nuclear change Definitions: radioisotopes, radioactivity, radioactive decay and unstable nuclei The three types of radiation Detection of radioactivity	Splitting of an atom Students’ conceptions No experiments New topic
	Properties of radiation.	Penetrating power of each type Deflection in a magnetic field	*Deflection in magnetic or electric fields

* This difficulty was mentioned by T12 during the post-observation interview

5.4.3 T12’s teaching strategies for addressing learning difficulties

5.4.3.1 Identification of T12’s strategies

A similar procedure as in subsection 5.3.3 was used with PDs 12 and 13 to identify the strategies T12 used to attempt to address the relevant difficulties. The strategies T12 used for each difficulty are shown in Table 5.6. From Table 5.6 patterns in the strategies used could then be identified.

Table 5.6: Strategies used by T12 to address identified difficulties

Identified difficult aspect	**Strategy used to try to address it**
1 Conception: Confused neutrons with newtons	T12 first expressed surprised Then he asked the question 'Newtons?'
2 Conception: Failure to grasp the difference between and atom and a sample.	T12 tried to explain to no avail Then T12 asked if any of other students could explain, but to no avail.
3 Conception: The belief that an atom cannot be split	Just explained
4 Conception: The belief that radiation is harmful	Not addressed as it only came up during student interviews. T12 reinforced this view
5 Scientific explanations: Difficulties with explanation	Just explained
6 Mass of neutron: Failure to give the mass of a neutron	Express surprise Then let another student to attempt
7 Mass number: Failure to determine mass number of chlorine	Express surprise Then asked another student to attempt Then teacher explained
8 Principle on electrons: Failure to apply principle that the number of electrons is equal to number of protons in a neutral atom	Let the students complete statement 'number of protons in a neutral atom is equal to number of …' row by row, which could be described as drill Then explain using example
9 Calculation of average mass: Students mentioned use of ratios in the calculations as difficult	Explained Use analogy to explain ratio Mixed the explanations with leading questions
10 No experiments: That there are no experiments to do makes understanding difficult	Not addressed as only surfaced during student interview
11 Deflection of radiation in a magnetic or electric field: needs knowledge from topic on electromagnetism	Explained Use chart paper to present diagram Used leading questions where T12 felt necessary

5.4.3.2 Patterns in T12's strategies

Table 5.7 has been constructed from Table 5.6. The first column indicates all the strategies that T12 used to try to address the observed difficulties. The other columns show the difficulties to which a particular strategy applied. A number, the same as one indicated against a particular difficulty in Table 5.6, has been used to represent that difficult in Table 5.7. Letter 'X' has been used to indicate the strategies employed with each difficulty. The distribution of 'Xs' revealed how the strategies were combined and the overall T12's strategy. Colour coding has been used to depict different combinations (See below).

Some patterns are evident in Table 5.7. Firstly, the top row shows that T12 used about seven strategies in the two lessons, after allowing for duplications in counting. These included: use of questions, giving an explanation, use of chart diagrams to illustrate an idea, use of analogy, use of drill and giving students a chance to respond to another student's query. Secondly, like T25, T12 also tended to use these strategies in combination. In most cases, a combination of two or more strategies was used. The only exceptions were difficulties 3 and 5 where a single strategy was used. Thirdly, some combinations were more common than others. For example there are only two combinations where the teacher used only explanation, but five where he combines explanation with other strategies. Fourthly and lastly, the bottom row of Table 5.7 shows that some strategies belong to more combinations than others. For example, among the nine learning difficulties that T12 attempted to address (disregarding those he did not attempt), he used, explanations with seven of them. He used drill with only one learning difficulty.

5.4.3.3 T12's prevalent combinations of strategies

Table 5.7 shows that the following three combinations of teaching strategies were noted with T12, starting with the most prevalent:

Combination 1 - colour code blue (frequency of five)

Teacher begins with explanation

If problem persists, ask another student to explain.

Use leading questions to guide students to understanding.

Where possible, use chart diagrams or analogies in explaining.

Combination 2 - colour code green (frequency of three)

Express surprise with student idea

Use leading questions to guide students to accepted scientific view

Give other students a chance to attempt to give scientific view

Then explain if necessary.

Combination 3 - colour code pink (frequency of two)

Begin with drilling the students on a difficulty.

Then explain if necessary.

Table 5.7: T12's combinations of teaching strategies

Strategy	**Difficulty number as in Table 5.6**										
	1	**2**	**3**	**4***	**5**	**6**	**7**	**8**	**9**	**10***	**11**
Express surprise with student input	X					X	X				
Explain		X	X		X				X		X
Give other student(s) chance to explain		X				X	X				
Drill								X			
Use analogy to explain									X		
Ask questions	X								X		X
Use chart paper diagram									X		X
Explain							X	X			

*These difficulties only appeared during the student interview and the teacher did not attempt to address them

To illustrate how T12 used the combinations of strategies identified, I present one extract from the PD 12 or 13 for each. The extracts have been chosen because they are typical of how T12 used each combination.

5.4.3.4 T12's use of combination 1 of his teaching strategies

Firstly, I present an extract from PD 12, which shows how T12 used combination 1 to attempt to help students who had difficulties understanding the calculation of average atomic mass. The difficulty was mainly with understanding the relative abundance between chlorine-35 and chlorine-37. The extract below shows how T12 tried to address this problem. In paragraph 365 of the extract the teacher explained by way of stating and restating the ratio of chlorine-37 to chlorine-35. Actually one gets the impression that there was is a bit of drilling (doing the same thing repeatedly) going on as well. However, students did not understand, as shown by paragraph 366. The teacher then tried to explain again, but this time bringing in a diagram showing symbols for chlorine-37 and chlorine-35 with only masses indicated (paragraphs 368 – 370). Still some students did not understand as exemplified by S27 in paragraph 371. Then the teacher brought in an analogy of ratio of boys to girls in paragraph 372, which apparently helped a minority of students to understand. However, the majority still did not understand and the teacher explained again using the analogy in paragraph 376, which helped more students to understand. In paragraph 379, the teacher offered to continue may be after noting it was only a minority that still had difficulties (paragraph 378). In this extract, though, the teacher did not ask students who had understood to explain to others, as was the case with difficulty 2 shown in Table 5.6 and 5.7.

> **365 T12:** To answer this question here where you are saying why then that chlorine eh you have got eh thirty-five point five as its atomic mass? To answer that one, it is found that in nature in nature these chlorines occur in the ratio of one is to three. Okay, so for every, for every one chlorine thirty-seven, you have got ah three chlorine thirty-fives. You understand, in nature if you take a sample you if you take a sample of chlorines, you find that for every one chlorine thirty-seven you have three chlorine thirty-five. You are clear there eh?
>
> **366 Majority of students:** No.
>
> **367 T12:** I'm saying in nature, these occur, when they take a sample of chlorine, it is mostly it is found that for every one chlorine thirty-seven, you have got three chlorine thirty-five *[Uses diagrams shown below]*
>
> **368** 37 35
> **369** Cl Cl
> **370**
>
> **371 S27:** Sir, you are saying for every one chlorine … *(Interrupted by teacher)*

372 T12: Yes, for every for every chlorine thirty-seven, for every one atom of chlorine thirty-seven, you have got three atoms of chlorine thirty-five. So, they occur in the ratio of one is to three *[Writes "1:3" on the board]*. It's like we we say for every three girls you have got one boy. For every three girls you have got one boy. You understand?

373 Minority of students: Yes.

374 T12: So in nature if lets say if you sample, …

375 Majority of students: Aah, aah *[Seemingly in protest against those who said yes]*

376 T: if you sample out a group, you find for every three girls you have got one boy. So its like this one, in nature if they take a sample of chlorine, right, if you take a sample of chlorine, you find that if you analyse that one, for every one chlorine thirty-seven, okay for every one atom of chlorine thirty-seven, you have three atoms of chlorine thirty-five. Is that difficult to understand?

377 About half students: No

378 Minority of students: Yes.

379 T: It isn't. Let's move on may be you will understand as we go down.

The literature supports the finding that students have difficulties understanding the concept of average atomic mass (e.g. Geddis et al., 1993). Geddis et al. (1993) explain that this is the case because students are used to simple averages and have difficulties understanding the use of weighted averages. They also recommend that to help students understand average atomic masses, teachers need to focus on conceptual knowledge, not procedural knowledge, as was the case with T12.

5.4.3.5 T12's use of combination 2 of his teaching strategies

With combination 2, T12 started by expressing surprise with a student's idea. He then used leading questions to guide students to an accepted scientific view, where this was deemed fit. He could then give other students a chance to attempt to give scientific view. Finally, the teacher would explain whenever it was necessary. The extract below shows how the teacher used this combination to address difficulty 6 in Table 5.6: failure to state the correct mass of a neutron. The extract shows that S10 mentioned zero as the mass of a neutron in atomic mass units (paragraphs 209 and 211), instead of one. It seems S10 confused mass and charge of a neutron. The teacher then expressed surprise in paragraph 212 in form of questions. The questions are also leading in that they tell students that zero cannot be the answer. He then asked another student (S11), who correctly mentioned 1.

> **208 T12:** Remember ah these units are not the mass like one kilogram. It's a special mass, which is in atomic mass units. It is used for small particles, okay. How about a neutron, what is the mass? Yes S10
>
> **209 S10**: Zero
>
> **210 T12:** Sorry!
>
> **211 S10:** Zero.
>
> **212 T12:** Zero? Uhm, mass ah of a neutron? Uh, yes.
>
> **213 S11**: One.
>
> **214 T12:** Okay, it's again one.

5.4.3.6 T12's use of combination 3 of his teaching strategies

Combination 3 of T12's teaching strategies involves starting to address a difficulty with drill and then following up with explanation. 'Drill' here refers to the strategy where T12 starts a statement and lets students complete it as a group repeatedly. The following extract from PD 12 illustrates the use of this combination. In paragraph 286 T12 asks a question that requires use of the principle 'in a neutral atom the number of protons is equal to the number of electrons' to answer. Some students fail to give the correct number of electrons, given the number of protons (paragraph 287). The teacher then moves from one bench to another, asking students to complete the statement 'In a neutral atom the number of protons is equal to the number of …' I call this strategy 'drill'.

> **286 T12:** And so we know that this one is the number of what protons. Taking this one to be our neutral atom, it means it also has got how many electrons. How many electrons?
>
> **287 Students:** *[Some say eight, while others mention ten].*
>
> **288 T12:** Ten. I'm saying in a neutral atom the number of protons is equal to the number of …
> **289 Students:** Electrons.
>
> **290 T12:** Please. In a neutral atom, in a neutral atom, the number of electrons is equal to the number of *[Teacher walks closer to the front row]…*

291 Majority of students: Protons.

292 T12: If an atom is neutral, if it has got five protons, you also should know that it has got five electrons. Are are we together?

292 Majority of students: Yes.

293 T12: *[Walks to second row and used even gestures]* In a neutral atom the number of protons is equal to the number of …

294 Majority of students: Electrons.

295 T12: Here *[Moves to the third row]* In a neutral atom the number of protons is equal to the number of …

296 Third row: Electrons.

297 T12: This one is …. If you don't understand that one you have got problems. So taking this one as a neutral atom, it has got ten protons, then it also has how many electrons in total? Ten *[some students join to say ten]*. But we know, from what we said, the first shell contains how many electrons?

5.4.4 Reasons given for the strategies used to try to address difficulties

T12 used a number of strategies in his teaching that were combined in different ways in an attempt to address observed difficulties. During the pre-observation interviews, post-observation interviews and discussion of the video recordings, the teacher was asked to explain the use of certain strategies. This sub-section identifies the reasons associated with teaching strategies that T12 used to try to address learning difficulties. A similar procedure as in sub-section 5.3.4 was used to identify the reasons. Appendix 21 contains codes that identify portions of the relevant transcripts where the teacher gives the reasons. Such codes have names that start with 'Reason'. Using the code manager of *Atlas.ti 5.2,* it was possible to double click on a code to retrieve the relevant quotations and identify the reasons given by the teacher. By reading such quotations closely it was also possible to infer reasons that the teacher did not mention explicitly, the implied reasons. Table 5.8 gives the reasons identified for T12's use of the teaching strategies. Again, since the implied reasons are gathered from the data, I will not distinguish them in discussing Table 5.8. In addition, I will not focus on individual reasons, but the general patterns that emerge.

To begin with, the theme of helping students to easily remember some facts, ideas or information emerges. Strategies associated with this theme included: expressing a surprise, use of drill and use of leading questions. The emphasis here was on facts or principles. For instance, at one point the teacher asked the students to state the mass of a neutron. At another point, the teacher used drill to help students remember the principle relating number of protons and number of electrons in a neutral atom. This theme fits well with the description of a traditional approach to physics teaching that emphasises transmission of content (Flores et al., 2000).

Another theme that emerges is to convey information. Examples of strategies in Table 5.8 that support this theme are: teacher explaining, giving another student a chance to explain to fellow students, and use of diagrams. Here too the theme of conveying information fits well with description of traditional physics teaching that it focuses on transmission of content (Flores et al., 2000) or telling students the physical rules that seem to guide the universe and demonstrating how to use the rules to solve problems (Van Heuvelen, 1991). Actually, at some point during the post-observation interview following the second lesson (PD 13), T12 defended the decision not to solicit student views as follows:

> **046 T12:** Uhm basically there is no definite formula for making ah a decision, sometimes its situational. You can actually see your students. Ah at this point I realised that now we have entered a very new, very, very new topic may be very, very new concept so I decided to let them just have it. Yah, because I really realised that it was a very, very new topic and at one point I did ask them ah that is this very new and they actually said very, very new.

In other words, the decision to just convey information was apparently based on the assumption that students do not know anything about a new topic. Such an assumption is in contrast with the research-backed belief that indicate students come with deeply-rooted ideas to science lessons (Driver et al., 1989; Duit & Treagust, 2003; McDermott, 1998).

Yet another theme that emerges from Table 5.8 is one on facilitating understanding. Strategies that support this theme are: explaining, giving a student a chance to explain to other students, use of diagrams drawn on the chalkboard or chart paper, use of drill and use of analogy. Of course the theme of facilitating understanding fits well with one of the aims of science learning and teaching. However, the critical question is ‘Understanding of what?’ The PSS (Ministry of Education Science and Technology, 2001) spells out that students need to “acquire and develop scientific knowledge, skills and attitudes” (page viii). T12 seemed to emphasise only acquisition of knowledge. One could argue that this was the case because of the nature of the lessons and that if more of his classes were observed, may be T12 would have been seen focusing on skills and attitudes as well. However, at some point it is the teacher himself who associated radioisotopes with danger, which could enhance negative attitudes in students. A study in Norway found a similar view with high school students who tended to associate radiation with danger (Henrikssen & Jorde, 2001). This shows that this view is not unique to Malawi. So, when speaking about dangers it should also be pointed out that there are ways of minimising the dangers and maximising the benefits. Also discussion of the atom, which took a good part of the first lesson, presented opportunities to talk about how scientific models are used, yet the teacher talked about the planetary model of the atom as reality. The teacher would have allowed the students to critique the model as Coll (2005) suggests that enabling students to construct and critique their own models and scientists’ models of scientific phenomena effectively supports conceptual development outcomes.

Finally, there is the theme of involving students in the lesson. This theme is mainly associated with use of questions. The extract taken from PD 13 below exemplifies this. In paragraph 198 T12 is explaining the direction of the magnetic field. He then asks the question ‘Which one is the plane of the board?’ and calls a student to the board to try to illustrate what the teacher had said, thereby involving the students in the lesson in two ways: the question must have set the students into thinking and the chosen student (S11) was given a chance to explain (paragraph 199) and to illustrate on the board (paragraph 201).

> **198 T12:** So we are saying this magnetic field, okay I have got this one here, this is the part here, okay. Okay it's ah we are saying that's where the magnetic field is *[Shades with white chalk the area of the magnetic field]*. But we are saying this magnetic field is at right angles to the plane of the board. Which one is the plane of the board? Hah? Anyone who can show me the plane of the board? Yes, is it new? There is a topic in geometry in form one I think, if not form two, where you do this. Yet, and then is it that geometry or algebra when you start drawing graphs? So its algebra, so … may be we can … anyone? Okay, so yes.
>
> **199 S11:** The plane of the board is flatness.
>
> 200 T12: This flatness of the board *[Waves to the board surface]* and can you come and show using this *[Refers to the board ruler in his hands]* when we are saying the magnetic field is at right angles to the plane of the board, how should this one be? Can you come?
>
> **201 S11:** *[Comes to the board and points the ruler to the board such that the angle made is ninety degrees]*.

One thing that should be pointed out is that the way of involving students illustrated by the above extract was rare. Most of the questions the teacher asked involved the students in giving short answer responses. A typical way in which questions were used to engage students is shown in the extract from PD 13 below. In this extract, the students just mention one-word responses (paragraphs 120, 122, 124 and 126).

> **119 T:** Okay, so elements having, elements having the same number of protons but different mass numbers. Okay, so those are ah … isotopes. *(Looking at a book on the front bench)* On the nucleus of atoms, you have got two types of particles there. Can you give me one particle or particles, a group of particles that are found there? Yes, yah.
>
> **120 S2:** Neutrons.
>
> **121 T12:** Yes, we have got both neutrons and …
>
> **122 Majority of students:** Protons.
>
> **123 T12:** And surrounding the nucleus are, you have what? What things surround the nucleus?
>
> **124 S3:** Electrons.
> **125 T12:** Where are they, where exactly can you find these electrons? Yes.

126 S4: In the shells.

127 T12: Okay, in the electron ah shells.

Engaging students in giving short response does not allow the students to articulate their reasoning. Yet, this is one way of deepening the students' understanding(Grossman, 2005).

Table 5.8: Reasons for T12's use of identified teaching strategies

Teaching strategy	**T12's reasons for using it**	**Implied reasons**
Expressing surprise	Not probed directly	To indicate to students that they are supposed to easily remember
Explaining	The topic is new	To convey information To facilitate understanding To describe something
Giving other students chance to explain	Fellow student might explain using simpler language Might explain in a different way	
Use of a chalkboard diagram	Facilitate understanding To help students visualise a concept As a way of simplifying a concept	To convey information
Use of chart diagram		
Use of drill	Facilitate understanding	Facilitate easy remembering
Use of analogy	To facilitate understanding	
Use of leading questions	To check if the students remember To see if there are deviations from the accepted view To get them involved in the lesson	

5.5 T23's teaching strategies

5.5.1 T23's teaching context

T23 teaches at a community day secondary school (CDSS). As already mentioned, CDSSs tend to be less resourced than conventional secondary schools in terms of teachers, books, classrooms, laboratories and laboratory stock. The teachers are government employees, but management of CDSSs is left to the communities in which the school is located. T23 referred to the room in which the lessons were held as the physical science laboratory. However, instead of benches, desks – similar to those in other classrooms – were placed in it. Students sat on the two-seater desks facing the front, where a chalkboard was fixed on the wall. There were no sinks, taps or power points. I only saw a few bottles of chemicals in a back room, where we had the post-observation interviews. At some point during our interaction the teacher admitted that they lack resources to teach nuclear physics and other topics. I also learnt from the head teacher that T23 was the only one who could handle physical science, which has implications for preparation time.

When I started interacting with T23, he did not have the minimum qualification of a teaching diploma that is required for one to teach in a secondary school. By the time I observed his lessons, he had just obtained his teaching diploma from one of the secondary teachers' colleges. T23 should have participated as an unqualified case teacher, so his qualification changed the situation. Nevertheless, compared to T25 and T12 who held bachelor of education degrees, he was less qualified. Prior to his qualification he had been teaching for seven years in CDSSs, using his primary school teaching certificate. Among the physical science teachers in CDSSs, T23 was considered as one of the best by one of the district education methods advisors.

As with other case teachers I observed, two of T23's lessons were on nuclear physics. Twenty-seven students attended the first lesson and twenty-nine students attended the second one. Each of the two lessons was 40 minutes long.

5.5.2 Content covered in T23's lessons

The content covered in T23's lessons has already been identified in the previous chapter (Table 4.9, PDs 14 & 17). The first lesson (PD 14) covered particles of the atom. The second lesson (PD 17) centred on isotopes. Following a similar procedure as described in sub-section 5.3.2, I give details of what was covered under this content to provide context in which the teaching strategies are used. Table 5.9 summarises the details covered under each of these content areas and the difficulties associated with that content. The first column of Table 5.9 shows the relevant lesson and the PD for that lesson; the second column shows the content area, which is the major idea under consideration; the third column still shows content, but in a more detailed way; and the fourth column shows the difficulties related to the content.

Table 5.9 shows that under the section "particles of the atom", T23 covered the definition of an atom, characteristics of protons, neutrons and electrons, atomic number, mass number and notations for representing atoms. It also shows that he covered definition of an isotope, examples of isotopes and calculation of average mass numbers under isotopes. Analysis of the relevant section of the PSS revealed that this content covered the first three of the thirteen objectives under nuclear physics. Those objectives are that students should be able to: "name constituent particles of atomic nuclei, express composition of a particular nucleus in standard notations and describe isotopes as atoms of the same element with different mass numbers due to different numbers of neutrons in their nuclei" (Ministry of Education, Science and Technology, 2001: 52 – 53). These objectives focus on the nucleus, but T23's also covered electrons and shells in considerable detail. He even taught density, boiling points and melting points of isotopes, which gives the impression that he may not be very conversant with the curriculum requirements.

Table 5.9 also shows that difficulties were noted in the course of T23's lessons. Those difficulties that manifested themselves in both lessons include: student conceptions, use of symbols and understanding of mass number. Students also mentioned learning without doing any experiments as a difficulty in the first lesson. The difficulties that appeared in the second lesson only include: understanding of proton number, calculations involving neutron, proton and mass numbers, definition of isotopes and density of isotopes. In the next sub-section, I present the strategies that T23 used in addressing the identified difficult aspects.

Table 5.9: Content covered in T23's lessons and the related difficulties

	Content area	**Details of content covered**	**Observed difficulties**
First lesson (PD 14)	Particles of the atom	Definition of an atom Planetary model of the atom Parts of an atom: shells, nucleus Three particles of an atom: protons, neutrons, electrons Properties of protons, neutrons and electrons Atomic and mass number Notation for representing atoms	Students' conceptions Mass number Use of symbols No experiments
Second lesson (PD 17)	Isotopes	Definition of an isotope Examples of isotopes Average atomic mass of isotopes Density, melting points and boiling point of isotopes	Calculations Students' conceptions Definition of isotope Isotope density Mass number Proton number Use of symbols

5.5.3 T23's teaching strategies for addressing learning difficulties

5.5.3.1 Identification of T23's strategies

A similar procedure as in subsection 5.3.3 was used with PDs 14 and 17 to identify the strategies T23 used to address the relevant difficulties. I used the code manager of *Atlas.ti 5.2* to isolate quotations in PDs 14 and 17 associated with those difficulties. I then read through those quotations at least twice, noting how the teacher handled learning difficulties. Those strategies are shown in Table 5.10. From Table 5.10 patterns in the strategies used could then be identified.

Table 5.10: Difficulties and the strategies T23 used to try to address them

Identified difficult aspect	**Strategy used to try to address it**
1 Conception: The thinking that a neutron does not have mass	Teacher asked other students to comment Teacher commented if true or not Teacher asked group to explain
2 Conception: The thinking that neutrons do not experience a force	Asked group concerned to explain Asked the class if explanation was true Then teacher attempts to explain
3 Conception: The thinking that protons and neutrons combine to form atomic mass	The teacher did not follow up on this one
4 Conception: The ideas that mass number determines atomic number of an element	Asked class if this is true Asked group spokesperson to elaborate Teacher explained Used an example to explain further
5 Conception: The thinking that density, boiling point and melting point of an isotope increases with mass	Teacher seemed to share the view so did not attempt to address it.
6 Conception: The tendency to think that protons and neutrons do not move	Teacher shared the view, so did not attempt to address it
7 Calculations: Failure to get correct number of protons in deuterium.	Teacher asked the group to explain why they differed with other groups Group admitted it was a mistake
8 Use of symbols: Some students confused with swapped notation on the periodic table displayed	Just explained Used the example of carbon on periodic table displayed
9 Interpretation of symbols: Failure to identify atomic number, given symbol	Difficulty 9 and 7 involved same task, so approach was the same
10 Definition of isotope: 'Is the element which has the same atomic number but different mass number	Asked students to comment on a group's definition Teacher then commented if right or not Teacher then explained

5.5.3.2 Patterns in T23's strategies

Table 5.11 has been constructed from Table 5.10. The first column indicates the strategies employed. The columns to the right indicate the difficulties to which those strategies applied. The difficulties have been represented by numbers 1 to 10, which correspond with numbers against each difficulty in Table 5.10. Letter 'X' has then been used to indicate the strategies used with each difficulty. The distribution of 'Xs' revealed how the strategies were combined and the overall T23's strategy. Colour coding has been used to depict different combinations (See below).

Some patterns can be identified in Table 5.11. Firstly, column one shows that T25 tried to use different strategies in the two lessons. These included: asking other students to comment on a group's response/idea, the teacher indicating whether a student response/idea is true or not, asking the concerned group to explain their response/idea, asking rest of the class if a group's explanation is true, teacher giving an explanation and teacher explaining using a specific example.

Secondly, like the other cases so far, T23 also tended to use these strategies in combination. Of the seven difficulties he attempted to address, T23 used combinations of strategies in five of them. He used single strategies only with two difficulties (7 and 9). Also some combinations were more prevalent than others. For instance, the colour coding in Table 5.11 reveals that the pink and green combinations each were only used with one difficulty, while the blue one was used with two difficulties.

Thirdly, there are some difficulties that the teacher did not attempt to address. There are three such difficulties: 3, 5 and 6. Reading the relevant sections of the PDs revealed that the teacher also had similar difficulties. For instance, the students thought that density, boiling points and melting points of isotopes increase with mass. In comparing isotopes of hydrogen, the students thought deuterium (hydrogen atom with mass number two) should have a lower boiling point than tritium (hydrogen with mass number three). The teacher accepted this thinking. Yet, naturally, any sample of hydrogen should contain all these isotopes, so one cannot talk of separate or different boiling points. The extract below from PD 17 shows the interaction between T23 and students on this aspect. In paragraph 250, the group one spokesperson clearly said that density, melting points and boiling points would be different because they have different mass numbers and consistently maintains this view in paragraphs 252 and 254. At the end of it the teacher did not follow up.

> **249 T23:** It's constant, not changing. Right, so do you expect density, melting points, boiling points to be the same? Explain, how did you answer that one?
>
> **250 Group 1 spokesperson:** No, because they have different mass numbers.
>
> **251 T23:** So there will be no, no change, or no, you don't expect density, melting to be the same; you expect them to be the same.
>
> **252 Group 1 spokesperson:** No
>
> **253 T23:** They will be different?
>
> **254 Group 1 spokesperson:** Yes *[Also nods]*

Finally, Table 5.11 shows that some strategies belong to more combinations than others. For example, teacher indicating if a students' response is true or not was used with two combinations only (blue and green), but teacher explanation was used with all the four combinations (red, blue, green and pink).

5.5.3.3 T23's prevalent combinations of strategies

Table 5.11 shows that the following combinations of teaching strategies were noted with T23, starting with the most prevalent:

Combination 1 - colour code red (frequency of three)

Teacher begins asking a group to explain their response/ ideas.

Then the teacher may or may not ask the class if the group explanation is true or not.

If group's explanation is lacking, then teacher explains.

Combination 2 - colour code blue (frequency of two)

Teacher asks the class to comment on a group's report.

Teacher may then indicate if the group's report is true or not.

Teacher may then ask the concerned group to explain.

If need be, teacher may then explain.

Where necessary enhance explanation with an example.

Combination 3 - colour code pink (frequency of one)

Teacher explains.

The teacher then enhances explanation with an example.

Combination 4 - colour code green (frequency of one)

Teacher asks the class to comment on a group's report.

Teacher may then indicate if the group's report is true or not.

Then teacher explains.

Table 5.11: T23's combinations of teaching strategies

Strategy	**Difficulty number as in Table 5.10**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Ask students to comment on group report	X			X						X
Teacher indicates true or not	X									X
Ask concerned group to explain	X	X		X			X		X	
Ask class if group's explanation is true		X								
Explain		X		X				X		X
Use example to explain				X				X		
No attempt made to address			X		X	X				

To illustrate how T23 used the combinations of strategies identified, I present one extract from the PD 14 or 17 for each. The extracts have been chosen because they are typical of how T23 used each combination.

5.5.3.4 T23's use of combination 1of his teaching strategies

Combination 1 (colour code of red) involved some or more of the following steps: Teacher begins asking a group to explain their response/ ideas, then the teacher may or may not ask the class if the group's explanation is true or not. If the group's explanation is lacking, then the teacher explains. The extract below from

PD 14 shows how T23 used this combination of strategies to deal with difficulty 2: that neutrons do not experience a force. It might be that students were thinking only about electrostatic forces between charged particles. Yet, in a nucleus it is believed that there are other forces that apply to neutrons as well like the strong nuclear force, the weak nuclear force and gravitational forces (Giancoli, 1998). In paragraph 247 of the extract below, T23 asks the concerned group to explain their view that neutrons do not experience any force. A member of the group (S12) explained that this should be so because they do not have any charge. In paragraph 251 the teacher asks the class if the explanation is true. In paragraph 253 the teacher explains.

> **247 T23:** What about this point here: why, they do not experience any force. What do you mean by the force that they do not experience? Uh *[Points to another member of group 2, S12 - male]*
>
> **248 S12:** The force of repulsion and attraction.
>
> **249 T23:** The force of attraction?
>
> **250 S12:** Yah, because they do not have any charge.
>
> **251 T23:** Because they do not have any charge. Okay. Is that true?
>
> **252 Some three students:** No, no, no *[Seems to indicate that other students may have been in agreement with thoughts of group 2]*
>
> **253 T23:** Okay (4). So, all right, so when you talk of the force that you have talked about there, the attractive force, of course we expect it covers the whole nucleus …

The view that neutrons do not experience a force because they do not have any charge shows that some students did not think that the law of gravitation could apply to nuclear particles. This result is similar to what Taber (1998) found with A level students who thought the Coulombs law did not apply to protons and electrons in an atom. Those A-level students considered that an atomic nucleus gives rise to a certain amount of attractive force which is shared equally among the electrons. T23 may not have been aware that students might think the laws of physics that apply to the atom (which is at the sub-microscopic level) should be different from those that apply at the macroscopic level.

5.5.3.5 T23's use of combination 2 of his teaching strategies

Combination 2 (colour code blue) involved the following steps: Teacher asks the class to comment on a group's report; he then indicates if the group's report is true or not. Next, he asks the concerned group to explain. If need be, teacher may then explain and where necessary enhance explanations with an example. I illustrate how T23 used this combination with difficulty 4 where the view that "a neutron has no mass" manifested. The teacher planned a task for students to discuss in groups and come up with properties of neutrons. One group gave the following properties of a neutron: "has 0 charge (no charge), does not move, has no mass, found in the nucleus and does not experience any force." Of course this list of properties has other problems, but here I only focus on mass of a neutron just for illustration purposes. The extract below from PD 14 shows how T23 handled this difficulty using combination 2. In paragraph 239 the teacher asked other students to comment, if they had reservations, on a group's list of properties of neutrons. In paragraph 243, the teacher indicates that it is wrong to say a neutron has no mass and goes on to ask the group to explain. Finally, the teacher explains that a neutron has a mass of one atomic mass unit.

> **239 T23:** Neutrons we are saying they got no charge; ah they do not move; they have no mass; and they are found in the nucleus; they do not experience ah any force. Do we have any reservation about any point in neutrons? Yes.
>
> **240 S10:** *[Male, acted as spokesman for group 4]*. You have listed that they have no mass.
>
> **241 T23:** Hey!
>
> **242 S10:** I think that came from, because a neutron has a mass of one a.m.u.
>
> **243 T23:** So, this point is wrong. You say …Why do you have that point to say that neutrons they have got mass? *[Students murmur because apparently teacher referred to wrong group, instead of group 2]*. Oh, it's that group! Why do you say that they have got no mass? Uh *[Points to one member of group 2, S11 - male]*
>
> **244 S11:** ….*[inaudible]*
>
> **245 T23:** So, it means that this point is not true, yah?
>
> **245 Majority of students:** Yah *[As teacher cancels point that neutron has no mass from list]*

> **246 T23:** We know they have got a mass according to this point here it says *[Point to it on the board]* it has got a mass of one atomic unit.

5.5.3.6 T23’s use of combination 3 of his teaching strategies

With combination 3 (colour code pink) the teacher is basically just explaining. However, some of the explanations are supported with use of specific example(s). This combination was used to try to address the difficulty that arose with symbols. T23 had told the students that the notation for an atom is as shown in Figure 5.1.

Atomic mass A
X An atom (Element)
Atomic Number Z

Figure 5.1: Notation for an atom

However, there was a point at which the teacher brought in a periodic table and that periodic table swapped the positions of A and Z. This caused confusion. To illustrate how the teacher tried to address this difficulty, I present the extract below from PD 14. In paragraph 313, a student (S13) was surprised with the difference in notations between what the teacher gave and what the periodic table used. During the post-observation interview, T23 actually admitted that he did not anticipate this problem with symbols. To address the problem, the teacher went straight into explaining (paragraph 314) that sometimes the order is reversed. The teacher also isolated carbon on the periodic table and used it as an example to illustrate how the students could distinguish atomic and mass numbers.

> **313 S20:** Then I’m wondering the way you have written it *[Apparently referring to the fact that the symbol for an atom that the teacher gave put a on top and z below, while the periodic table displayed put a below and z on top]*.
>
> **314 T23:** In fact, what, what I have said is there some books in which a is put on top then z downwards. Then there are some other ah books they put it like the way how the periodic table is here. You can see that six is on top *[Points to the periodic table on carbon]* and then ah twelve is below, which means this is the mass and that one is the atomic number *[Points to 12 and 6 respectively on carbon]*. So the best thing that I think you should

> take hold it's the symbols that are there *[Points to A and Z on the symbol for an atom]*. If a is there *[Points to top left of X]*, then it will still represent what, atomic mass. If z is down there, it will represent atomic number. And again you can be even looking at the figure itself. Most of the times atomic mass is smaller than what, I mean atomic mass they are bigger than atomic number. So whenever you see a big number on that you should know that it is representing mass of that element.

5.5.3.7 T23's use of combination 4 of strategies

With combination 4, the teacher asks the class to comment on a group's report. The teacher then indicates if the group's report is true or not. Next, the teacher invokes explanation. This combination was used to try to deal with a difficulty that arose in the second lesson with definition of an isotope. One group defined an isotope as: "An element having the same number of protons but different number of neutrons." According to T23, this definition has a problem in that there is reference to neutrons instead of mass numbers. I use the extract below from PD 17 to illustrate how T23 attempted to address this problem. Firstly, the teacher asked students to comment on the definition in paragraph 313. Some students gave their views in paragraphs 314 and 316, with S11 thinking it is right and S12 thinking it is 'not really true'. Finally, in paragraph 314, the teacher indicated that the first definition was not right and then went on to explain.

> **313 T23:** Now let's look at together, the first definition …, says it is an element having the same number of protons but different number of neutrons. How do you look at that definition? (9) Yes *[Points to S11]*
>
> **314 S11:** I think that definition is right because … it is showing us that …
>
> **315 T23:** Anybody?
>
> **316 S12:** Actually if you look at the table *[Pointing to the table on the board]*, realising element number two which has got, you can see that there is a proton number of one and neutron number of one as well which means that the first one isn't really true …
>
> **317 T23:** Right, so what he is saying is the definition, according to his observation is not right because here we are saying the proton for this second element *[Points to the board]* the proton number is one, while the neutron number is one, which means the number of protons and neutrons they are the same. Therefore, he says it's not right. What are other observations? Okay, right. Lets look at another the other definitions. These are elements with different atomic mass but having the same atomic number. The third one, these are elements with, with different atomic

> mass, but having the same atomic number. These are the elements with the same atomic, atomic number, but different atomic masses. So all these three definitions, they are, they are, they agree with each other, but first one is what is having a problem. So really I agree with these three definitions *[Referring to second, third and fourth definitions]*, but this one *[Points to first definition]* is not right in the sense that when we are talking of isotopes, of course we are saying isotopes these are the elements. Of course those elements they have got different atomic ah different masses. That's right, but the atomic numbers are the same. If you look at these elements that I gave you *[Those in the table]*, if you look at the mass of this one, you've got it to be, its one; but for this one is two, then the third one is three. So, we are talking masses; they are always different, but the atomic numbers are always the same.

5.5.4 Reasons given for the strategies used to try to address difficulties

T23 used a number of strategies in his teaching. During the pre-observation interviews, post-observation interviews and discussion of the video recordings, the teacher was asked to explain the use of certain strategies. This sub-section identifies the reasons associated with teaching strategies that T23 used to try to address learning difficulties. A similar procedure as in sub-section 5.3.4 was used to identify the reasons. Appendix 21 contains codes that identify portions of the relevant transcripts where the teacher gives the reasons. Such codes have names that start with 'Reason'. Using the code manager of *Atlas.ti 5.2,* it was possible to double click on a code to retrieve the relevant quotations. I could then read through the quotations and note the reasons given for a particular strategy. By reading such quotations closely it was also possible to infer reasons that the teacher did not mention explicitly, the implied reasons. Table 5.12 gives the reasons identified for T23's use of the teaching strategies. The implied reasons were obtained in a similar way as described in sub-section 5.3.4. Again, since the implied reasons are gathered from the data, I will not distinguish them in discussing Table 5.12. In addition, I will not focus on individual reasons, but the general patterns and themes that emerge.

The reasons captured in Table 5.12 reveal a number of themes pertaining to use of strategies. First is the theme of helping students identify problems/difficulties. This theme is related to the following strategies: asking students to comment on a group's report, asking the concerned group to explain and asking the class if a group's explanation is true or not. This theme fits well with the view that learning begins with dissatisfaction with an existing conception (Duit & Treagust, 2003; Hewson, 1996). Also, T23 created an atmosphere for students to freely come up with ideas and to have them commented on by others without reprisal. This is important for effective participation, which is another theme that I identified.

Another theme was to encourage participation, as mentioned previously. This theme was associated with use of the following strategies: asking students to comment on a group's report, asking the concerned group to explain and asking the class if a group's explanation is true. This theme is in line with what Van Heuvelen (1991) found with 152 engineering students who had done one semester of introductory physics after analysing patterns in performance on a test. He found that active cooperative learning in lectures should provide opportunities for students to:

1. Be active participants during lectures in constructing concepts, reasoning qualitatively using the concepts, and in solving problems;
2. Evaluate their own thinking and that of their classmates;
3. Make unpenalised mistakes while getting immediate feedback from the professor.

T23 encouraged participation and students seemed to have enjoyed this aspect, as evidenced by the level of participation.

A third theme that emerged was to aid understanding. Strategies associated with this theme were: asking students to comment on a group report, asking the concerned group to explain, teacher explaining and use of examples. I agree with T23 that encouraging students to comment on others' work or a group to explain their work could aid understanding because it encourages thinking as one examines the work and such thinking could improve understanding. Also use of examples can help to demonstrate how to apply a principle, thereby encouraging understanding. However, for T23 the focus was on directing students towards the accepted scientific view. The use of the word 'true' assumes there is just one accepted view. I felt the teacher should have engaged the class in deciding why a certain view is more plausible than another, in line with the conceptual change approach (Hewson, 1996).

A fourth theme was to give feedback on whether student input is true or not. Of course this is important in a system where standardised examinations and/or tests are still a large part of the evaluation system. The concern for examinations was clear when I asked the teacher to explain his use of examples. He argued that the example he used was an examination question, apparently referring to a past examination. The extract below shows how T23 responded:

> **113 I:** The information that students might have problems with averages, how did you come to know about that one?
>
> **114 T23:** Ah (5) of course this question it's an examination question. When the MANEB *[Stands for Malawi National Examinations Board]* is asking they also hint on the average part of this and then I took that one as a better example so that whenever they are approached to that, they can be able to handle it.
>
> **115 I:** Okay. So it was taken from an exam paper?
>
> **116 T23:** An exam paper, yes.

However, to only indicate that a student input is true or not, rules out other possibilities. And indeed this was observed with the definition of an isotope described as not right. A group had defined an isotope as "an element with the same number of protons but different number of neutrons." Of course the definition differed from the one the teacher preferred: that "isotopes are atoms with the same number of protons but different masses". However, it agrees with the one Giancoli (1998: 917) gives: that "nuclei that contain the same number of protons but different numbers of neutrons are called isotopes."

A fifth theme regards the use of examples. The teacher chose certain examples because they involved common elements. For instance, the example on calculation of average masses, the teacher used chlorine, and argued that this element is common. Also in the examples of isotopes that students gave, they did not include carbon and the teacher included it. When I asked why it was still important to include carbon when students had already given a number of examples, T23 answered that it is because carbon is common, referring to the fact that many living and non-living things contain carbon and students should be familiar with it. . It might be that this is based on the assumptions that use of familiar examples improves understanding. Such assumptions would be in line with Hewson's (1996) argument that the kinds of knowledge a learner possesses, which Hewson calls a learners' 'conceptual ecology', provide the context in which conceptual change occurs.

A sixth and final theme involves the use of explanation. T23 indicated that he was covering new things, so 'high' explanation was needed. Here too, like with use of examples, familiarity seems to be a major factor in the use of the strategy because if something is new to learners, chances are that it is also unfamiliar. Much as this makes sense that where unfamiliar content is being covered, the teacher is likely to do more of explaining, but it does not mean that students know nothing about that content, as research shows that students come to science lessons with deeply rooted ideas about phenomena the following is Driver et al. (Driver et al., 1989; Duit & Treagust, 2003). However, it should be observed that despite the unfamiliarity of the content, the teacher still tried to involve the students in the lesson.

Table 5.12: Reasons for T23's use of identified teaching strategies

Teaching strategy	**T23's reasons for using it**	**Implied reasons**
Ask students to comment on group report	To see if students can identify problems To help students understand To encourage participation	
Teacher indicates true or not		As feedback to concerned student(s)
Ask concerned group to explain	To help students understand To help them identify problems/misconceptions	To encourage participation

Ask class if group's explanation is true	To see if students can identify problems	As one way of giving feedback to the students concerned To encourage participation
Explain	To emphasise important ideas New things, so 'high' explanation needed	To aid understanding
Use example to explain	The examples involve common elements It was an examination question	To aid understanding

5.6 T10's teaching strategies

5.6.1 T10's teaching context

T10 teaches at a CDSS. As already mentioned, CDSSs tend to be less resourced than conventional secondary schools and the teachers are government employees, but management of CDSSs is left to the communities in which the school is located. The school had a library where we had all the pre-observation interviews, post-observation interviews and discussion of the video. T10's lessons were held in an ordinary classroom and the school did not have a laboratory. There was a new building being built, which T10 said would be used as a laboratory once completed. As in the case with other case teachers, I observed two of T10's lessons on nuclear physics. Fifty-one students attended the first lesson, while 47 students attended the second lesson. The students sat on two-seater desks facing the front, where a chalkboard was fixed on to the wall. T10 was not qualified to teach at secondary level as he only had a primary school teaching certificate.

5.6.2 Content covered in T10's lessons

The content covered in T10's lessons has already been identified in the previous chapter (Table 4.9, PDs 15 & 16). The first lesson (PD 15) centred on nuclear particles and the second one on nuclear stability. I give details of what was covered under this content to provide context in which the teaching strategies are used. A similar procedure as described in sub-section 5.3.2 was followed to come up with details about the content covered. Table 5.13 summarises the details covered under each of these content areas and the difficulties associated with that content. The first column of Table 5.13 shows the relevant lesson and the PD for that lesson; the second column shows the content area, which is the major idea under consideration; the third column shows content still, but in a more detailed way; and the fourth column shows the difficulties related to the content.

T10's first lesson, according to Table 5.13, covered the following details under nuclear particles: definition of an atom, constituent particles of atomic nuclei, protons and neutrons, standard notation, mass and atomic number, definition of isotopes and average masses of isotopes. From Table 5.13, details covered in the second lesson include: students' conceptions, guidelines for stability, limit for nucleon number and the concept of stability. Analysis of the relevant section of the PSS revealed that the content covered in the first lesson is part of the curriculum. It addressed the objectives under nuclear physics. Those objectives are that students should be able to: "name constituent particles of atomic nuclei, express composition of a particular nucleus in standard notations and describe isotopes as atoms of the same element with different mass numbers due to different numbers of neutrons in their nuclei" (Ministry of Education, Science and Technology, 2001: 52 – 53).

However, the discussion on nuclear stability went beyond the syllabus requirements. For instance, there is no objective in the PSS that covers guidelines for nuclear stability. Analysis of the commonly used textbooks (Abbey & Essiah, 1990; Duncan & Kennett, 2001) revealed that even these textbooks do not cover the guidelines. The inclusion of content not intended in the curriculum has implications for PCK and I will follow up on this in chapter 6.

Table 5.13 also shows difficulties were noted in the course of T10's lessons. Those that manifested in both lessons include: calculations, students' conceptions use of symbols, guidelines for stability, concept of limit for nucleon number and concept of stability. In the next sub-section, I present the strategies that T10 used to try to address the identified difficult aspects.

Table 5.13: Content covered in T10's lessons and the related difficulties

	Content area	**Details of content covered**	**Observed difficulties**
First lesson (PD 15)	Nuclear particles	Definition of an atom Constituent particles of atomic nuclei: protons and neutrons Composition of nuclei in standard notation Mass and atomic number Definition of isotopes Average masses of isotopes	Calculations Students' conceptions Use of symbols
Second lesson (PD 16)	Nuclear stability	Nuclear binding force Nuclear stability Parent and daughter nuclei Guidelines for stability Neutron: proton ratio	Students' conceptions Guidelines for stability Concept of limit for nucleon number Concept of stability

5.6.3 T10's teaching strategies for addressing learning difficulties

5.6.6.1 Identification of T10's strategies

A similar procedure as in subsection 5.3.3 was used with PDs 15 and 16 to identify the strategies T10 used to attempt to address the relevant difficulties. I used the code manager of *Atlas.ti 5.2* to isolate quotations in PDs 15 and 16 associated with those difficulties. I then read through those quotations at least twice, noting how the teacher handled learning difficulties. Those strategies are shown in Table 5.14. From Table 5.14 patterns in the strategies used could then be identified.

Table 5.14: Difficulties and the strategies T10 used to address them

Identified difficult aspect	**Strategy used to try to address it**
1 Calculations: how to calculate average mass of chlorine	Teacher explains As explaining do the calculation on board Let students simplify the expression by calculation using a calculator Let one student mention final answer Tell the class the final answer
2 Conception: That a nucleus is kept together by intermolecular, electrostatic, or gravitational force	Just tell the students that it is nuclear binding force
3 Conception: Tendency to confuse protons and neutrons	Ask again the question another three times Then go on to explain
4 Conception: Confuse protons neutrons and electrons in defining isotopes	Express disapproval in form of question Ask another student to give correct definition of isotope Then use leading questions to guide students to accepted definition
5 Standard notation:* Students indicated that they did not understand what it means	Use periodic table to show notations Use the example of lithium Ask guiding questions Finally give the general symbol for an atom
6 Stability of an atom: Failure to identify the applicable guideline in determining stability of an atom	Ask students the guideline they used Continue asking the students to solicit more responses on the rule used Finally, teacher states the rule used
7 Stability of an atom: failure to understand meaning.	Just explained
8 Concept of limit: Students had difficulties understanding the concept of a limit	Used role-play involving girls Then used analogy of the circle of girls to explain

*This difficulty was mentioned during the student interview, so teacher may not have been aware of it. The strategies given are thus just the part of the normal course of the lesson.

5.6.6.2 Patterns in T10's strategies

Table 5.15 was constructed from Table 5.14. The first column indicates the strategies employed. The columns to the right indicate the difficulties to which those strategies applied. The difficulties have been represented by numbers 1 to 8, which correspond with numbers against each difficulty in Table 5.14. Letter 'X' is used to indicate the strategies used with each difficulty. The distribution of 'Xs' revealed how the strategies were combined and the overall T10's strategy. Colour coding is used to depict different combinations, with a column of Xs representing one combination (See Table 5.15).

Table 5.15 shows the patterns in strategies that T10 used to address learning difficulties associated with the two lessons. The first column shows the strategies that T10 used. These include: explanation; teacher doing calculation on the chalkboard; use of chart diagrams, examples or an analogy in explaining; and engaging students in role-play. The list indicates that the teacher attempted to use different strategies.

Another pattern involves the way in which the strategies were combined. Five different combinations could be identified from Table 5.15 by using colour coding. Clearly, of the five combinations, only one is a single-strategy combination (combination 2), where the teacher just used explanation. The rest are multiple-strategy combinations. Each of the combinations involves some explanation, which indicates that T10's teaching was centred on explaining.

From Table 5.15, I also note that some of the strategies were used with more combinations than others. For instance, the use of role-play appears only in one combination, while the use of explanation appears in all combinations. This seems to indicate that the teacher had preferred strategies. Reasons for the preference will be explored where I discuss the reasons the teacher chose those strategies.

5.6.6.3 T10's strategy combinations

I have already mentioned that T10 combined the strategies in different patterns and that colour coding has been used to identify similar patterns. For instance, pink represents a pattern where the teacher just explains. The combinations are identified as follows:

- Combination 1 – colour code red (frequency of one)
  - Teacher begins with explanation.
  - While explaining the teacher does the calculation on the board.
  - Let students calculate the final answer and let one mention it.
  - Tell the class the final answer.
- Combination 2 – colour code pink (frequency of three)
  - Teacher just goes on to explain.
- Combination 3 – colour code blue (frequency of two)
  - Teacher asks questions.
  - Teacher lets students attempt to answer.
  - Teacher uses leading questions as much as possible.
  - Teacher explains or tells the final answer.
- Combination 4 – colour code green (frequency of one)
  - Teacher begins explaining with aid of a chart diagram.
  - Teacher explains further using a specific example.
  - Teacher uses leading questions as much as possible.
  - Teacher tells final answer or explains.
- Combination 5 – colour code dark red (frequency of one)
  - Teacher begins with explanation.
  - Teacher engages students in role-play.
  - Teacher explains further using a chart.
  - Teacher uses leading questions to guide student thinking

To illustrate how T10 used the combinations of strategies, I present one extract from the PD 15 or 16 for each. The extracts were chosen because they are typical of how T10 used each combination.

Table 5.15: T10's combination of teaching strategies

Strategy	**Difficulty number as in Table 5.10**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Ask question(s)				X		X		
Teacher explains	X	X	X				X	X
Use analogy in form of role-play								X
Use chart diagram in explaining					X			X
Let another student attempt				X		X		
Teacher does calculation on the board	X							
Let students use calculator to find final answer and ask one to mention it	X							
Use specific example to explain					X			
Use leading questions				X	X	X		X
Tell the class the final answer or explain	X			X	X	X		

5.6.6.4 T10's use of combination 1 of his teaching strategies

During the interview I had with five students after T10's first lesson, one of these five showed that she had difficulties understanding relative abundances of isotopes. This surfaced when she was trying to explain what she had learnt from the lesson. The extract below from PD 15 shows this:

> **295 S5:** And how to calculate isotopes.
>
> **296 I:** How to calculate …
>
> **297 S5:** An isotope.
>
> **298 I:** Okay, can you give me an example just to have it very clear?
>
> **299 S5:** For example an isotope of chlorine. It has percent abundance of twenty-five and mass number of seventy-five *[Another student intervenes in vernacular to say she is ignorant]*.
>
> **230 I:** Let her say it.
>
> **231 S5:** And it has percent abundance of twenty-five and *[looks to other students while smiling, may be to seek approval]* mass number of thirty-seven.

In paragraph 295, S5 just said she had learnt how to calculate isotopes. I followed this up in paragraph 296 and she repeated the same thing. I probed further in paragraph 298 by requesting her to give me an example. In paragraph 299 and 231 S5 just tried to give the relative abundances, of course with some confusion of mass number and percentage abundance of chlorine in paragraph 299. She could not explain that the percentage abundances and the mass numbers of the isotopes are used to calculate the average atomic mass. I then went back to the relevant portion of PD 15 to get an idea of how T10 helped students understand calculation of average masses. He used combination one of strategies. The extract below illustrates how he did this.

In line with combination 1, after writing the question, T10 began with an explanation involving interpreting the question in paragraph 265. Then T10 explained further how to tackle the question, while writing the calculation on the chalkboard (step 2 of combination 1). He then asked students to work out the final answer and S25 mentioned the answer in paragraph 266, which is the third step in combination 1. Finally, in paragraph 267 T10 mentioned the answer to the class and explained further. With this combination of strategies, the teacher did not make an attempt to explain what some of the terms meant like average atomic mass and percentage abundances. Nor did he give students a chance to think about and explain the terms. It might be that this was due to time that was running out and the teacher alluded to time (beginning of paragraph 265).

> **265 T10:** We are running short of time *[Teacher writes the following statement on the board: "Calculate the average relative masses of the following isotopes whose percentages are shown in brackets* $^{35}_{17}Cl$ *(75%) and* $^{37}_{17}Cl$ *(25%)"].* The elements having the same atomic number but different mass numbers, for example, that is chlorine. Seventeen, that is an atomic number, but we have chlorine thirty-five, chlorine thirty-seven. Calculate the atomic average masses of the following isotopes whose percentages are shown in brackets. So, chlorine thirty-seven is seventy-five percent and chlorine thirty-five is seventy-five percent and seven is twenty-five percent. Now, say find the mean, which is the average of the two. Simply, you write thirty five times seventy-five, which is percent *[Divides 75 by 100 in the process]* plus thirty-seven times twenty-five percent *[Divides 25 by 100 in the process. The final expression written on the board is 35 x 75/100 + 37 x 25/100].* …. Can you work that one out?

> Can you work that one out? Let's find that one out. Can you do that individually *[Says these words as students are talking to one another]*? Can you work that one out? What is the average of the two?
>
> **266 S25:** Thirty-five point five.
>
> **267 T10:** Thirty-five point five. So chlorine, if you did as she has done, it will be thirty five times zero point seven five plus thirty seven times zero point two five *[While writing: "35 x 0.75 + 37 x 0.25"]* and if you worked very carefully, you should come with thirty five point five *[Writes: "35.5"].*

T10's use of combination 1 supports the observation that physics teaching seems to put too much emphasis on solving equations and calculating numbers without securing a qualitative understanding of the key concepts (Schecker, 1993). It is possible that more students may not have understood what was going on. The way the teacher proceeded did not reflect the fact that calculations in general are difficult for students (Malawi National Examinations Board, 2006; Rawy, 1999). Actually, Geddis *et al.* (1993) found that Canadian students faced difficulties with computation of average atomic masses. It could be that T10 was not aware of such a difficulty or simply decided to ignore it.

5.6.6.5 T10's use of combination 2 of his teaching strategies

Combination 2 involves just explaining. I illustrate the use of this combination with the difficulty where a student did not understand the meaning of stability. The student wanted to know the meaning of stability. In the extract below, taken from PD 16, the teacher used combination 2 by just going straight into explaining (paragraph 237 of extract below). The teacher did not attempt to seek other students' views.

> **236 S11:** Sorry sir, I want to know the meaning of nuclear stability.
>
> **237 T10:** Ah, nuclear stability, nuclear stability simply means the neutrons and the protons can be held together, but as the number increases *[Points to the nucleus on the chart]* the nucleus can no longer hold. That's why I say there is a limit, right? There is a limit. As we saw that, we all agreed to say if all girls went into the circle, then the circle would no longer be able to hold, right? We've been saying it can break because the limit has reached. Likewise, if the limit has been reached, these can no longer keep these together *[Points to the circle representing the boundary of the*

> *nucleus on the chart]*. So nuclear stability simply means the protons, neutrons are held together.

Of course the teacher's explanation does reveal that the teacher himself also did not understand what it means to say a nucleus is stable or not. T10 gives the impression that only stable nuclei stay intact and that when the 'limit' in the contents of the nucleus has been reached, then the nucleus can no longer hold together. This is not scientifically right as there are nuclei described as unstable, yet they can stay intact for long periods of time. It could be that the teacher's deficiencies in subject matter knowledge may have played a part in the choice of this strategy. This should be the case because subject matter knowledge makes a difference in how one teaches (Borko & Putnam, 1996; Even, 1990).

5.6.6.6 T10's use of combination 3 of his teaching strategies

Combination 3 includes the following: teacher asks questions, teacher lets students attempt to answer, teacher uses leading questions as much as possible and teacher explains or tells the final answer. The extract below from PD 15 illustrates how T10 utilised this strategy with the difficulty on confusing protons, neutrons and electrons. In the extract, T10 asked students a question in paragraph 249 and then let students attempt to answer. S23 attempted to answer in paragraph 252 and confused electrons with protons and protons with neutrons. To try to address this difficulty, T10 utilised combination 3 of strategies. In paragraphs 253 he asked a question to which students were expected to respond and they did. Then he chose S24 to try to give the correct definition of an isotope. In paragraphs 257 to 260 the teacher used leading questions to help students understand further. In paragraph 261 the teacher explained further the meaning of an isotope with reference to hydrogen.

> **249 T10:** Isotopes. Now what is an isotope? Now who can define an isotope? Who can define an isotope? Yes
>
> **250 S23:** An isotope is an element …
>
> **251 T10:** So, we are talking of an element *[While writing "element" on the board]*.

252 S23: which have the same number of electrons, but different numbers of protons.

253 T10: Electrons? *[In a tone that showed disapproval]* Electrons, did I mention of an electron as part of the nucleus of an atom?

254 Some students: No. *[Some students continue to raise their hands]*

255 T10: Yes *[Points to another girl student]*

256 S24: It's an element, which has got same number of atomic mass, but different number of neutrons.

257 T10: Simply, as an element having same atomic number *[While writing the words on the board]*, but what's the difference?

258 All students: Number of neutrons.

259 T10: But with different mass what?

260 Few students: Number

261 T10: Mass number. So we are saying isotope, it's the same element for hydrogen one hydrogen two. That we should see same number of atomic one, one, one, but the mass number is different. The mass number is different.

From the above extract, I argue that T10's use of combination 3 was aimed at directing students to the accepted definition. The use of questions did not include eliciting students' thinking with the aim of following up on it. The teacher's response to S23 in paragraph 253 is evidence for this. If there were intentions to follow up on student thinking, T10 should have given S23 a chance to explain.

5.6.6.7 T10's use of combination 4 of his teaching strategies

With this combination of strategies, the teacher begins explaining with aid of a chart diagram. Then the teacher explains further using a specific example.

The teacher uses leading questions as much as possible. Finally, the teacher offers an explanation or just tells the final answer. I illustrate how T10 used this combination with difficulty on standard notation. During my interviews with students, it surfaced that students had not understood the use of notations. Then I revisited the relevant PD to find out how the teacher had tried to help the students understand. The extract below shows how T10 used combination 4. In paragraph 178, T10 began explaining with the aid of a chart (periodic table). He then used a specific example (lithium) to explain how to get information about number of protons and neutrons. He further asked a leading question to help students give the atomic number. Then in paragraphs 181 to 183, the teacher gave the standard notation for lithium. Through a series of leading questions, the teacher explained to students the information contained in the notation (paragraphs 184 – 195). Finally, in paragraph 196, the teacher explained the meaning of atomic number and mass number.

> **178 T10:** Now, what is, what do we mean by saying standard notation using the periodic table? Now, as we have looked at this one, the periodic table shows, the two things that we have, we are talking of the nucleus of an atom, the protons, and the neutrons. These can also be reflected using the periodic table. These are reflected on the periodic table. For example we have lithium *[Writes Li on the board]*. Lithium, if we are looking at, this is lithium *[Points to Li on the second chart]*; we have taken this as an example where the protons and neurons are reflected on the periodic table. We have seven *[Writes 7as a superscript on the left of Li]*, we have, is it what?
>
> **179 Majority of students:** Three.
>
> **180 T10:** Three. *[Writes 3 as subscript on the left of Li to get the diagram shown below:]*
>
> **181** 7
> **182** Li
> **183** 3
>
> **184 T10:** Now, this three represents what *[Points to three against Li]*? Yes.
>
> **185 S10:** Proton *[Rather faintly]*
>
> **186 T10:** Yes, proton. So this number represents the number of protons. But what about this one? What is 7 telling us? Yes.
>
> **187 S11:** Neutrons.
>
> **188 T10:** Neutrons? (3) Yah, it's not very far.
>
> **189 S12:** Mass number.
>
> **190 T10:** Mass. What is meant by mass number? (6)
>
> **191 S13:** Number of nucleus and …*[Scratches his head]*
>
> **192 T10:** What?
>
> **193 S14:** Number of nucleus and protons equals mass number *[Scratches his head]*
>
> **194 T10:** Uh. Nucleus?
>
> **195 S14:** Neutrons.
>
> **196 T10:** Neutrons, so the sum of the neutrons and protons. If you add the protons and the neutrons, it is going to give you this top number and these

> numbers have their special names. This is, so we have mass, mass number and atomic, atomic number *[While writing these two terms on the board]* Mass number and also atomic number. Mass number is sum of the protons and the neutrons, while atomic number is the number of protons only. Questions before we proceed (4). It's by writing a, z *[then quickly puts X to get the following diagramme]*

This strategy put T10 as the main player in this segment of the lesson. The teacher did most of the talking and directing, while students were engaged in giving one-word answers, the result of use of leading questions.

5.6.6.8 T10's use of combination 5 of his teaching strategies

With this combination the teacher begins with explanation. He then engages students in role-play. The teacher then explains further using a chart. The teacher used this combination to explain the concept of limit for number of protons and electrons in the nucleus. At some point one student alluded to the fact that this concept was not very clear, which indicates that they found it difficult. I then examined the relevant portion of PD 16 to find out how T10 had explained this concept to students. The extract below shows how this was achieved using combination 5. In paragraph 206, after explaining what the lesson would focus on, T10 brought in role-play where four girls formed a circle by holding each other hand-to-hand and also encouraged as many other girls as possible to go into the circle. Through some leading questions, T10 led students to the desired conclusion: that the circle would break because of force (paragraphs 207 to 213) as more girls squeezed into it. In paragraph 214 the teacher explained further using a chart mounted on the board and connected the girls' activity with what happens in the nucleus.

> **206 T10:** …Volunteers girls; any four girls in front. Four girls volunteers four girls. Four girls. … Can you go inside the circle, go inside. Aha, another one. Girls, please go. Join, join, join. Girls, girls please go in join girls. What would happen to the circle, excuse me, what would happen to the circle if all girls went inside?
>
> **207 S1:** It will break.
>
> **208 T10:** … Why should it break? Indeed, if all girls went inside while the four kept on holding their hands, it indeed would break, why? …
>
> **209 S2:** Because the circle is overloaded.

210 T10: Overloaded

211 S3: Because there is a lot of pressure in that circle.

212 T10: Pressure. Yes

213 S4: Because of the great force which has existed inside.

214 T10: It is because of the force, right? Can you go back *[Meanwhile, the teacher mounts a chart on the board. The chart shows a big circle containing many tiny circles. Some of the tiny circles carry a red x inside them, while others are blank. Outside the big circle are five red arrows pointing to the surface of the circle from].* We have said, from the demonstrations made by girls, the girls kept on going into the circle, but we have all agreed that I if all went inside, the circle would break because of force ... Likewise, the nucleus of an atom where we looked at saying the neutrons and protons are inside.

There is no doubt that the students enjoyed the role-play activity, as they kept on talking and laughing and the volunteers did so enthusiastically. The students also easily reached the conclusion that the circle would break at some point, indicating that there was a 'limit' in the number of girls that could go into the circle. This observation agrees with the assertion that use of analogies facilitates conceptual understanding and generate a sense of interest (Treagust, Harrison, & Venville, 1998). However, the teacher did not engage students in analysing the differences in the analogy and the scientific view of forces that act in the nucleus. Such an analysis would aid understanding. It might be that the teacher may not have known that students do not always establish the relationship between an analogy and the scientific concept (Greca & Moreira, 2000).

5.6.4 Reasons given for the strategies used to address difficulties

T10 used a number of strategies in his teaching. During the pre-observation interviews, post-observation interviews and discussion of the video recordings, the teacher was asked to explain the use of certain strategies. This sub-section identifies the reasons associated with teaching strategies that T10 used to address learning difficulties. A similar procedure as in sub-section 5.3.4 was used to identify the reasons. Appendix 21 contains codes that identify portions of the relevant transcripts where the teacher gives the reasons. Such codes have names that start with 'Reason'. Using the code manager of *Atlas.ti 5.2,* it was possible to double click on a code to retrieve the relevant quotations. I could then read through the quotations and note the reasons given for a particular strategy. By reading such quotations closely it was also possible to infer reasons that the teacher did not mention explicitly, the implied reasons. Table 5.16 gives the reasons identified for T10's use of the teaching strategies. The implied reasons were also obtained in a similar way as described in sub-section 5.3.4. Again, since the implied reasons are gathered from the data, I will not distinguish them in discussing Table 5.16. In addition, I will not focus on individual reasons, but the general patterns and themes that emerge.

The reasons captured in Table 5.16 reveal a number of themes pertaining to use of strategies. One theme that emerges is that of encouraging participation. This theme was associated with use of the following strategies: use of questions, use of role-play and asking students to do a final calculation. This theme agrees with the assertion that learning is facilitated when students engage in purposeful dialog with the teacher and/or with groups of their peers (Jones & Baker, 2005). The use of role-play did engage students in purposeful dialogue as it enabled the teacher to ask questions that required students to predict what would happen and to explain. However, the use of questions mainly engaged students in giving short answers and this might have reduced the effectiveness of the lesson.

Another theme that emerges is that of checking if students were following the lesson. The strategy that supported this theme is the use of questions. Actually, this theme is related to assessment of student achievement and evaluation of effectiveness of the lesson. Geelan (2003) argues that monitoring learning and providing feedback is one aspect of teacher expertise. Thus, this is an important theme. It should be pointed out though that the sort of questions asked does matter. T10 mainly asked questions requiring recall answers. Such questions do not enable students to explain their thinking. Geelan (2003) further contends that giving students opportunities to explain their understandings to the teacher and other students is a valuable part of teaching strategies. The extract below from PD 16 illustrates how T10 typically used questions for evaluation and most of the questions used solicit short responses. After teaching about guidelines for stability, T10 gave students a task of deciding if certain nuclei were stable. This was one way of monitoring if students could apply the rules. The extract given below shows students could just mention the rule number without explaining (paragraphs 293, 295 and 297).

> **292 T10:** Rule number two, which rule did we use?
>
> 293 S20: One.
>
> **294 T10:** Yes, what rule? *[Points to a male student]*
>
> **295 S21:** Rule number four.
>
> **296 T10:** Rule number four?
>
> **297 S22:** Sir, rule number one *[Another student echoes "rule number 1". Other students just murmur, perhaps unsure of what to say]*
>
> **298 T10:** Rule number four, right?
>
> **299 Minority of students:** Yes.

A third theme from Table 5.16 is that of conveying information. The strategies that contributed to this theme are: explanation, use of chart diagram and use of chalkboard. As already pointed out, this theme is in line with the traditional approach to physics teaching which puts emphasis on content transmission (Flores et al., 2000). The extract below shows how T10 used explanation to convey information about nuclear stability.

> **214 T10:** We have said, from the demonstrations made by girls, the girls kept on going into the circle, but we have all agreed that if all went inside, the circle would break because of force. …. Likewise, the nucleus of an atom where we looked at saying the neutrons and protons are inside. That is, these arrows indicate *[Pointing to the arrows outside the big circle]* that there is a force holding these inside particles: the neutrons and the protons. They are held together. This is indicating there is force *[Pointing to the arrows]*, which is holding these ah these protons and nucleus together *[Pointing to circle contents]*. They are held together; this is indicating there is a force.

A fourth theme that emerged is that of using a strategy because it makes methodological sense. This theme was supported by the use of role-play. Statements that the teacher made like to "make the lesson child-centred", "to vary the methods", "introduce the lesson" and to help students discover what would happen". This is important as it can enhance the quality of a teacher's instruction. However, on its own this theme would become redundant, as the goal of teaching should be to facilitate learning. The PSS (Ministry of Education Science and Technology, 2001) mentions that the aim of the senior secondary school physical science course is to enable "learners acquire a systematic body of scientific knowledge, skills and attitudes" (page vii). T10 mentioned that the use of the analogy in a form of role-play was also to facilitate learning of the fact that there is a 'limit' in the number of protons and neutrons that a nucleus can hold. This use of a strategy because it makes sense methodologically and at the same time because it facilitates learning of some concepts is an important aspect of PCK (Shulman, 1986) and it enhances teaching.

A fifth and final theme that I could identify from the teacher's reasons is that of helping students relate ideas, which I fee is connected to understanding. Strategies that were used for this reason are: use of analogy in form of role-play, use of chart diagrams and use of the chalkboard. This is an important aspect of physics learning. T10 engaged students in answering questions that encouraged thinking and understanding with the role-play activity. He asked students to predict and to explain what would happen to the circle. However, most part of lessons emphasised facts and principles. Such an emphasis was at the expense of the goal of helping students acquire skills and attitudes as required in the PSS. Of course it could be argued that the two lessons observed may not have presented opportunities for developing skills and attitudes. Such opportunities arose; for instance, one student asked how the guidelines were developed. Such a question provided a chance to talk about how scientists work. The teacher simply answered they were agreed upon, without indicating elaborating how scientists use evidence to make decisions.

Table 5.16: Reasons for T10's use of identified teaching strategies

Teaching strategy	**T10's reasons for using it**	**Implied reasons**
Use of question(s)	To check if students are able to do what is asked To check if students are following To get feedback	To encourage participation
Teacher explanation	To summarise main ideas of a lesson	To convey information
Use analogy in form of role-play	To allow students discover what would happen To vary the methods To introduce the lesson To encourage the girls To show that there is a limit to which binding force can hold As one way of making the lesson child-centred	
Use chart diagram in explaining	To enable students follow the lesson To emphasise certain ideas To help students relate ideas	
Teacher using the chalkboard	Not probed	For students to see how to do it To capture what is said To convey information
Let students use calculator to find final answer and ask one to mention it	Not probed	To encourage participation
Use specific examples to explain	To see if students could apply general information As a way of consolidating what has been learnt	

5.7 Conclusion

In this chapter, I have presented and discussed the strategies that each of the case teachers used to address learning difficulties. All the case teachers used a multi-strategy approach to the difficulties. By multi-strategy I mean that for a difficulty that presented itself, a case teacher could use a combination of more than one strategy to help deal with the difficulty. I have also explored the reasons that the case teachers gave for using certain strategies and discussed them in terms of themes that emerged. The themes that emphasised content were prevalent, while I did not identify any theme that emphasised skills and attitudes.

In the next chapter, I partly draw on results from this chapter and Chapter 4 and PDs to discuss the nature of the case teachers' pedagogical content knowledge.

CHAPTER 6

CASE TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE

6.1 Introduction

In this chapter I answer the last question of my research: "What can be learnt from the study of teaching strategies about the nature of some Malawian PSTs' PCK with respect to nuclear physics?" To answer this question, I use questions adapted from the statements that Loughran et al. (2004) used in constructing content representations as a way of capturing and portraying the participating teachers' PCK. Loughran et al. (2004) used the statements shown below.

> 1. What you intend the students to learn about this idea.
> 2. Why is it important for students to know this?
> 3. What else you know about this idea (that you do not intend students to know yet)?
> 4. Difficulties/limitations connected with teaching this idea.
> 5. Knowledge about students' thinking which influences your teaching of this idea.
> 6. Other factors that influence your teaching of this idea.
> 7. Teaching procedures (and particular reasons for using these to engage with this idea).
> 8. Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).
>
> (Page 376)

Statements two and three were deemed inapplicable to this study, as there was no data where they could be applied. The rest were converted into questions that were used to interrogate the data. The questions are shown below:

1. From the content covered, what would be the main ideas that the teachers intended the students to learn?
2. What do the results on difficulties reveal about the teachers' knowledge of difficulties associated with learning of those ideas?

3. What knowledge about students' thinking may have influenced the choice of teaching strategies?
4. What other factors may have influenced the teachers' choice of teaching strategies?
5. What do results on teaching strategies reveal about the teachers' knowledge of strategies that could aid understanding of those main ideas?
6. How did the teachers ascertain students' understanding?

The above questions have been discussed in separate sections. The only exceptions are questions 3 and 4, which have been discussed in one section because they both focus on choice of teaching strategies.

6.2 Main ideas of the lessons

6.2.1 How the main ideas were obtained

The content and concepts covered in the lessons were examined in order to come up with main ideas the teachers may have intended the students to learn. The content covered is the same as presented in Chapter 5. All the concepts that featured in the lessons were coded and this enabled me to use the quotation count output of *Atlas.ti 5.2* to identify the concepts covered in the lessons. A quotation count shows the list of codes in each PD and the number of quotations to which a particular code applies. Codes of concepts, associated with more than five quotations, were examined to come up with main ideas. Where a main idea could not be easily identified, I read through the relevant portions of the PDs to get a sense of that main idea. For instance, if codes 'atom', 'protons' and 'neutron' appeared most frequently, I would speculate that the teacher wanted students to learn that an atom is believed to have a structure. I could then read the relevant portions of the transcripts to ascertain this. I hoped that this would shed light on the teachers' subject matter knowledge. I present the results in tables. I also include, in those tables, some evidence for the decision to call an idea a main idea.

6.2.2 Main ideas covered in T25's lessons

Table 6.1 shows the main ideas covered in T25's lessons. The first column shows the content covered (from Table 5.2), the second column shows the main concepts and the last column shows what I think could be the main ideas of T25's lessons reflected in the content and the concepts. The table shows that the first lesson centred on four main ideas:

1. Some atoms can emit particles and/or radiation.
2. There are three types of radiation.
3. The three types of radiation have different characteristics.
4. The three types of radiation can ionise matter.

Table 6.1 also shows that the second lesson centred on two main ideas:

1. As atoms emit particles and/or radiation, new nuclei are formed.
2. Scientists use symbols and equations to represent the emission of particles and/or radiation.

Table 6.1: Main ideas identified from T25's lessons

Content covered	Main concepts*	Main ideas
Lesson 1, PD 10		
Types: alpha, beta, gamma Alpha particle as helium nucleus Beta particle as an electron Gamma radiation as electromagnetic wave Charge of each type Calculating charge and mass of alpha particle Notations for each type Ionising effect of each type Penetrating power Deflection in electric fields Deflection in magnetic fields	Atom (7) Atomic mass (6) Electric field (10) Electron (18) Helium (13) Ion (12) Magnetic field (10) Negative charge (8) Neutron (10) Nucleus (13) Penetrating power (8) Positive charge (15) Proton (12) Alpha radiation (21) Beta radiation (13)	Some atoms can emit particles and/or radiation There are three types of radiation The three types of radiation have different characteristics The three types of radiation can ionise matter

	Radioactive emission (6) Gamma radiation (6)	
Lesson 2, PD 11		
Definition of radioactivity Process of each type of decay Parent and daughter nuclei Changes in atomic and mass numbers during each decay General equations for alpha, beta and gamma decay Calculating missing values in given nuclear equations Equation for decay of a neutron into a proton and an electron	Atomic mass (25) Atomic number (27) Daughter nucleus (17) Electron (16) Isotope (6) Neutron (18) Nuclear equation (9) Nucleus (21) Parent nucleus (10) Proton (17) Alpha radiation (29) Beta radiation (23) Gamma radiation (6)	As atoms emit particles and/or radiation, new nuclei are formed Scientists use symbols and equations to represent the emission of particles and/or equations

** The numbers in brackets show the number of quotations associated with the concept in the PD.*

Comparing the main ideas obtained from the content covered with what T25 said he would cover during the pre-observation interview revealed that the teacher was aware of the main ideas of his first lesson. The following extract from PD 10 shows this. In paragraph 20 T25 clearly mentions the focus of the lesson: types of radiation, radiation emitted by radioactive substances and behaviour of radiation (which is an aspect of characteristics). The only one not mentioned directly is the idea of radiation being able to ionise matter, but this he seems to have included in the phrase ‘focus on describing the types of radiation’.

> **19 I:** would like to find out: could you please enlighten me on what you are going to do today?
>
> **20 T25:** Okay, thank you Mr. Lungu. Ah ah in my today’s lesson basically what I want to do is to discuss with the students ah the types of radiations. Of course, before that students will be reminded of what they did previously or what we discussed previously. But for today’s lesson it will mainly focus on describing the types of radiation emitted by radioactive substances. In which case, what I will focus on is alpha radiation, also talk

> about beta radiation, gamma radiation and then finally what I want to discuss with the students is the behaviour of these types of radiations in an electric field and in a magnetic field.

For the second lesson (PD 11), T25 had this to say about what he would cover:

> **20 T25:** Ah, today's lesson will centre on radioactive decay. You remember yesterday we just looked at characteristics of ah radioactive particles, that is alpha particle, beta particle and gamma rays. So today we just want to proceed and look at radioactive decay. In this case what we will do is look at nuclear reactions together with nuclear equations. We will look at ah how exactly the, the alpha decay, the beta decay ah occur. And ah in this case we will centre much on looking at ah radioactive decay which finally results in formation of ah a different ah isotope altogether.

Again, this extract shows that T25 knew the ideas the lesson would centre on. He clearly mentioned that the lesson would cover "nuclear reactions together with nuclear equations". He also emphasised the formation of different isotopes. These agree with what I obtained as main ideas from the content actually covered. For the lessons observed, I conclude that T25 knew the main ideas he would cover.

6.2.3 Main ideas covered in T12's lessons

Table 6.2 shows the main ideas covered in T12's lessons. The first column shows the content covered (from Table 5.6), the second column the main concepts and the last column what I think could be the main ideas of T12's lessons reflected in the content and the concepts. The table shows that the first lesson centred on three main ideas:

1. An atom has a structure.
2. An atom is made up of different particles.
3. Some atoms have isotopes.

Table 6.2 also shows that three main ideas were covered in the second lesson:

1. There are three types of radiation.
2. The three types of radiation have different characteristics.
3. Some nuclei undergo decay because they are unstable.

Table 6.2: Main ideas identified from T12's lessons

Content covered	Main concepts*	Main ideas
Lesson 1, PD 12		
Definition of an atom Characteristics of protons, neutrons and electrons Structure of the atom Concept of 'nucleus' Atomic and mass number Electron shells and configuration Definition of isotopes Examples of isotopes Calculating average atomic mass	Atom (34) Atomic mass (14) Atomic number (17) Electron (23) Isotope (7) Mass (10) Neutron (14) Nucleus (7) Periodic table (14) Proton (30)	An atom has a structure An atom is made up of different particles Some atoms have isotopes
Lesson 2, PD 13		
Compare radioactivity with nuclear change Definitions: radioisotopes, radioactivity, radioactive decay and unstable nuclei The three types of radiation Detection of radioactivity Penetrating power of each type Deflection in a magnetic field	Atom (15) Chemical change (7) Magnetic field (7) Negative charge (2) Alpha radiation (10) Beta radiation (9) Gamma radiation (11) Radioactivity (15)	There are three types of radiation The three types of radiation have different characteristics Some nuclei undergo decay because they are unstable

** The numbers in brackets show the number of quotations associated with the concept in the PD.*

Comparing the main ideas obtained from the lessons and what T12 said he would cover during the pre-observation interviews revealed that this case teacher could not distinguish main ideas from ideas meant to just support learning of the main ideas. The excerpt below taken from PD 12 shows this. In paragraph 19, I asked T12 about the first lesson. In paragraph 20, he answered in brief. When I asked him directly to tell me the main ideas (paragraph 22), he tried to run through all ideas, instead of just the main ones.

> **19 I:** Now to begin with tell me about today's lesson.
>
> **20 T12:** Ah uh, I will teach nuclear physics, basically radioactivity. That is the topic I'm going to teach this morning.
>
> **21 I:** And what main ideas are you going to cover?
>
> **22 T12:** Ahhh, I will start ah with the uhh the structure of an atom. I will explain to them that an atom has got nucleus and that on the nucleus you have got protons that are positively charged and also you have got neutrons, these particles have got no charge and going out you have got electron shells or energy levels, that's where you can find electrons. And I will also ah give them the nuclear notation, how to write an element. This is basically to allow them understand better ah the concept of ah the concept of an atom. Then after that I will talk about isotopes, ah these are atoms of the same element having the same atomic number but they have different mass number. I will explain to them that concept and after that, in brief, I will ah ah give some examples of elements that are isotopes.
>
> **I:** Okay, okay.

T12 did not distinguish main ideas from those just meant to support the learning of the main ones. This might have been the case because he could not distinguish between the two. I conclude that for these two lessons, T12 could not identify the main ideas. This is supported further by his tendency to take considerable time on ideas that are covered in the chemistry portions of the PSS, like the concept of electron configuration, energy levels and chemical change.

6.2.4 Main ideas covered in T23's lessons

Table 6.3 shows the main ideas covered in T23's lessons. The first column shows the content covered (from Table 5.10), the second column shows the main concepts and the last column shows what I think could be the main ideas of T23's lessons reflected in the content and the concepts. The table shows that the first lesson centred on two main ideas:

1. An atom has a structure.
2. An atom is made up of different particles.

Table 6.3 also shows that two main ideas were covered in second lesson:

1. Some atoms have isotopes.
2. Isotopes of an element have different physical properties.

Table 6.3: Main ideas identified from T23's lessons

Content covered	Main concepts*	Main ideas
Lesson 1, PD 14		
Definition of an atom Model of an atom Parts of an atom: shells, nucleus Three particles of an atom: protons, neutrons, electrons Properties of protons, neutrons and electrons Atomic and mass number Notation for representing atoms	Atom (14) Atomic mass (14) Atomic number (12) Electron (14) Mass (24) Matter (5) Neutron (15) Nucleus (16) Proton (17)	An atom has a structure An atom is made up of different particles
Lesson 2, PD 17		
Definition of an isotope Examples of isotopes Average atomic mass of isotopes Density, melting points and boiling point of isotopes	Atomic mass (21) Atomic number (17) Electron (5) Isotope (10) Neutron (15) Physical properties** (5) Proton (9)	Some atoms have isotopes Isotopes of an element have different physical properties

* The numbers in brackets show the number of quotations associated with the concept in the PD.
** Physical properties refers to density, boiling point or melting point

I compared the main ideas identified in Table 6.3 with what T23 said he would cover in the lessons. The comparison revealed that this teacher tended to focus on the details, not the main ideas. The extract below from PD 14 shows this (paragraph 20). When I directly asked him to name the main ideas (paragraph 22), the teacher still focused on the details of what students should be able to do at the end of the lesson (objectives) (paragraph 23).

> **19 I:** Now tell me about today's lesson.
>
> **20 T23:** Yah, today's lesson it is under on the same topic of nuclear physics. Then since it's, it's an, it's the first time to teach it under these

> students that are that we are having today, that means it will, it will look at the, ah, the background of the topic in the sense that we are going to look at the, ah the atom, and we will look at the, the particles of the atom, which of course comprises of ah the protons, the electrons as well as the, ah, the, ah, of course the, the nucleus, but the emphasis will be on the nucleus and the, and I mean neutrons and the protons which are in the nucleus, hence, nuclear physics.
>
> **21 I:** Okay.
>
> **22 T23:** Yes.
>
> **22: I:** And what main ideas are you going to cover in the lesson?
>
> **23 T:** Yah, the major ideas, rather, am trying to, want to, by the end of that lesson ah that students should be able to, to name those three particles of an atom, specifically the nuclear parts of the particles of an atom. And again, I want them to be able to give ah the properties of ah those, those subatomic ah particles of an atom.

For the second lesson T23 also tended to dwell on the objectives, not the main ideas, as the excerpt below from PD 17 shows in paragraph 22.

> **19 I:** Now tell me about today's lesson.
>
> **20 T23:** Okay, today's lesson, ah I'm going to discuss with them on the isotopes.
>
> **21 I:** Uh.
>
> **22 T23:** And the major objectives for this lesson is, to be achieved rather, is I want them by the end of the lesson is to be able to define the word ah isotope, then to give examples of isotopes, as well as to calculate the relative atomic mass of isotopes.

It would seem T23 did not think about his lessons in terms of main ideas that would be covered. This could explain the inclusion of the idea on different physical properties for isotopes of an element, which is not covered by the objectives that the teacher mentioned. Actually, this idea reveals that the teacher held the conception that isotopes of the same element occur in different substances. This is different from the scientific view that an element is a mixture of its isotopes (Giancoli, 1998).

6.2.5 Main ideas covered in T10's lessons

Table 6.4 shows the main ideas covered in T10's lessons. The first column shows the content covered (from Table 5.14), the second column the main concepts and the last column what I think could be the main ideas of T10's lessons reflected in the content and the concepts. The table shows that main ideas of the first lesson were:

1. A nucleus of an atom is made of particles.
2. Some atoms have isotopes.

Table 6.4 also shows that the second lesson centred on the following two ideas:

1. Some nuclei are stable; others are not.
2. Unstable nuclei break down into smaller nuclei.

Table 6.4: Main ideas identified from T10's lessons

Content covered	**Main concepts***	**Main ideas**
Lesson 1, PD 15		
Definition of an atom Constituent particles of atomic nuclei: protons and neutrons Composition of nuclei in standard notation Mass and atomic number Definition of isotopes Average masses of isotopes	Atom (11) Atomic mass (9) Atomic number (7) Neutron (9) Nucleus (7) Proton (8)	A nucleus of an atom is made of particles Some atoms have isotopes
Lesson 2, PD 16		
Nuclear binding force Nuclear stability Parent and daughter nuclei Guidelines for stability Neutron: proton ratio	Binding force (7) Nuclear stability guidelines (9) Neutron (12) Nucleus (10) Proton (13) Stability (15)	Some nuclei are stable; others are not Unstable nuclei break down into smaller nuclei

* The numbers in brackets show the number of quotations associated with the concept in the PD.

When I compared the main ideas identified in Table 6.4 with what T10 said he would cover in the lessons, I concluded that T10 did not think in terms of main ideas of these two lessons. The extract below from PD 15 illustrates this tendency. In paragraph 19, the teacher does not mention the sort of ideas about the nucleus that he would be covering. When I probed further and directly about the main ideas, the teacher still did not mention them. He just alluded to the content (constituent particles, standard notation and isotopes) without mentioning the main idea the content would help to develop.

> **19 I:** Now to begin with, what is today's lesson about?
>
> **20 T10:** Ah, today's lesson is about nuclear physics. Ah, we will be looking, centring our concern on the, the atomic nuclear particle bit.
>
> **21 I:** Okay, what main ideas are you going to cover?
>
> **22 T10:** To cover, ah I hope to cover the constituent particles of the atomic nuclei, and also express composition of particular nuclei in standard notation, as well as describe isotopes as atoms of the same elements with different mass numbers due to different numbers of neutrons in their nuclei.
>
> **23 I:** Okay.
>
> **24 T10:** Those are the things that I feel to cover. Ah, time permitting I may as well do some an example, ah, calculation of isotopes in terms of relative atomic masses

6.3 The teachers' knowledge about learning difficulties

6.3.1 Approach to the section

Learning difficulties have already been covered, in considerable depth, in Chapter 4. In this section I will dwell on the patterns that were identified in section 4.4 and what I feel those patterns reveal about the teachers' knowledge of difficulties associated with the lessons observed.

The patterns that were identified in section 4.4, pertaining to learning difficulties, were as follows:

1. The observed difficulties are far more than the anticipated ones.
2. A majority of the anticipated difficulties were also observed in the lessons or during student interviews.
3. Some of the anticipated or observed difficulties were more prevalent than others.

I discuss the first pattern only in the sub-section below because it has implications for teacher knowledge of difficulties.

6.3.2 Ratio of anticipated to observed difficulties

The lessons for the different case teachers were of different lengths. Thus, to get an idea of who anticipated more of the observed difficulties, I have calculated the ratio of anticipated to observed difficulties from results given in Table 4.9. These ratios are shown in Table 6.5 below. The table shows that the overall ratio of anticipated to observed difficulties was 0.168, which is 0.2 to one decimal place. What this means is that the case teachers mentioned very few of the possible difficulties associated with the lessons. Therefore, it seems reasonable to postulate that the case teachers had low ability to anticipate difficulties for the lessons observed. Table 6.4 also shows that teacher qualification did seem to have an effect on ability to anticipate difficulties for the lessons observed. For instance, T10 was under-qualified and he could not anticipate any difficulty, giving a ratio of 0.000. During the pre-observation interviews T10 made it very clear that he could only comment on difficulties after the lesson. Also T12 (with a BEd) was more qualified than T23 (with a Dip. Ed.), and his ratio is also higher than that of T23. However, T25 breaks the pattern in that he was more qualified (with a BEd) than T23, yet T23's ratio is higher. This just shows that the situation is more complex as other factors like nature of the content covered may have an influence.

Table 6.5: Ratios of anticipated to observed difficulties for each teacher

Teacher	**Ratios of anticipated to observed difficulties**		
	Lesson 1	**Lesson 2**	**Average ratio**
T25	0:7	1:6	0.077
T12*	3:12		0.250
T23	2:4	1:7	0.182
T10	0:3	0:4	0.000
Overall average ratio of 0.168			

* For this teacher, only one pre-observation interview was done, so the ratio of 3:12 is for both lessons

6.4 Factors that influenced choice of strategies

6.4.1 How the factors were determined

In chapter 5, I discussed the reasons the case teachers gave for the strategies they adopted. Some themes were identified from those reasons. In this subsection, I analyse these themes in order to gain insight into the factors that might have influenced choice of related strategies. It is hoped that such an analysis could provide answers to the questions "*What knowledge about students' thinking may have influenced the choice of teaching strategies?*" and "*What other factors may have influenced the teachers' choice of teaching strategies?*" To facilitate this analysis, I present Table 6.6 below. The table shows the themes that emerged from the reasons given by the teachers for strategies, the teacher(s) to whom a particular theme applied and interpretations regarding possible factors that may have influenced choice of strategies.

To ensure that my interpretations in Table 6.6 are credible and dependable, I went back to the PDs and read through the relevant sections (especially the post-observation interview and video discussion transcripts) where a case teacher and I discussed the strategies used. For instance, in Table 6.6, I have identified two beliefs that may have influenced the teachers' use of strategies that encouraged participation. One of the beliefs is that student involvement facilitates learning and the other is that students knew something, which meant they could contribute during the lesson. The excerpt below (from PD 12) was one of those used to support the interpretation that there was the belief that students' involvement facilitates learning. In this excerpt, T12 and I were discussing the use of questions to get students involved by attempting to answer those questions. In paragraph 122, the teacher explains that involvement facilitates learning, which is in agreement with my interpretation. This process of checking agreement of interpretations was done with all the interpretations in the third column of Table 6.6.

> **121 I:** Okay. In defining isotopes, you gave the students a chance to define the isotopes. Why didn't you just tell them?

122 T12: Uh, in, if you remember, in the first place I had asked them *"Do you know isotopes?"* some students said yes. So I wanted them to define or those who knew the definition to define ah it so that if there are mistakes or deviations, then we could actually rectify them. Actually I wanted to involve them because learning ah takes place well when you involve your students as much as possible.

Table 6.6: Factors that might have influenced choice of strategies

Theme from reasons for strategies	**Case teacher(s)**	**Factors that may have influenced choice of related strategies**
To encourage participation	T10, T23, T12	1. Belief that student involvement facilitates learning 2. Belief that students knew something, so could contribute
To check if students could follow the lesson	T10	3. Belief that a teacher should ensure students learn something
To convey information	T10, T12, T25	4. Belief that science teaching is about transmitting information 5. It was difficult to do experiments
The strategy made methodological sense	T10	6. Belief that some strategies are better for certain functions
To aid student understanding	T10, T23, T12, T25	7. This is one of science goals 8. Emphasis on facts and principles implies examinations influence
To help students identify problems/difficulties	T23	9. Belief that teaching should elicit the difficulties students have with ideas
To feedback if student input is true or not	T23	10. Students needed to know what is true, perhaps for examinations
To use common examples	T23	11. Familiar examples aid understanding
New things require teacher explanation	T23	12. Belief that students know very little about new topics

To help students easily remember information	T12	13. Belief that recalling information is part of learning the topic 14. Belief that certain strategies facilitate recall more effectively
To remind students about previous work	T25	15. Belief that science learning is about connecting ideas
To guide students to the accepted scientific view.	T25	16. Belief that the scientific view is more important than others 17. Teacher's urge to help students pass examinations

6.4.2 Knowledge about students' thinking

Table 6.6 shows three factors based on knowledge of students' thinking. These factors are: 2 (student knows something), 9 (students have difficulties with science ideas) and 12 (students know very little about new topics). Factor 2 applies to three of the four case teachers. It seems the teachers were aware that students knew something, which they could contribute to the lessons. However, the focus on contributing something to lessons seems to emphasise ideas that are scientifically acceptable. This is supported by the fact that only one case teacher (T23) alluded to the need to identify student difficulties (factor 9), which, according to him, included conceptions not consistent with science views. Thus, I conclude that student thinking in terms of ideas not consistent with those of science may have influenced T23's choice of strategies, but not the others. This conclusion is consistent with the observation earlier that the ratio of anticipated difficulties to those observed was very small.

T12 also mentions factor 12, which seemingly, contradicts factor 2. This apparent contradiction could indicate that T12 believed students know something for some portions of the lessons but not for others. This view contradicts the research findings that students construct ideas about natural phenomena (Redish, 2000).

6.4.3 Other factors that may have influenced choice of strategies

The factors in Table 6.6 could be classified as follows:

1. Teacher's beliefs about how learning is facilitated (factors 1, 6, 11 and 14).
2. Teacher's beliefs about science learning (factors 13 and 15)
3. A teacher's beliefs about science teaching (factors 3, 4, 7 and 9).
4. A teacher's beliefs about students (factors 2, 9 and 12).
5. A teacher's beliefs about the status of scientific knowledge (factor 16)
6. The demands of modes of assessment (factors 8, 10 and 17)
7. Nature of the lesson and requisite resources (factors 5 and 12)

These classes of factors influencing choice of strategies correspond with what the literature says. For instance, Borko and Putnam (1996) identify factors that shape teaching to be what teachers already know and believe about teaching, learning and learners. The fact that the factors are many confirms the complex and messy nature of science teaching (Geddis & Wood, 1997). Here I only discuss beliefs related to teaching science. An examination of the factors in Table 6.6 reveals that all the four case teachers were influenced by the view that science teaching should aid understanding, especially of facts and principles (factors 7 and 8). Then there is the view that science teaching is about conveying information, which influenced three of the four case teachers (factor 4). The rest apply to one teacher each, except the one on student participation. These views support the traditional view of physics teaching as transmission of content (Flores et al., 2000). Thus, I conclude that the case teachers were guided by beliefs consistent with the traditional view of physics teaching.

6.5 The case teachers' knowledge of teaching strategies

6.5.1 General teaching strategies

Appendix 21 shows all the codes pertaining to the teaching strategies employed in all the lessons. Table 6.7 below has been extracted from Appendix 21. This table only shows codes of strategies that were actually used in the lessons, and thus only codes from the video transcripts portions of PDs are reflected. I use the table to discuss the patterns in the strategies used, and in turn to get an idea of the teachers' knowledge about teaching strategies. This is possible since the naming of codes was systematic. For instance, code 'Meth diagram Vi' refers to the teaching strategy where a teacher uses a diagram. The numbers indicate frequencies of codes, which is the number of quotations associated with a particular code. The frequency gives an indication of how often a strategy was used. A simple count of codes in the first column reveals that 24 different strategies could be identified. Some code names are shortened, so it may not be easy to read what they mean. Thus, I give a list of what each code represents below. The list also serves as an indication of the possible strategies observed.

Meth call quest Vi: Teacher calls for questions from students.
Meth caution Vi: Teacher cautions students to pay particular attention.
Meth chart Vi: Teacher uses a chart.
Meth class discus: Teacher engages student in class discussion.
Meth compare Vi: Teacher engages students in comparing.
Meth demo Vi: Teacher is using demonstration.
Meth diagram Vi: Teacher uses a diagram.
Meth example Vi: Teacher goes through examples with students.
Meth exercise Vi: Teacher gives an exercise for students to do in class.
Meth expose Vi: Teacher uses exposition/explanation in teaching.
Meth gestures Vi: Teacher emphasises a point with gestures.
Meth group Vi: Teacher engages students in working in groups.
Meth history Vi: Teacher explains historical background of a concept.
Meth preview Vi: Teacher previews work to be done
Meth questions Vi: Teacher asks questions for students to answer.
Meth reps Vi: Teacher uses symbols or equations in teaching.
Meth review Vi: Teacher reviews previous work.
Meth roleplay Vi: Teacher engages students in role-play.
Meth rpt phrase Vi: Teacher repeats a phrase or a sentence(s).
Meth rpt response Vi: Teacher repeats what the student said.
Meth st help Vi: Teacher asks one student to try to explain another.

Meth st to board Vi: Teacher calls a student to show something on the board

Meth vernacular Vi: Teacher use local language, other than English.

Meth write board Vi: Teacher writes on the chalkboard.

Table 6.7 shows that the following strategies were used by all the case teachers and in all the lessons with very high frequencies:

1. Exposition or teacher explanation.
2. Teacher asking questions for students to answer.

Exposition or explanation indicates that the lessons emphasised the role of a teacher as a transmitter of information. Questions from the teacher mainly required students to give a correct and short answer. This too shows the emphasis put on students in acquiring information.

The table below also shows the strategies that were used in all the lessons but with relatively lower frequencies than the first category:

1. Use of symbols and equations in teaching.
2. Repeating a phrase or statement.
3. Repeating a student response.
4. Writing on the chalkboard.

This group of strategies also emphasised science learning as acquiring of information. For instance, the teachers used symbols and equations to convey scientific principles and procedures like how to find missing numbers in equations.

Then there are those strategies, which were used with considerable frequency but not in all the lessons. These were use of diagrams and examples. With these too the focus was on presenting information. Use of charts and reviewing previous work were used in most of the lessons but with low frequencies and they also emphasised the view of physics teaching as presenting information. The patterns are similar for all the case teachers, which seems to suggest that qualifications may not have had much influence. However, it is not easy to be conclusive on qualifications, as ‘minor’ differences in frequencies do exist. These differences could be due to the qualifications, nature of the lessons or the teaching environment. One would have to explore further.

The rest of the strategies like use of history of physics, group work and role-play were used in few lessons and/or with very low frequencies.

Table 6.7: Distribution of codes pertaining to teaching strategies used

	PRIMARY DOCUMENTS							
CODES	10	11	12	13	14	15	16	17
Meth call quests Vi	0	0	0	0	0	1	5	0
Meth caution Vi	2	0	0	0	0	0	0	0
Meth chart Vi	6	0	5	1	1	4	3	0
Meth class discus Vi	0	0	0	0	0	0	4	0
Meth compare Vi	1	2	0	1	0	0	0	0
Meth demo Vi	2	0	0	5	0	0	0	0
Meth diagram Vi	20	26	9	14	4	2	0	1
Meth example Vi	6	7	20	2	4	8	0	7
Meth exercise Vi	0	0	0	0	0	0	2	0
Meth expose Vi	43	48	29	31	14	12	11	7
Meth gestures Vi	1	1	0	2	0	0	0	0
Meth group Vi	0	8	0	0	2	2	1	3
Meth history Vi	1	0	0	5	0	0	0	0
Meth preview Vi	0	0	0	0	0	1	1	0
Meth question Vi	36	52	53	15	23	23	10	20
Meth reps Vi	19	22	18	3	6	6	1	4
Meth review Vi	5	1	1	2	5	1	1	0
Meth roleplay Vi	0	0	0	0	0	0	2	0
Meth rpt phrase Vi	11	8	10	5	4	4	1	3
Meth rpt respose Vi	11	18	15	3	2	6	1	15
Meth st help Vi	0	3	0	0	0	0	0	0
Meth st to board Vi	3	6	2	1	0	0	0	0
Meth vernacular Vi	13	4	0	0	0	0	0	0
Meth write board Vi	21	25	20	17	9	5	5	9

As pointed out already, the case teachers mostly used strategies that supported the traditional view of science teaching as transmission of information (Flores et al., 2000). These results support Schecker’s (1993) argument that physics teaching seems to put too much emphasis on solving equations and calculating numbers without securing a qualitative understanding of the key concepts. Van Heuvelen (1991) identifies the following characteristics of traditional physics teaching among others, which are also supported by these results: telling students the physical rules that seem to guide the universe and demonstrating how to use the rules to solve problems.

These results show that the case teachers did not use some of the strategies recommended in the literature like use of cooperative learning groups (Gautreau & Novemsky, 1997), allowing students to critique their own and scientific models (Coll, 2005) and grounding teaching on a theoretical framework such as conceptual change strategies (Buty et al., 2004).

6.5.2 Subject-specific teaching strategies

6.5.2.1 Examples of subject-specific strategies from T25's lessons

In this sub-section I give three examples of subject-specific teaching strategies that T25 used in his lessons. The first example involves a group activity in which the teacher asked students to find the values of q and r in the equation below.

$$^{q}_{r}\mathrm{Na} \rightarrow {}^{24}_{12}\mathrm{X} + {}^{0}_{-1}\beta$$

All students found the correct value of q to be 24. However, some students could not find the correct value of r (which is 11). To help such students, T25 asked the class to state what happens to the atomic number of the parent nucleus during beta decay. He then said that twelve is just the same as atomic number r plus one. Next, T25 did the calculation on the chalkboard as shown below.

$$r + 1 = 12$$
$$r = 12 - 1 = 11$$

Lastly, T25 explained the above calculation to the whole class. In this example, T25 transformed the nuclear equation into an algebraic equation using the principle about what happens to atomic numbers during beta decay. This seems to indicate that T25 may have been aware that teaching involves transformation of subject matter (Geddis, 1993; Geddis et al., 1993). However, there was no evidence to indicate that T25 was aware that students find symbolic representations difficult. According to Treagust et al. (2003), it is not always easy for students to think at a symbolic level.

The second example concerns the deflection of alpha and beta particles in electric fields. T25 wanted the students to learn that a beta particle, being lighter, gets deflected more than an alpha particle in a given electric field. To achieve this, he used the analogy of two metal blocks of different masses located at the same distance from two identical magnets. Through a question and answer session, the teacher then led students to the conclusion that the metal that is lighter will be attracted more easily than the heavier one. The use of this analogy may have aided understanding because students have experience of how a given magnet attracts metals of different mass but not the microsopic beta and alpha particles. This example shows that T25 had some knowledge of analogies that applied to the lesson or topic. However, the teacher did not point out limitations of the analogy use. The analogy was about interaction between magnets and metal blocks made up of neutral atoms, while of beta and alpha particles carry a net charge. It might be that the teacher may not have known that students do not always establish the relationship between an analogy and the scientific concept (Greca & Moreira, 2000).

A third example of subject-specific strategies for T25 concerned the general equation for alpha decay. T25 wrote the following equation on the chalkboard.

$$\underset{\text{Parent nucleus}}{{}^{A}_{Z}\mathrm{X}} \longrightarrow \underset{\text{Daughter nucleus}}{\mathrm{Y}} + \underset{\text{Alpha particle}}{{}^{4}_{2}\alpha}$$

T25 then asked one student to go to the board to write atomic and mass numbers for Y in terms of Z and A. Next, he asked the class to explain the equation. No student offered an explanation, so the teacher used leading questions to guide students to the following explanation:

> ${}^{A}_{Z}X$ minus ${}^{4}_{2}\alpha$ will give us ${}^{A-4}_{Z-2}Y$. If you can take this to the left *[alpha particle]*, then you will have this on the right *[Y]*.

In this third example T25 explains how the mass and atomic numbers are found to be A-4 and Z-2 respectively using an algebraic language (${}^{A}_{Z}X$ minus ${}^{4}_{2}\alpha$ will give us ${}^{A-4}_{Z-2}Y$), which is also a kind of transformation. However, the teacher did not explain why the subtraction involved the superscripts and subscripts, which is not the case in mathematics. This might be indicative of the tendency to emphasise more on development of procedural than on the development of conceptual knowledge (Geddis et al., 1993).

6.5.2.2 Examples of subject-specific strategies from T12's lessons

In this sub-section I give three examples of subject-specific teaching strategies that T12 used in his lessons. The first example pertains to the relative abundances of isotopes of an element. Students had difficulties understanding the concept of ratio as applied to isotopes. This is not surprising as the discussion of isotopes happens at symbolic and sub-microscopic levels, which students sometimes find difficult (Treagust et al., 2003). T12 used the case of chlorine by stating and restating the ratio of chlorine-35 to chlorine-37, but students still did not understand. The teacher then used the analogy of ratio of boys to girls to explain the concept. When the teacher repeated the explanation using the analogy of ratio of boys to girls, more students seemed to have understood. T12 seems to be aware of the power of analogies and used the example of ratio of boys to girls to aid understanding. This analogy may have served two purposes: it might have helped students to develop the concept of ratio and to think interms of concrete objects (people). The fact that use of the analogy helped more students to understand reinforces the assertion that analogies aid development of abstract concepts (Treagust et al., 1998).

The second example pertains to the students' failure to use the principle that in a neutral atom the number of protons is equal to the number of electrons. The teacher said this principle aloud and asked students bench by bench to repeat after him, a strategy I call *drill*. It would seem T12 wanted the students to simply memorise the principle and use it to determine numbers of protons or electrons in neutral atoms. This again shows the focus on development of procedural knowledge. Also the teacher spent considerable time on this principle, yet it is not the focus in nuclear physics. I feel the teacher may not have had a well-developed sense of curriculum saliency (Geddis et al., 1993; Shulman, 1986) regarding how the status of this principle in nuclear physics.

Thirdly, some students gave the mass of a neutron to be zero instead of one. The teacher then tried to help such students by asking a fellow student to simply state the correct mass without following up with an expalanation in a different form. May be T12 could not think of a different way like asking the students to compare masses of different atomic particles.

6.5.2.3 Examples of subject-specific strategies from T23's lessons

In this sub-section I give three examples of subject-specific teaching strategies that T23 used in his lessons. The first example relates to some students' conception that a neutron does not experience a force. T23 helped such students by asking them to explain their view. He then asked other students if their explanation that a neutron does not have charge was true. The teacher then simply stated, "When you talk of the force that you have talked about there, the attractive force, of course we expect it covers the whole nucleus." T23 did not give details about the nature of the "attractive force" maybe because he himself may not have been sure. It seems inadequate knowledge of subject matter affected T23's ability to explain and this would support Even's (1990) argument. Also, the thinking that neutrons do not experience a force because they do not have charge seems to indicate that the students did not think that the law of gravitation could apply to the nucleus. Such a view is similar to what has been found that sometimes students think that Coulomb's law does not apply to the atomic (Taber, 1998).

Secondly, there was a tendency among students to think that a neutron has no mass. T23 tried to address this thinking by commenting that this conception was wrong. He then went on to declare that a neutron has got a mass of one atomic unit. It seems T23 was not aware that conventional instruction was ineffective in modifying students' conceptions (Driver et al., 1989).

The third example involves the problem created by nuclear notations. T23 used the notation below to represent an atom.

$$\begin{array}{rl}\text{Atomic mass} & {}^{A} \\ & \quad X \\ \text{Atomic Number} & {}_{Z}\end{array}$$

However, the periodic table that the teacher brought in interchanged the positions of A and Z, which confused the students. To try to clear this confusion, T23 began by stating that sometimes the order is reversed. He then isolated carbon and used it as an example to illustrate how the students could distinguish atomic and mass numbers. Next, he restated that the order for A and Z are sometimes switched. Lastly, he told the students that the important thing to note is that atomic mass is bigger than atomic number. Thus, by looking at the numbers they could tell which one is the mass number or atomic number. The use of the example was good and helped a number of students to clear the confusion. However, I felt T23 could have given students practise with different elements from the periodic table because, as Geddis et al., (1993) found with novice teachers, clear articulation of content alone does not necessarily result in understanding. In addition, such practice was important since students sometimes find symbolic representations difficult (Treagust et al., 2003).

6.5.2.4 Examples of subject-specific strategies from T10's lessons

In this sub-section I give three examples of subject-specific teaching strategies that T23 used in his lessons. To begin with, students had difficulties with calculation of average atomic masses. To assist the students with this difficulty, T23 wrote a problem involving isotopes of chlorine on the chalkboard. He then read through it and explained how to get the average atomic mass while doing the calculation on the board. The calculation looked as follows:

$$35 \times 75/100 + 37 \times 25/100$$
$$35 \times 0.75 + 37 \times 0.25$$
$$35.5$$

As already pointed out, students find the calculation of average atomic masses difficult because of the use of weighted averages (Geddis et al., 1993). However, the teacher did not seem aware of this difficulty as he just went through the calculation quickly. Also, the above calculation involved a number of mathematical transformations: percentages to fractions with denominator 100, fractions to decimals and computing the final average of 35.5. The teacher did not explain this. Thus, it would seem the emphasis was just on the procedure.

Another subject-specific strategy for T10 related to a student's definition of an isotope as "an element with same number of electrons but different number of protons". The teacher reacted to this by querying the student, "Did I mention of an electron as part of the nucleus of an atom?" Through leading questions T10 then guided students to the definition "It is an element with same atomic number but different mass number." There was an opportunity for T10 to probe if the problem was deep-rooted or a simple error. The teacher did not do this and just proceeded to guide students to the accepted definition.

Finally, I present the strategy used to help students understand that there is a limit to the number of neutrons and protons a nucleus can hold. For this T10 used an analogy. He asked four girls to come to the front of the class and to form a circle by holding each other hand-to-hand. He then encouraged as many other girls as possible to go into the circle. Through some leading questions, T10 led students to the desired conclusion: that the circle would break because of increasing force as more girls squeezed into it. Using a chart diagram he then explained that the nucleus of an atom breaks as more protons and neutrons enter the nucleus because of increasing force. However, T10 did not discuss limitations of the analogy much as it was effective in helping students appreciate that the nucleus of a particular atom can only hold a limited number of nucleons. I noted from the PSS that the concept of limit to the number of protons and neutrons in the nucleus is not part of the curriculum, but T10 spent considerable time on it. Nor is there evidence in the PSS that such a concept would be applicable in other topics or lessons. Therefore, the emphasis that T10 put on this concept seems to reveal that he may not have been aware of the curriculum saliency of this concept. Awareness of curriculum saliency enables a teacher to judge matters such as depth of treatment (Barnett & Hodson, 2001).

6.6 How case teachers ascertained understanding

Although this study did not specifically investigate how the teachers assessed understanding, it is possible to shed light on how this was done within the lessons. This is possible because all the activities that took place in the lessons were coded. The code 'St response Vi' is useful as it identified the responses students gave to teacher stimulus. There were a total of 234 quotations where this code applied. Thus, in each PD, every fifth of those quotations was read, together with text just before the quotation to identify what triggered the response. Table 6.8 shows the modes of assessment that could be identified. The numbers show the quotations that were read that contained a particular mode of ascertaining student understanding. A number of patterns emerge from the table.

Firstly, there seems to be a relationship between qualification and the total frequency of attempts to ascertain student understanding in the bottom row. T25 and T12, who both qualified to university degree level, have a higher frequency of such attempts than T23 and T10, who had lower qualification. One could argue that case teachers with higher qualifications had better appreciation of the learning difficulties associated with nuclear physics, hence the need to ascertain if students understood. The finding that T10, one with lowest qualification among the case teachers, could not anticipate any difficulties before the lessons supports this argument.

Secondly, Table 6.8 shows that of the six modes of ascertaining student understanding, four involved use of oral questions. Adding the relevant totals in the last column revealed that 32 of the 44 quotations read involved use of oral questions to elicit a student response. This could have been the case because the case teachers: considered use of oral questions to be more important than other modes, did not know other modes or oral questions are easier to use than other modes. The reasons the teachers used oral questions more frequently than other modes were not probed in this research, so this is a gap, which other studies might fill.

Thirdly, of the oral questions used, very few required students to explain their reasoning. Of the 44 quotations read, only two were questions requiring explanation. Most of the questions were 'what' ones requiring students to recall facts and principles. The questions to check if students were following or could remember mainly engaged in chorus one-word answers like 'yes' and 'no'. For example, a teacher could ask, "Are we together?" and students could answer, "No" or "Yes" as a group. Such questions emphasise low order thinking. Thus, it would seem the case teachers lacked ability to assess higher skills for the lessons observed. Of course T25, T23 and T10 attempted to use group class activities to assess learning, but the group activities were mainly on procedures for manipulating numbers.

Table 6.8: Case teachers' modes of ascertaining student understanding

Mode of ascertaining understanding	**T25**	**T12**	**T23**	**T10**	**Totals**
Use of oral questions to review previous work and answered orally	4	9	2	1	16
Use of oral questions to review previous work and answered by a student on chalkboard	1	0	0	0	1
Use of oral question to check if students were following or could remember and answered orally	3	10	0	0	13
Students called to the board to complete missing number in equations written on the chalkboard	3	0	0	0	3
Oral questions requiring students to explain their reasoning orally	1	0	1	0	2
Give group class homework written on the chalkboard, then group presents final answer, which class discusses	4	0	3	2	9
Totals	16	19	6	3	**44**

T10 and T23 each also gave homework in one of their lessons. Although these teachers were about 400 kilometres apart, their homework was similar in that both involved calculation of average masses. T10 gave the following homework:

1. The three isotopes of hydrogen are hydrogen -1 hydrogen -2 and hydrogen -3. Write down the way those isotopes are written to show the atomic number, mass number and atomic symbol.
2. Calculate the relative atomic mass of the following isotopes whose percentages are shown in brackets: $^{63}_{29}Cu$ (69.09%) and $^{65}_{29}Cu$ (30.91%)

T23 gave the following homework:

1. Calculate the relative atomic mass of the following isotopes whose percentages are shown in brackets $^{12}_{6}C$ (98.89%) and $^{13}_{6}C$ (1.11%)
2. Define isotopes.
3. Give three examples of isotopes.

The questions involving calculation of relative atomic masses are the same, the only difference being the isotopes: one uses copper (Cu) while the other uses carbon (C). When I followed it up with T23 during the post-observation interview, he admitted that he had taken the question from a past examination paper. This indicates that T10 may also have taken the question from a past examination paper. It would seem homework is highly influenced by the need to prepare students for national examinations. This observation agrees with Geddis et al.'s (1993) finding that novice teachers tended to focus on providing students with a clear articulation of the content to be learnt about isotopes and the calculation of average atomic mass. However, such articulation did not result in better student understanding allegedly because students failed to reconcile their conception of simple average with the weighted average expression used to compute average atomic masses.

Also, the above homework questions required students to just follow a procedure done in class. Question 1 for T10 required students to follow a procedure that had been done in class. Questions 2 and 3 for T23 are recall questions as they had been already answered in class. It would seem T10 and T23 did not take into consideration issues of curriculum saliency and alternative representations of the subject matter as discussed by Geddis et al. (1993). This supports the observation that the teachers tended to dwell on low order skills. It would be interesting to explore further if this is the case with all the lessons on nuclear physics or in other topics.

6.7 Conclusions

In this chapter, I have used questions adapted from Loughran et al. (2004) to understand the nature of the case teachers' PCK in the lessons observed. From the results discussed the following could be said about these teachers' PCK.

The case teachers anticipated very few, if any, difficulties for the lessons. Actually, one made it clear that he could not comment on difficulties before the lesson. For the rest, the ratio of anticipated to observed difficulties was small (less than 0.300) for the lessons observed.

The case teachers were aware that students knew something, which they could contribute to lessons. However, the focus was on students contributing something to lessons that was scientifically acceptable. Only one case teacher (T23) alluded to the need to identify student difficulties. It would seem student thinking in terms of ideas not consistent with those of science might have influenced T23's choice of strategies, but not the others.

One case teacher (T25), a qualified and experienced teacher, articulated the main ideas of his lessons; the rest did not know, as they tended to focus on detail at the expense of main ideas. Ability to identify main ideas helps teachers to know what to emphasise or not (Shulman, 1986). Lack of such ability is likely to affect teaching of a lesson.

Other predominant factors that influenced choice of teaching strategies were the view that science teaching should aid understanding, especially of facts and principles and that science teaching is about conveying information.

Pertaining to teaching strategies, the case teachers mostly used those that supported the traditional view of science teaching as transmission of information emphasises solving equations and calculating numbers without securing a qualitative understanding of the key concepts.

Regarding ascertaining of student understanding, the case teachers mainly used oral questions that emphasised low order skills. The less qualified teachers tended to use less of such assessment compared to the more qualified one. Some evidence of the influence of examinations in homework given to students was also witnessed.

In the next chapter I summarise the results of this study and discuss their implications.

CHAPTER 7

SUMMARY OF RESULTS, DISCUSSION AND IMPLICATIONS

7.1 Introduction

In Malawi, some pre-service and practising teachers view nuclear physics as the most difficult topic in the PSS from both teaching and learning points of view. This study was conceived to explore how some of the PSTs taught a topic perceived as difficult and to shed light on the nature of their PCK in nuclear physics. The study specifically sought answers to the following questions:

1. What reasons do Malawian PSTs give for rating *nuclear physics* as the most difficult topic to teach?
2. What teaching strategies do Malawian PSTs use to address difficulties students face in learning *nuclear physics* concepts?
3. What reasons do the teachers give for choosing some teaching strategies?
4. What can be learnt from the study of teaching strategies about the nature of Malawian PSTs' pedagogical content knowledge (PCK) with respect to nuclear physics?

In the previous three chapters I presented results and discussed how those results addressed the above questions. In this chapter, I summarise those results and discuss them further in terms of their implications. Some recommendations are then drawn from the summary of results and discussion. I use the above questions to organise this chapter into the following sections:

1. Reasons for rating nuclear physics as the most difficult.
2. Teaching strategies
3. Reasons for choice of teaching strategies.
4. The case teachers' PCK.

5. Reflection on the research process
6. Conclusions and recommendations.

7.2 Reasons nuclear physics is the most difficult

7.2.1 Preamble

In Chapter 4, I presented and discussed results pertaining to difficult aspects of nuclear physics and the reasons the 12 PSTs gave for rating the topic as most difficult to teach or learn. The results from other sources (interviews, lesson observation, discussion of video recording and analysis of CERs) corroborated those found with the 12 PSTs. Also, the second administration of the questionnaire showed that there was consistency in the teachers' responses. Thus, I consider results from the 12 PSTs as credible.

7.2.2 Nuclear physics as the most difficult topic

There are two findings of this study related to nuclear physics. Firstly, 12 of the 28 teachers who returned the questionnaire chose nuclear physics as the most difficult to teach from a list of five physics topics (see Appendix 6) provided. I consider this to be an important finding because, to my knowledge, no one has sought the views of teachers about the topics that PSTs find difficult to teach in the PSS. Of course I do not intend to generalise because of the small sample used. However, this result does indicate that there are some practising teachers who find the topic to be the most difficult to teach in the PSS. The finding has implications for a number of groups of people: physics teacher educators, curriculum planners, researchers and the teachers themselves. For the physics teacher educators there seems to be a need to allow pre-service teachers to engage with the topic in the form of identifying the main ideas, the potential teaching difficulties and possible strategies to address those difficulties. Curriculum planners and developers might need to develop supportive teaching resources. Also, there is need for researchers to explore more about the type of teaching difficulties associated with the topic, possible strategies for teaching the topic and to evaluate the available teaching resources. The practising PSTs need to find ways of working as a team to try to find ways of teaching this difficult topic.

Secondly the 12 PSTs were able to mention the aspects of the topic that they found difficult to teach. In Chapter 4 (Table 4.2) I presented those aspects and they were six: nuclear process (what goes on in the nucleus of an atom), calculations (like that of half-life), nature of each of the three types of radiation, detectors of radioactivity, nature of radioisotopes and applications of nuclear physics in order of decreasing frequency. Results from lesson observations also revealed aspects that students found difficult. Some of them were the same as those mentioned by the 12 PSTs like the decay of a neutron into a proton and an electron, which is one of the nuclear processes. Knowledge of difficult aspects of a topic is an important aspect of PCK (Shulman, 1986). I feel these findings are important in that they indicate specific aspects that might be difficult to teach and/or learn. I feel such findings have implications for physics teacher educators, methods advisors, the teachers themselves, researchers and curriculum developers. Physics teacher educators could design their courses such that there is emphasis on teaching of portions deemed as difficult. Methods advisors could use the information to give specific and targeted advice about how to teach those aspects. The PSTs could form cooperative groups in which teaching of these aspects could be discussed. Researchers could explore why specific aspects are problematic for teachers and/or students. Only two of the 12 PSTs mentioned teacher inadequacies, as some of the reasons nuclear physics is difficult to teach. Therefore, further research on PSTs' understanding of nuclear physics is apparently needed. Curriculum developers could tap on information about difficult aspects to develop supportive materials that focus on helping teachers cope with the difficult aspects.

7.2.3 Reasons for nuclear physics being most difficult to teach

In Chapter 4, the reasons that the 12 PSTs gave for choosing nuclear physics as the most difficult topic were found to be as follows, starting with the most and ending with the least prevalent: lack of teaching materials, most concepts are abstract, the topic is new, it is difficult to do experiments at this level, it is complex for students, and teacher inadequacies. I argue that the reason given by more teachers was more compelling than the one given fewer teachers. Thus, availability of teaching materials was the most compelling for the 12 PSTs. Lack of basic teaching resources such as books, laboratory supplies, laboratories and demonstration apparatus means that only a well-trained, flexible teacher can be effective (Stoll, 1994). An average teacher is likely to find teaching a topic where resources are unavailable difficult. I contend that any intervention to help the 12 PSTs, and others like them, with teaching of nuclear physics should target teaching resources for greatest impact.

Three of the case teachers (T25, T23 and T12) mentioned that there is no specific textbook to go along with the PSS. When I enquired with T10 he simply said I used sources of my own and he did not mention them. As a result teachers use textbooks for courses in the United Kingdom or other countries. I analysed the list of references provided in the PSS and I found that of the 25 references provided, only one book (Wallis, 1992) was published in Malawi. Even this one was meant for the old syllabus, not the current one introduced in 2002, and it does not include nuclear physics. From schools, I found that the commonly used texts, especially for nuclear physics were "*G. C. S. E. Physics*" (Duncan & Kennett, 2001)and "*Physics for Senior Secondary School*" (Abbey & Essiah, 1990), both not published for the Malawian situation. I argue that the use of textbooks meant for foreign countries have implications for the type of curriculum that is actually implemented and that there seems to be need for textbooks tailored to the PSS to be written. Of course, this study did not focus on textbooks, so before this argument could be taken further it might be necessary to research how the use of foreign textbooks is affecting delivery of the curriculum.

The next most compelling reason for choosing nuclear physics as the most difficult to teach was that the concepts involved are abstract. The teachers might have found this reason compelling because it is difficult to enable students experience abstract concepts. Constantinou and Papadouris (2004) argue that physics learning has the following components: acquisition of experiences with natural phenomena, development of concepts, development of epistemological awareness and development of scientific and reasoning skills. They further argue that real learning in physics can only emerge when all these components of physics learning are promoted in unison, which is difficult with abstract concepts.

The finding on abstract concepts has implications for providers of teacher development programmes in Malawi, methods advisors, and researchers. Teacher development programmes, be it pre-service or in-service, need to equip teachers with skills to teach the abstract concepts in nuclear physics. Where abstract concepts are involved, scientists tend to use models to understand those concepts. Other authors have argued that modelling is one of a scientist's main activities (Coll, 2005; Harrison & Treagust, 2000), hence teachers need to know how to use models in teaching. For instance, teachers should have the skill to demonstrate how a scientific model was developed and why it may have been changed, if it has been changed. Such an approach was tried with grade 11 chemistry students in Israel and was found to help weak students achieve better performance during evaluation (Ben-Zvi & Hofstein, 1996). For physical science methods advisors there seems to be need for them to work with teachers to develop ways of teaching various abstract concepts in nuclear physics. Researchers might need to explore the issue of abstract concepts further with more teachers in order to determine prevalence of the view that nuclear physics is difficult to teach because of abstract concepts. Research could also be extended to other topics to explore if teachers also find it difficult to teach abstract concepts in topics other than nuclear physics. Also there may be need to conceive, develop and evaluate strategies for simplifying teaching abstract concepts in nuclear physics and other topics.

The other reason given for labelling nuclear physics as the most difficult to teach was that it is difficult to do experiments. This is related to the first two reasons: lack of materials and abstract concepts. Here the teachers might have assumed that where it is possible to do experiments then teaching becomes easy. This assumption ignores the fact that there is more to learning science than just doing experiments. For instance, there has been an attempt to classify learning in science into deep and surface learning approaches (Biggs, 1999; Chin & Brown, 2000).

Chin and Brown (2000) point out that deep learning is characterised by: intrinsic motivation, focus on understanding the meaning of the learning material and an attempt to relate parts to each other, new ideas to previous knowledge and concepts to everyday experiences. They also point out that surface learning approaches are used where the learner perceives learning tasks as demands to be met, tends to memorise facts, terms and procedures and views tasks in isolation. Biggs (1999: 60) contends, "The surface approach is therefore to be discouraged, the deep approach encouraged - and that is my working definition of good teaching." I contend that, much as ability to do experiments may contribute to science learning, on its own it may not lead to use of deep learning approaches, especially if the experiments just involve following procedures. There seems to be need for science education researchers to explore further on the type of experiments that the PSTs had in mind and how they thought doing experiments would simplify teaching of nuclear physics.

The other reasons for labeling nuclear physics as the most difficult were: the topic is new (six years now since it was introduced); the topic is complex for students and teacher inadequacies. These reasons are related in that a new topic means teachers may not have developed the relevant PCK in nuclear physics, hence the feeling of inadequacy. This feeling of inadequacy has implications for the confidence with which the teachers handle the topic with students, making it difficult for students as well. What is interesting for me is that this feeling of inadequacy even applied to qualified and experienced teachers, for instance, the extract below taken from PD 11 shows how one of the qualified and experienced case teachers (T25) responded to my question. In paragraph 39, T25 makes two points: that his explanation may have been deficient and that he was not sure.

> **038 I:** I don't know what you think about today's lesson, how it went?
>
> **039 T25:** Ah, generally I would say that it also went well of course with some two short falls. The first one was still on this issue where the neutron breaks down into a proton and an electron. I remember a student asked and ah I think my explanations I think were still deficient on certain information. I think I need to still investigate and find a better way of trying to explain that point because I can see its now coming now and

> again. Now and again so I think I just need to do a little more on that one. Secondly, if you also noticed, I think somewhere I really didn't even I also didn't give ah sufficient information; I wasn't sure I should say.

The finding that both qualified and unqualified teachers felt inadequate in teaching some aspects of the topic supports the argument that teachers need more than just knowledge of content but a well developed PCK, which identifies the distinctive bodies of knowledge for teaching (Shulman, 1987). I conclude that the fact that the topic is new implies that the 12 PSTs did not have adequately developed content knowledge, which is a prerequisite to the development of PCK (Halim & Mohd.Meerah, 2002), making the teaching of the topic difficult for teachers and in turn the learning of it difficult for students. This finding has implications for the way the teachers may have been oriented to the new topic. It is argued that the process of introducing a new topic (or curriculum) should involve re-education of the implementers (Tamir, 2004). Tamir points out that the re-education should be at two levels: familiarity with the programme in terms of its strategies at the required operational level and the meta-level of commitment, identifying with the philosophy and the spirit of the programme. It might be that such re-education may have been limited among the PSTs. I contend that such re-education is still needed and teachers need support in this. I acknowledge that further investigation would have to be done on a wider scale to establish extend to which such re-education is needed. This finding also supports the argument that support to teachers, who are the implementers, is critical in implementation of new curricula (Rogan & Grayson, 2003), which backs the importance of re-education (Tamir, 2004). This study has shown that in the absence of re-education, the case teachers found teaching of the new topics difficult.

7.2.4 Reasons for nuclear physics being most difficult to learn

The results in Chapter 4 (Table 4.5) showed that the teachers thought nuclear physics would be difficult to learn for students mainly because of the following two reasons: some ideas are hard to understand and lack of teaching materials like detectors. The other reasons, each mentioned by just one of the 12 PST, were deemed less compelling.

The teachers simply mentioned that some ideas are hard to understand without explaining why those ideas are hard to understand. I can think of two possible explanations for this: either the 12 PSTs were just lazy to explain or they did not have any other explanations. I rule out laziness because the same teachers managed to explain why nuclear physics is difficult to teach, so laziness could not apply to one item. Thus, I conclude that the 12 PSTs could not find explanations why nuclear physics is hard to learn, other than to just say the concepts are hard to understand. I contend that this failure to explain indicates that the 12 PSTs only had a superficial understanding of students' learning difficulties. For example, it is widely believed that students come to science lessons with ideas and beliefs that might affect learning (Cocking, Mestre, & Brown, 2000; Mestre, 2001). Cocking et al. (2000: 4-3) argue that "Some of the ideas children hold are incomplete understandings based on true scientific concepts, others are false beliefs based on true concepts, and still others are logical extensions of false concepts that are incompatible with scientific theory." The 12 PSTs did not seem to know that such student ideas are a cause of learning difficulties in science, including nuclear physics. Apparently, there is need to assist the 12 PSTs and others like them to develop this category of knowledge of learners and their characteristics, which is one of the seven categories of the knowledge base for teachers (Shulman, 1987; Wilson et al., 1987). It is also one of the components of PCK that Lee and Luft (2008) identified with mentor science teachers in the United States of America. Teacher training institutions, methods advisors, science teachers and science education researchers could come together to conceive programmes aimed at developing this aspect of knowledge in practicing teachers in Malawi.

7.3 Strategies for dealing with learning difficulties

7.3.1 Preamble

In Chapter 5, I presented and discussed results pertaining to strategies for dealing with learning difficulties. I also presented and discussed reasons the teachers gave for using those strategies. In this subsection, I summarise findings pertaining to the strategies the case teachers used to try to address the observed learning difficulties and the reasons given for choice of those strategies. I also discuss the implications of those findings.

7.3.2 Discussion of results on the case teachers' strategies

7.3.2.1 Summary of results on strategies

The results pertaining to the case teachers' teaching strategies are summarised in Table 7.1. The table shows the combinations of methods that formed a particular strategy for each case teacher (indicated by numbers 1, 2, 3, … in the top row and in bold). The methods are indicated by codes such as q for use of questions. For instance, T25's first combination of strategies consists of q, sa, d, m, and e, which respectively represent use of questions, student explaining to class or helping another to answer a question, diagrams drawn on the chalkboard or chart paper, meeting students outside lesson for further help and teacher explanation. The numbers in the bottom row indicate the frequency of each combination. Table 7.1 reveals the following results about the case teachers' strategies:

1. All the four case teachers, irrespective of their qualifications, used multiple-method strategies. For example the teachers could combine use of questions, giving students a chance to answer, teacher explanation and use of diagrams on the board or chat paper in various ways (combinations). There are only two combinations that consisted of just one method: combination 5 for T25 and combination 2 or T10.
2. Some strategy combinations occurred with higher frequency than others. For example combination 1 occurred more frequently than combination 3 for T12.
3. Some of the strategies belonged to more combinations than others; for instance, teacher explanation belonged to all combinations except one (combination 5 for T25). On the other hand, use of role-play belonged to only one combination (combination 4 for T10)

I discuss the implications of these findings in subsection 7.3.2.2.

Table 7.1: Combinations of teaching strategies for the case teachers

Strategy combinations																
T25*					**T12**			**T23**				**T10**				
1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**
q	q	q	q	q	e	e	e	sa	sa	o	sa	e	e	e	e	e
sa	o	o	o	o	sa	sa	o	e	e	e	e	o	o	o	o	c
d	d	d	o	o	q	q	o	o	tf	o	tf	o	q	q	q	o
m	o	o	o	o	d	o	o	o	eg	eg	o	o	o	d	d	o
e	e	e	e	o	o	x	o					o	eg	o	eg	o
o	o	o	tf	o	o	o	dr					o	o	o	r	o
4	3	2	2	1	5	3	2	3	2	1	1	3	2	1	1	1

* For T25 combinations 2 and 3 contained same methods but differed only in sequence and the table is not sensitive to sequence of methods in each combination.

Interpretation of the codes:

c: teacher asks students to calculate final answer; e: teacher explanation; d: use of diagram to explain; dr: teacher drills students; eg: teacher used example in explaining; m: teacher volunteers to meet students outside lesson if difficulty persists; o: method applicable to that row does not apply; q: use of questions; r: teacher engages students in role play; sa: teacher asks other students to explain or answer question; tf: teacher points out that student response is true or false; x: teacher expresses surprise.

7.3.2.2 Discussion and implications of results on teaching strategies

One of the findings is that all the four case teachers used multiple-method findings. This meant the teachers could vary methods used, may be with the hope of helping students overcome the difficulties met. This is in line with the assertion that a teacher should be able to modify instruction to help struggling students improve (Staver, 2007). Staver (2007: 23) further argues that

> Teachers must embrace the view that effective teaching means constantly being aware of and attending to students' struggles to learn science and continually adjusting their teaching strategies and techniques to help students work through difficulties.

It would seem that the case teachers attempted to adjust their strategies in an effort to help students work through difficulties. In the process, a number of combinations of methods appeared. I feel this is where the case teachers' strength lay and may be this is the reason why they were considered as the best in their category (either teaching at CSS or CDSS). Some teachers, who may not be able to use different combinations of methods to try to assist students, could learn from them. This finding has an implication for research: there seems to be a need to explore the extent to which average physical science teachers in Malawi are able to use different combinations of strategies when dealing with learning difficulties.

It should be pointed out though that just using different multi-method teaching strategy combinations is not enough. Effectiveness of those combinations has to be evaluated by assessing student achievement or comparing them with characteristics of effective instruction. This is related to the finding that some strategy combinations occurred with higher frequency than others. It is also related to the finding that some of strategies belonged to more combinations than others. I contend that by examining the combinations and their constituent methods, it is possible to get an idea of the focus of the strategies.

Examining combinations for T25 reveals that his combinations mainly involved use of questions, explanation and diagrams. The majority of those questions were leading questions, which solicited short answers, as pointed out in Chapter 5. Combination 1 shows that there were instances when T25 asked students to explain or answer a question. However, the use of questions was meant to elicit an answer that is scientifically correct, not to diagnose students' ideas. T12's combinations were also dominated by teacher explanation, asking students to give scientifically acceptable explanation, some use of questions and use of diagrams to a small extent. T23's strategies were dominated by teacher explanation and asking students to give a scientifically acceptable explanation or answer. T23 also used some examples in explaining and some clear feedback to students if their input was true or false. Explanation dominated T10's teaching strategy. He asked some questions and brought in some diagrams and examples to support explanation. These strategies, while still helpful, do not meet criteria for effective teaching as described by Cocking et al. (2000), especially the one on ability to diagnose students' concepts. The strategies fit into the broadcast model (Larkin, 2000). Cocking et al. (2000: 4) argue that:

> Good teachers are able to diagnose and understand a student's underlying concepts and use them as a scaffold for more complex learning. Effective instruction helps children distinguish between fruitful errors and misconceptions, between errors that are on the right path but stem from incomplete understanding, and plainly wrong ideas that will have to be replaced with more accurate notions.

The finding that the case teachers' teaching strategies did not meet Cocking et al.'s (2000) criteria for effective teaching has implications. Firstly, the case teachers and others like them need assistance to develop the skills to diagnose learning difficulties and base teaching on those difficulties. This means that teacher-training institutions in Malawi need to evaluate their programmes to decide if they equip pre-service teachers with skills to diagnose students' underlying ideas and to use them as a scaffold for learning. Providers of in-service training also need to do the same. If those programmes are found to equip teachers with the skills to diagnose learning difficulties, then research would have to be done to answer the question: "*Why are some physical science teachers, like the case teachers studied here, not transferring those skills into practice?'* I would like to argue that ability to diagnose student ideas about a topic or concept is important. Otherwise, how do the teachers come to know about learning difficulties in a specific topic in a specific context? Thus, I suggest that this ability should be included as one of the aspects of PCK. Many authors include knowledge of student conceptions and learning difficulties as one of the aspects of PCK but not ability to diagnose those conceptions. Examples of such authors are Lee and Luft (2008), Loughran et al. (2001), Fernández-Balboa and Stiehl (1995) and Shulman (1987, 1986).

Secondly, the case teachers, and others like them, need to be exposed to the literature on learning difficulties in physics, how to diagnose those difficulties and how to address them. Physical science methods advisors could create and coordinate cooperative groups where teachers discuss the implications of research findings on learning difficulties and how to diagnose them. Hopefully, this would influence the case teachers and others similar to them to reflect on and consider learners' prior knowledge and interests when selecting and using specific teaching strategies, which is a trait of effective science teaching (Staver, 2007). Of course teachers may not easily change their approach to teaching. For example, Larkin (2000) highlights the difficulties of changing professors' teaching approaches at the tertiary level from a broadcast to a learning support model. Firstly, such change requires practice, which is only possible if there are mechanisms for advice and feedback. Next, changing approach means that ones' knowledge is no longer sufficient for the new approach and dedicated effort would be required to master new knowledge about learning mechanisms. It is also known that teachers' conceptions of teaching a subject limit their efforts to learn to teach in new ways and can be resistant to changes through pre-service or in-service courses (Borko & Putnam, 1996). Thus, teachers would need support, for instance in form of cooperative groups. Such support could reduce the time teachers would take diagnosing difficulties that are already documented. Through this research, I learnt that teachers are extremely busy people as they do more than just teach. Thus, it would save the time for the other activities if already existing information were availed to them.

7.3.3 Summary of reasons given for the strategies used

7.3.3.1 Summary of the results on reasons for teaching strategies

In chapter 5, I presented and discussed results pertaining to reasons that each of the case teachers gave for adopting a particular strategy in detail. Those reasons were organised into themes that emerged. Those themes are summarised in Table 7.2. From the table a number of patterns emerge.

1. Fewer themes emerged from T25 and T12, who were qualified to degree level, than did from T23 and T10 who were less qualified.
2. Theme of facilitating understanding emerged with all four case teachers.
3. Theme of conveying information also emerged with all case teachers.
4. Methodological reasons emerged only with T23 and T10.
5. Theme of helping students to remember emerged with T25 and T12.
6. Theme of guiding students to the scientific view emerged with T25.
7. Theme of helping students identify problems emerged with T23.
8. Theme of feeding back to students emerged with T23.

9. Theme of checking if students following emerged with T10.

I discuss the implications of these themes in subsection 7.3.3.2. Some I discuss separately, while others I discuss as a group because they are closely related, and have similar implications or the same implications.

Table 7.2: Themes constructed from reasons for the strategies

T25	T12	T23	T10
To remind students about past work To convey information To facilitate understanding of content To guide students to an accepted scientific view.	To help students easily remember principles/facts To convey information. To aid understanding of physics content	To help students identify problems. New things, so 'high' explanation needed – convey information To encourage participation To aid understanding of the scientific view To feedback on whether student input is un/true Examples involved common elements.	To encouraging participation. To convey information To help students relate ideas → understanding. To check if students following the lesson The strategy made methodological sense

7.3.3.2 Discussion of results on reasons for teaching strategies

One of the findings with reasons given for the teaching strategies is that fewer themes emerged from T25's and T12's, who were qualified to degree level, than did from T23 and T10 who were less qualified. It seems the qualifications had an impact on the reasoning behind choice of strategies. An examination of the themes for T25 and T12 revealed that these two focused on content only. This is evident from the themes of conveying information and helping students to remember. On the other hand examination of themes for T23 and T12 revealed that these two did not only focus on content, but also on methodology and this led to more themes emerging. This is understandable because T25 and T12 obtained their qualification from a university and universities tend to emphasise the transmission of content (Cocking et al., 2000; Larkin, 2000; Redish, 2000). Yet, as Cocking et al. (2000: 9) argue, “Universities are the gatekeepers of knowledge and pedagogy and the places where elementary and secondary teachers receive their preparation.” Cocking et al. further argue that faculty in the sciences tend to teach in the way that they were taught and this I feel also applies to teachers at secondary level. On the other hand T23 and T10 were initially trained to teach at the primary level. They obtained their primary teaching qualifications from teacher training colleges where the emphasis is on methodologies that encourage student participation in lessons. It seems there is need to revisit the strategies used in training teachers at universities and other institutions to find out if the strategies used mirror those that teachers are expected to use in teaching. I acknowledge that this is difficult because, as Redish (2000) points out, physics faculty lack knowledge about models for building nontraditional, more effective learning environments. Since the sample used here was small, it may be important to first establish the extent of such need.

There is also the finding that all the case teachers chose strategies to facilitate understanding. I argue that strategies aimed at facilitating understanding should be based on the view of effective science teaching I presented earlier. According to that view teachers should be able to diagnose students’ conceptions and use them as a scaffold for learning (Cocking et al., 2000). Results in Table 7.2 show that only T23 engaged students in identifying problems. However, even with T23, the focus was on mistakes made from a science point of view, not the view of understanding student underlying thinking. This supports the implications discussed earlier in subsection 7.3.2.2 pertaining to helping teachers develop skills in identifying and using students’ ideas in teaching.

The themes helping students to remember, guiding students to the scientific view, checking if students are following and feeding back to students if their input is true or not have an implication for the view of science portrayed. They just give one view of science: a collection of facts, principles and procedures. They do not portray science as a process of constructing knowledge. According to Staver

(2007), learning environments should support students' active construction of knowledge by helping them to recognize conflicts and inconsistencies in their thinking. None of the case teachers engaged students in such activities. It might be that if more lessons were observed such activities would have come up. However, the lessons observed presented opportunities that would have been used to engage students in knowledge construction. For instance, students had difficulties understanding decay of a neutron into a proton and an electron. The concerned case teacher should have engaged students in discussing their ideas about how they would explain beta decay and compare those views with the scientific view. This finding has implications for teacher educators, researchers and teachers themselves. For teacher educators, it is important that they discuss with pre-service teachers what science constitutes and how to plan teaching of specific topics that presents a balanced view of science. This is important because a teacher's behaviour and the classroom environment are influenced by the teacher's conception of the nature of science (Lederman, 1992). However, there were only four case teachers, so researchers would have to explore further the view of science promoted by physical science teachers in Malawi on a larger scale. Also, in Malawi there has been very little research into teacher training programmes, if any, so there is need to explore how those courses prepare teachers to present a balanced view of science in their lessons. Teachers, as suggested already, could form cooperative groups where they could be discussing teaching of topics like nuclear physics, with support from methods advisors. The PSS does point out that the course should enable students to acquire and develop scientific knowledge, skills and attitudes, but does not expand how this is to be done or what it means. I would argue that the PSS, being one of the documents teachers use almost daily, should be revised to include details that help teachers to interpret it without difficulty. I feel this is important since some of the physical science teachers are not qualified.

7.4 The case teachers' PCK

7.4.1 Summary of results on the case teachers' PCK

In Chapter 6, I used questions adapted from statements that Loughran et al. (2004) used in constructing content representations to interrogate the data as a way of capturing and portraying the participating teachers' PCK. A summary of results from that analysis is as follows:

1. One case teacher (T25), a qualified and experienced teacher, knew the main ideas of his lessons; the rest did not as they tended to focus on detail at the expense of main ideas.
2. All the case teachers anticipated very few difficulties for the lessons. Actually, one made it clear that he could not comment on difficulties before the lesson (T10).
3. The case teachers were aware that students knew something, which they could contribute to lessons. However, the focus was on students contributing something to lessons that was scientifically acceptable. Only one case teacher (T23) alluded to the need to identify student difficulties.
4. The other predominant factors that influenced choice of teaching strategies were the view that science teaching should aid understanding, especially of facts and principles and that science teaching is about conveying information.
5. Pertaining to teaching strategies, the case teachers mostly used those that supported the traditional view of science teaching as transmission of information, with emphasis on solving equations and calculating numbers.
6. Regarding ascertaining of student understanding, the case teachers mainly used oral questions that emphasised low order skills. The less qualified teachers tended to use less of such assessment compared to the more qualified ones. Some evidence of the influence of examinations in homework given to students has also been given.

7.4.2 Discussion and implications of results on case teachers' PCK

7.4.2.1 Case teachers' ability to articulate main ideas of lesson

Pertaining to main ideas, only one case teacher (T25) could clearly articulate main ideas of the lessons. The rest tended to dwell on detail. The case teachers knew I would observe their lessons and as such they prepared well as evidenced by their ability to prepare teaching aids such as charts. So, the teachers should have had time to reflect on the main ideas of their lessons. T25 was experienced and qualified and one could argue that this helped him to know the importance of identifying main ideas of a lesson or topic. However, this argument breaks down as one of the case teachers that did not articulate main ideas was also experienced and qualified. Therefore, I argue that the other three case teachers may not have known the importance of articulating main ideas. It might be that they were not aware that learning is facilitated when knowledge is structured around major concepts and principles (Gollub & Spital, 2002). The case teachers needed to know that not all ideas of a domain are of equal status and that 'key ideas' (the equivalent of main ideas) serve as anchors for the cognitive structure (Prawat, 1989a). I argue that this failure to articulate main ideas may explain inclusion of content that is not supposed to be covered under nuclear physics like discussing electron configurations (T12) and density of isotopes (T23).

The finding that three of the four case teachers could not articulate main ideas of their lessons has implications. Firstly, there is need to explore further the Malawian physical science teachers' ability to articulate main ideas with more teachers. Such research would shed more light on extent of this problem. Next, the cooperative groups for teachers suggested earlier, coordinated by methods advisors, could be used to engage teachers in discussing main ideas in nuclear physics and other topics that teachers might find challenging to teach. I also feel it would be worthwhile to identify teachers like T25, who are able to articulate main ideas and use them as facilitators of some sessions of the suggested cooperative groups to help fellow PSTs develop similar ability. Lastly, physics teacher educators in Malawi need to evaluate their courses and determine the extent to which those courses equip pre-service teachers with skills to identify main ideas from a topic like nuclear physics. If found necessary, those courses could be reviewed to enable pre-service physics teachers engage in organising physics content according to some hierarchy (Mestre, 2001). Mestre (2001: 49) offers the following argument:

> To learn lots of things about a topic, to recall that knowledge efficiently and to apply it flexibly across different contexts requires a highly organized mental framework. A hierarchical organization, in which the major principles and concepts are near the top of the hierarchy, and ancillary ideas, facts and formulas occupy the lower levels of the hierarchy but are linked to related knowledge within the hierarchy, is needed to achieve a high level of proficiency in a field.

7.4.2.2 Case teachers' knowledge about learning difficulties

Two findings are related to the case teachers' knowledge of learning difficulties in nuclear physics. Firstly, the number of difficulties the case teachers anticipated was far less than those observed in their lesson. Secondly, the case teachers expected some contribution from students in the lessons, but only in form of giving scientifically acceptable idea. I interpret these findings in two ways. To begin with, the case teachers' awareness of learning difficulties associated with the lessons observed was low. Next, the case teachers might not have taken time to think seriously about difficulties students could meet in their lessons. The first interpretation makes sense because I noted with all the case teachers the tendency to assume that students should find the lessons easy. For instance T10 had this to say at one instance during the first lesson:

> **246 T10:** Yah, so what I'm saying is that the positively charged particles that are getting released from this nucleus, in this alpha radiation, are just helium nuclei. We all know helium. Now let me ask ah this question: may somebody come and draw for us ah helium atom (7). Structure of a helium atom. I expect more hands *(After very few students raised hands to have a go at it).* We looked at helium when we were talking about a periodic table. Yes can you come *(Pointing at someone from the back)?*

The use of statements like 'We all know helium' and 'I expect more hands' indicates the teacher did not expect students to have difficulties identifying an alpha particle as a helium nucleus. Yet, chief examiners made it clear in one report that students had problems identifying an alpha particle as a helium nucleus (Malawi National Examinations Board, 2003).

The interpretation that the case teachers may not have thought about learning difficulties seriously is also plausible. It has already been pointed out that the lessons tended to focus on transmission of content and guiding students towards the scientific view. With such focus on content transmission, it is likely that the case teachers put less emphasis on thinking about content from a learning point of view, which includes difficulties students are likely to face. This focus on transmission of content could also explain why teaching strategies were dominated by explanation and use of questions that elicited short answers only.

One of the consequences of limited awareness of learning difficulties in nuclear physics was failure by the case teachers to begin their lessons with elicitation of student ideas. Yet, effective instruction needs to begin with such elicitation (McDermott, 2001; Shulman, 2000). This implies there is need to help the case teachers and others like them to develop awareness of existence of learning difficulties in nuclear physics. This could be done through in-service workshops for practising teachers. Pre-service physics teacher education courses need to be evaluated to find out if they help the pre-service teachers to develop awareness about teaching and learning difficulties in nuclear physics and other topics. Outcomes of such research could be used to decide if those courses need reviewing to include relevant activities or if research needs to be done to determine why there is no transfer of awareness of learning difficulties into classroom teaching.

7.4.2.3 Factors that influenced choice of learning strategies

This study found that the teachers' choices of strategies were mainly influenced by two case teachers' views: that science teaching should aid understanding of scientific facts and principles and that science teaching is about conveying information. This applied to all the case teachers. Differences in qualification seem to have had little impact on factors that influenced choice of strategies. All the four case teachers started their lessons with some questions, but these were mainly to remind students about previous work, not to elicit students' underlying ideas about concepts. It would seem the teachers were unaware that students would come to their lessons with some prior ideas. One of the case teachers even said that he used explanation because the topic was new, implying that students new nothing about nuclear physics. Thus, I argue that the choice of strategies was mainly influenced by the traditional view of physics teaching as described by Van Heuvelen (1991). According to Van Heuvelen (1991) traditional physics teaching involves, telling students physical rules that seem to guide the universe, demonstrating how to apply those rules to solve problems and supporting presentations with some experimental evidence. Actually, the aspect of experimental evidence did not appear with the case teachers.

Research on learning underlines the importance of recognising what students believe and understand and to use that as a starting point for instruction (Cocking et al., 2000; Shulman, 2000). The case teachers did not seem to have based their instruction on such thinking. Therefore, I argue that the case teachers' knowledge of students and their conceptions, which is an important aspect of PCK (Lee & Luft, 2008), was inadequate. This finding has implications. . Firstly, there is need to help the case teachers, and other teachers with similar difficulties to develop this particular aspect of PCK. Some of the suggestions made earlier apply here: the teachers could be organised into cooperative groups for discussing teaching aspects of nuclear physics, teacher educators could revisit their courses to see how they prepare teachers to adopt teaching based on student thinking. Secondly, I also observed that the classes were big (about 40 students per class), thus research would be needed to explore how teachers could cope with large classes while adopting strategies that take students' ideas into account.

7.4.2.4 Discussion of knowledge about teaching strategies

Pertaining to teaching strategies, the case teachers mostly used those that supported the traditional view of science teaching as transmission of information, with emphasis on solving equations and calculating numbers (Flores *et al.,* 2000).

I have already discussed findings on teaching strategies in subsection 7.3.2.2. Here, I will comment on what the findings reveal about the teachers' PCK. The use of strategies that focus on transmission of content could be interpreted in three ways: the teachers did not know alternative approaches, the teachers' beliefs about science and science teaching may have influenced them to choose the transmission model or context factors such as large classes may have had an influence.

If the teachers did not know alternative approaches, then there would be need to help the case teachers develop such approaches especially those based on the cognitive model of learning (Redish, 2000). The cooperative groups for teachers suggested earlier come to mind. The approach Loughran et al. (2004, 2001) used of engaging teachers in constructing CoRes and PaP-eRs could be adopted within the suggested cooperative groups or specially organised seminars with teacher educators or trained persons as facilitators. Research needs to be conducted with the case teachers and others to assess their knowledge of alternative teaching strategies. In the absence of research evidence, I only hypothesise that the case teachers had insufficient knowledge, if any, about alternative strategies as evidenced by the use of strategies that fit the transmission model.

If it is the case teachers' beliefs that influenced the use of the transmission model, then it means the case teachers believed physics is a body of knowledge and that physics teaching is about transmitting that body of knowledge. This argument is plausible because teachers' views of teaching and learning influence their classroom practice (Prawat, 1992). Prawat (1992) also asserts that when teachers view content and students in static, non-interactive terms, so much time and attention is devoted to the delivery of content instead of more substantive issues relating to content selection and meaning making on the part of students. The case teachers, and others like them, would have to be assisted to change their beliefs if their teaching is to change towards the cognitive model. Such change could only be possible if there is support in form of organising cooperative groups and in-service workshops.

If the teachers were influenced by context factors in using the strategies they did, then there is need to investigate what those factors are and how exactly they influence teaching strategies. One example is availability of relevant textbooks. I found that there is no textbook that is supposed to go with the PSS. Teachers used those textbooks published for foreign curricula. Analysis of two books, one by Abbey and Essiah (1990) and the other by Duncane and Kennett (2001), revealed that these two books are content-based. Also the books offer no teaching suggestions. One could research how use of books meant for foreign curricula affect the teaching of nuclear physics in Malawi. Also, there is need to develop a textbook for the course and relevant authorities like the Ministry of Education in conjunction with authors. Teachers and teacher educators could take this up. Other context factors are class sizes and the lack of infrastructure like laboratories and laboratory resources, especially for poorly resourced CDSSs. These too need to be researched in terms of how they influence teaching and how the teachers are coping. This study has shown with four case teachers that the teachers just resort to the model of teaching as transmission of content.

7.4.2.5 Knowledge about how to ascertain student understanding

Regarding ascertaining of student understanding, the case teachers mainly used oral questions that emphasised low order skills. The less qualified teachers tended to use less of such assessment compared to the more qualified ones. The use of questions that emphasised the low order skills of recalling, restating or engaging in procedural activities indicates that the case teachers may not have known that there is need to align teaching objectives and assessment. As already pointed out the teachers explained that they used certain strategies to aid student understanding and to convey information. However, assessment was mainly at the level of information. According to Biggs (1999) assessment at the understanding level is characterised by verbs such as relate, hypothesise, apply, explain, solve, analyse, and compare. The teachers, even those who are qualified, hardly used such verbs in the questions asked. In other words, the focus on the strategies that emphasised transmission of content was matched with the sort of assessment that emphasised recall of facts and principles. There were times when the case teachers could give other students opportunities to comment on another student's response, but this was mostly at the knowledge level or just to agree or disagree. I also noted that when an opportunity was created for a student to do something on the board, the students were not encouraged to make their thinking explicit. I feel that this points to the teachers' inability to engage in assessment of higher order skills like hypothesising, explaining, analysing and comparing. Of course the case teachers' mode of assessment may have been heavily influenced by the past examination questions. For instance, when I probed the choice of examples on calculation of average atomic masses, one case teacher admitted that he had taken it from a past examination paper.

It thus seems reasonable to suggest that the case teachers and others with similar characteristics need support in the form of workshops to discuss issues of classroom assessment. I argue that the way student understanding is ascertained and assessed is an expression of teacher expectations of the students. So, if students are only assessed at low levels, they will not do more than is expected of them. Thus, it is important, I feel, that teachers' skills to use questions that also assess higher order skills are developed. This cannot be achieved if the national examinations do not emphasise higher order skills because of the importance attached to them. Of course this study did not assess examination papers to check the sort of skills emphasised, so research is suggested to analyse questions asked in examinations papers from different years to identify the skills emphasised and the extent of alignment with objectives of the course.

7.4.2.6 Case teachers' ability to elicit ideas

One of the findings in this study has been that the case teachers did not begin their teaching by eliciting student ideas as suggested by McDermott (2001). I take this ability to be an important aspect of PCK because it is central to teaching based on the cognitive model of learning. However, as pointed out already, this ability is usually not included as a component of PCK. Thus, I argue for its explicit inclusion as a PCK aspect as at the moment it is just implied.

7.5 Reflection on the research process

In this section I briefly reflect on my experiences of doing this PhD study. To do this I focus on what I have learnt through this work. To begin with I have learnt that a high sense of responsibility and independent thinking are important. For other courses, the programme is well defined: objectives, curriculum materials, standardised assessment methods, and so on. The learner has just to present him or herself and be motivated. This is not the case with research-based studentship: one has to define own area of interest, work with minimum supervision, set own targets, know when to seek help and identify own supportive materials and this calls for a sense of responsibility and independent thinking. Even supervisors are able to guide and give feedback only when presented with something mainly in the form of thoughts generated independently on paper.

Next, I have learnt about the importance of critical reading in research. There is no part of my study that was not preceded or accompanied by some serious reading. Be it in preparation of the proposal, the data collection, the data analysis and organisation or the writing up stage they all demanded that I read, read and read. With the information explosion, I had to be selective. Decisions about what to select or not called for critical assessment of the documents to determine their relevance. Critical reading also applied to my own work. Asking apparently simple questions like 'What am I doing?' 'Why am I doing this?' or 'Am I making sense?' became the norm in the course of the research. Such questions helped me to appreciate the importance of metacognition, simply put which means being able to track one's thoughts.

Thirdly, doing research on an extended basis has taught me the joys and horrors of research. For instance, when I completed a task, such as having a topic approved as appropriate for PhD research, I could feel an immense sense of achievement and satisfaction. The sense of satisfaction that ensued kept me going even when the going was tough. This brings me to the horrors of research. One of the horrors is that I learnt that research requires both mental and physical strength, which is not always easy to maintain. Tasks such as preparing to make a presentation could bring in a lot of anxiety such that if mentally one is not strong it is easy to be totally stressed. Looking for a reference one has misplaced can be so disturbing. Receiving and accepting feedback on work also requires strength; as such feedback is not always favourable.

Fourthly, this study has brought me into contact with different kinds of people. This required people skills. For instance, there were times when I did not get something on time because it depended on other people like the permission to collect data in schools. It is easy to lose temper and spoil the relationship. I also had to know how to talk to or interact with my supervisors and others who have had input into the study. In research like this one, I learnt that much as independent thinking is vital, it is difficult to succeed without support of others.

Next, I have learnt about the importance of being organised. For instance, tracking documents read can be a daunting task if one is not organised. I remember the other day I was looking for a paper I read almost two years before. I needed it at that time, but I could not find it. If I had been more organised I would have found the paper easily and saved a lot of time.

Also, I now know how to write. In the past my difficulty was to find what to write about or how to write it. Now my problem is to stop writing, once I start. When I started writing this reflection, I thought I would not take more than half a page, but now it is close to two pages. I feel this lesson has set me on a career path of writing in my field of physics education.

Lastly, I have developed the ability to see with a different eye. For example, the process of drawing meaning from data was painful, but I eventually got something worth talking about out of the mess of things. I can say without fear of contradiction that the foundation of research is being able to see something extraordinary from the ordinary. I had to learn to look at data from different angles to get some sense.

7.6 Summary of recommendations

It has been found that nuclear physics is the most difficult topic in the PSS. Thus, I have recommended that:

1. Physics teacher educators should allow pre-service teachers to engage with the topic on nuclear physics in the form of identifying the main ideas, the potential teaching difficulties and possible strategies to address those difficulties. If such activities are not part of the curriculum, then it is necessary to review the physics teacher courses to include such activities.
2. Physical science teachers, facilitated by their methods advisors, should form cooperative groups where teaching of topics perceived as difficult like nuclear physics could be discussed.
3. There is need for researchers to explore more about the type of teaching difficulties associated with the topic, possible strategies for teaching the topic and to evaluate the available teaching resources.
4. Research is also needed to investigate the physical science teachers' understanding of nuclear physics concepts.
5. Curriculum planners and developers should develop supportive teaching resources like teachers' guides to assist teachers cope with the topic on nuclear physics.

This study has found that teachers used textbooks written for foreign curricula for this topic. I have made the following recommendations based on this finding:

1. Textbooks should be written based on the PSS.
2. Research should be done to assess how the use of books meant for foreign curricula is affecting delivery of the physical science curriculum.

The study has found that one of the reasons teachers gave for labelling nuclear physics as the most difficult to teach and learn is because of abstract concepts. From this, I have made the following recommendations:

1. Teacher development programmes, be it pre-service or in-service, should equip teachers with skills to teach the abstract concepts in nuclear physics.

2. Physical science methods advisors should work with teachers, perhaps through cooperative groups suggested earlier, to develop ways of teaching various abstract concepts in nuclear physics and other topics as well.
3. Research is needed to explore the issue of abstract concepts further with more teachers in order to determine prevalence of the view that nuclear physics is difficult to teach because of abstract concepts. Such research should extend to other topics in the PSS.
4. Researchers also need to conceive, develop and evaluate strategies for simplifying teaching abstract concepts in nuclear physics and other topics.

Case teachers also gave the reason that nuclear physics is difficult to teach and learn because it is difficult to do experiments. This finding implied being able to do experiments would simplify teaching of nuclear physics. From this I made the following recommendation:

1. Researchers should explore the type of experiments the PSTs had in mind and how doing those experiments would simplify teaching.

Although nuclear physics had been part of the PSS for six years at the time I collected data, the PTSs still thought the topic is difficult because it is new. In short teachers find it unfamiliar. From this I made the following recommendations:

1. Teachers need re-education in the ‘new’ topic and in this they need support.
2. Research is needed to examine the extent of re-education needed.

Another finding is that the case teachers I worked with did not display the skill to diagnose learning difficulties and base teaching on those difficulties. The following recommendations were made from this:

1. Methods advisors, physical science teachers and science education researchers could come together to conceive programmes aimed at developing this aspect of knowledge in practicing teachers. The

cooperative groups for teachers suggested earlier or in-service workshops could be utilised.

2. The case teachers, and others like them, need to be exposed to the literature on learning difficulties in physics, how to diagnose those difficulties and how to address them. The cooperative groups suggested earlier could help in this.
3. Physical science teacher educators should evaluate their programmes to determine how well they prepare pre-service teachers to diagnose learning difficulties and base teaching on them.
4. Research is needed to explore if physical science teachers possess skills to diagnose learning difficulties. And if they possess those skills, to explore what prevents teachers from transferring those skills.
5. Ability to diagnose student thinking should be explicitly included as a component of PCK.

I have also found that the case teachers adopted multi-method strategies. Those strategies were based on the transmission mode of teaching. The belief that physics is a body of knowledge and that teaching physics involved transmission of that body of knowledge, seems to have been the major factor in choice of strategies. The teachers were supposed to be the best in their category. Recommendations based on these are as follows:

1. Research should investigate on the extent to which average physical science teachers in Malawi are able to use different combinations of strategies when dealing with learning difficulties. Such research could also assess the teachers' knowledge of alternative teaching strategies.
2. The teacher educators should use strategies that model the strategies prospective physical science teachers are expected to use once they start teaching.
3. Physical science teacher educators should discuss with pre-service teachers what science constitutes and how to plan teaching of specific topics that presents a balanced view of science, not just as a body of knowledge.

4. There were only four case teachers, so researchers would have to explore further the view of science promoted by physical science teachers in Malawi on a larger scale.
5. Also, in Malawi there has been very little research into physical science teacher training programmes, so there is need to explore how those courses prepare teachers to present a balanced view of science in their lessons.

This research found the case teachers, except one, could not articulate main ideas of their lessons. Thus, the following recommendations have been made:

1. The cooperative groups for teachers suggested earlier, coordinated by methods advisors, should be used to engage teachers in discussing main ideas in nuclear physics and other topics that teachers might find challenging to teach.
2. Teachers like T25, who can articulate main ideas, should be identified and used as resource persons in the suggested cooperative groups.
3. There is need for further research to explore with more teachers the extent to which Malawian physical science teachers can articulate main ideas.

It has also been found that the classes for the case teachers were large. Thus, I recommended that research be done to explore how teachers could still adopt the model that encourages basing teaching on student learning difficulties.

The study also found that some case teachers included work not supposed to be covered under nuclear physics. This should have been related to problems of interpreting the PSS. Thus, the following recommendation: the PSS, being one of the documents teachers use almost daily, should be revised to include details that help teachers to interpret it without difficulty, especially that some of the physical science teachers are not qualified.

Finally, this study found that teachers mainly used low order questions to assess student understanding. From this I recommended that:

1. There is need to discuss issues of assessment with the case teachers and other teachers like them, in workshops or cooperative groups suggested earlier.
2. Research is needed to determine the influence of the national examinations on the teachers' modes of assessments and the skills emphasised by those examinations.

7.7 Conclusion

In this study I set out to answer four questions. Those questions were as follows:

1. What reasons do Malawian PSTs give for rating *nuclear physics* as the most difficult topic to teach?
2. What teaching strategies do Malawian PSTs use to address difficulties students face in learning *nuclear physics* concepts?
3. What reasons do the teachers give for choosing some teaching strategies?
4. What can be learnt from the study of teaching strategies about the nature of Malawian PSTs' pedagogical content knowledge (PCK) with respect to nuclear physics?

I attempted to answer the first question in Chapter 4, the second and third questions in Chapter 5 and last one in Chapter 6. In this chapter I have summarised the results from Chapters 4, 5 and 6. I have also discussed the implications of those results for classroom practise, teacher education courses and research.

In conclusion, I present the quotation from Shulman (2000: 133),

> "Fundamentally, teaching involves just two processes. Understanding begins with what is already inside the learner's head. All students come to us with prior ideas, and our first pedagogical challenge is to bring what is inside, out: to make the internal external, to make the private public, to make the implicit explicit."

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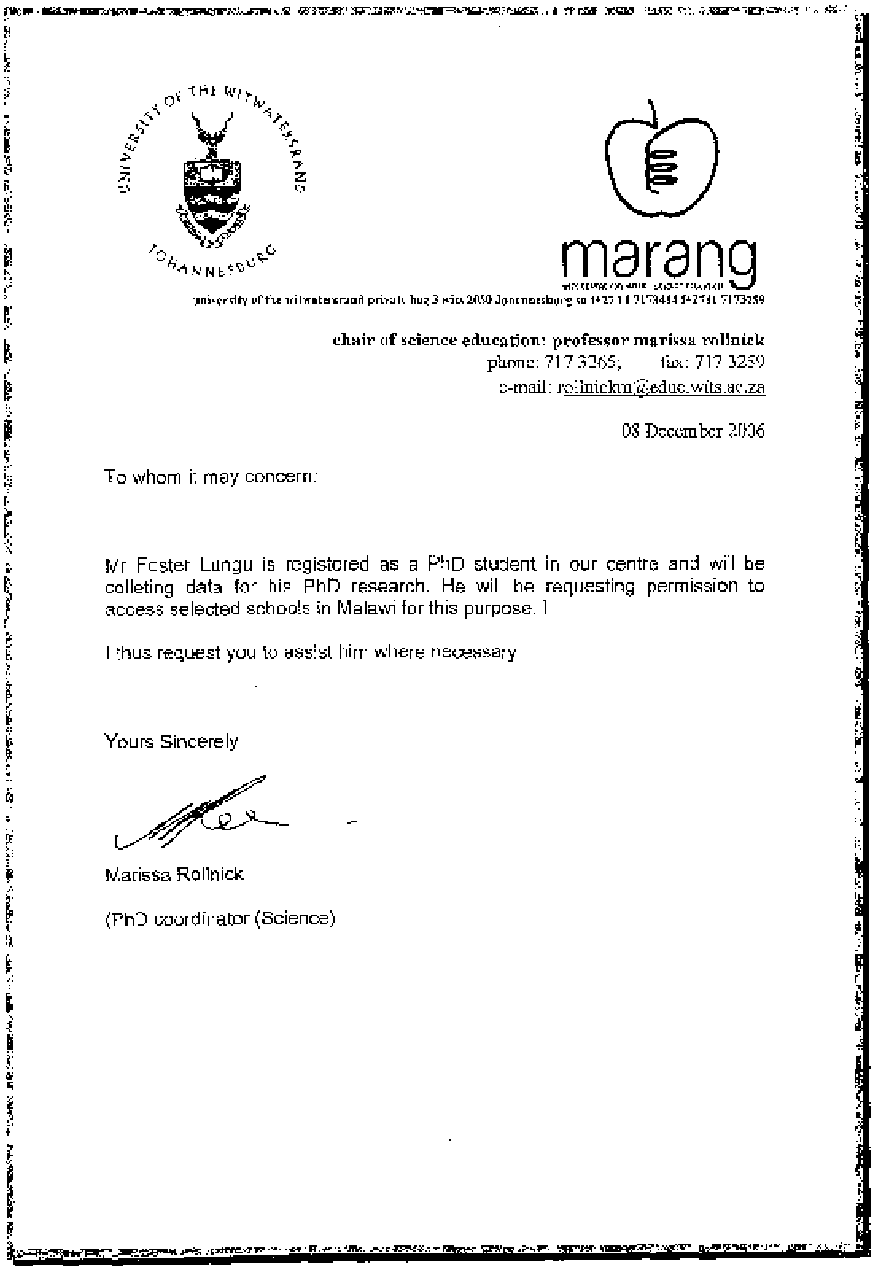
APPENDICES

Appendix 1: Letter of introduction from Wits University



university of the witwatersrand private bag 3 wits 2050 johannesburg sa t+27 11 7173414 f+27 11 7173259

chair of science education: professor marissa rollnick
phone: 717 3265; fax: 717 3259
e-mail: rollnickm@educ.wits.ac.za

08 December 2006

To whom it may concern:

Mr Foster Lungu is registered as a PhD student in our centre and will be colleting data for his PhD research. He will be requesting permission to access selected schools in Malawi for this purpose. I

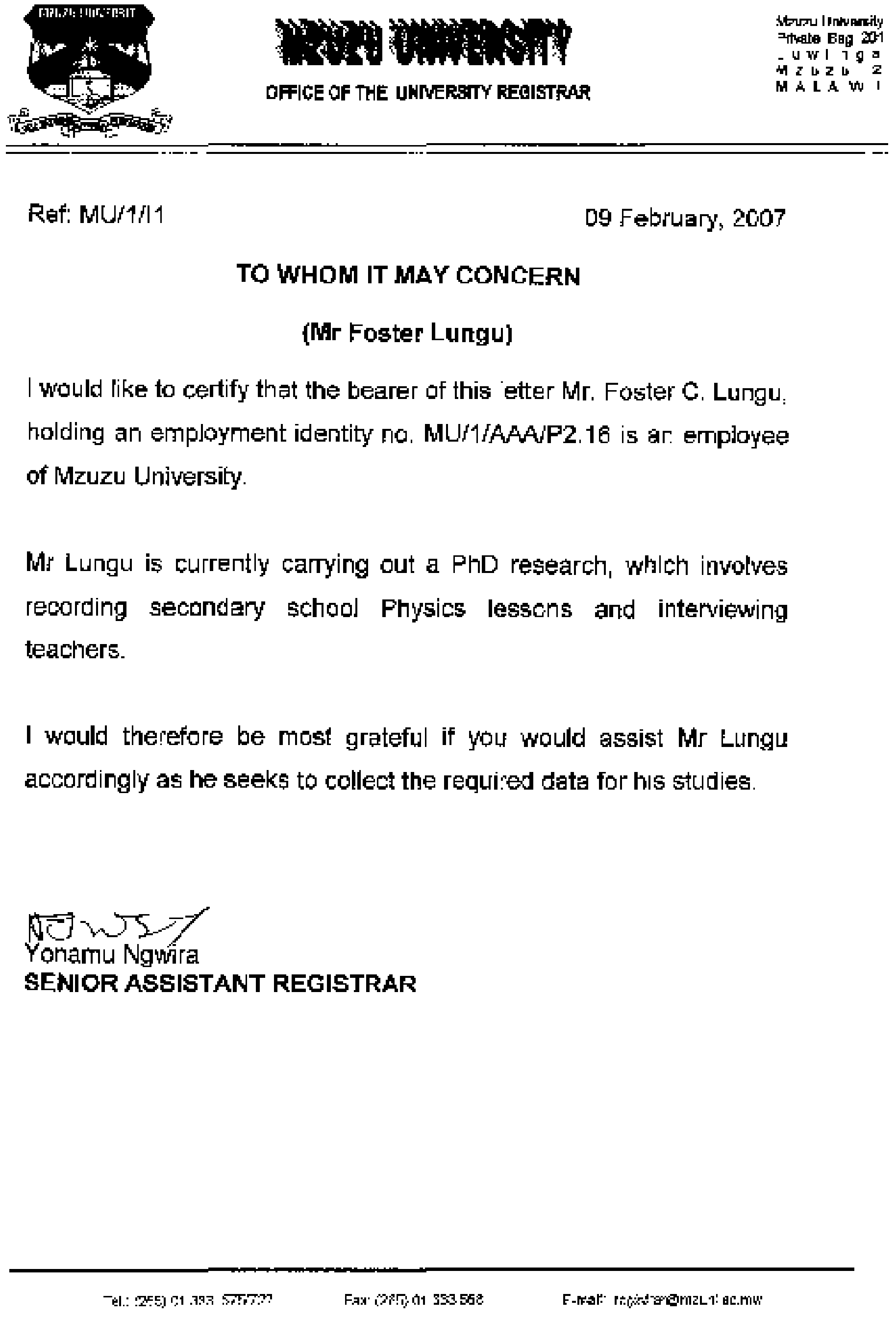
I thus request you to assist him where necessary

Yours Sincerely

Marissa Rollnick

(PhD coordinator (Science)

Appendix 2: Letter of introduction from my employer



MZUZU UNIVERSITY
OFFICE OF THE UNIVERSITY REGISTRAR

Mzuzu University
Private Bag 201
Luwinga
Mzuzu 2
MALAWI

Ref: MU/1/I1 09 February, 2007

TO WHOM IT MAY CONCERN

(Mr Foster Lungu)

I would like to certify that the bearer of this letter Mr. Foster C. Lungu, holding an employment identity no. MU/1/AAA/P2.16 is an employee of Mzuzu University.

Mr Lungu is currently carrying out a PhD research, which involves recording secondary school Physics lessons and interviewing teachers.

I would therefore be most grateful if you would assist Mr Lungu accordingly as he seeks to collect the required data for his studies.

Yonamu Ngwira
SENIOR ASSISTANT REGISTRAR

Tel.: (265) 01 333 [illegible] Fax: (265) 01 333 568 E-mail: registrar@mzuni.ac.mw

Appendix 3: Request for permission from Ministry of Education

Mzuzu University
Private Bag 201
Luwinga
Mzuzu 2
8 January 2007

The Secretary for Education
Private Bag 328
Capital City
Lilongwe3

Dear Sir/Madam,

REQUEST FOR PERMISSION TO CONDUCT RESEARCH IN SOME SECONDARY SCHOOLS IN MALAWI

My name is Foster C. Lungu and I work with Mzuzu University as a senior lecturer in physics education. Currently, I am pursuing PhD studies with the University of Witwatersrand in South Africa. Having successfully completed my proposal, I am ready to start data collection. My writing is to seek written permission from your office for me to start data collection in Malawian secondary schools.

The title of my research is: “Investigating Malawian physical science teachers’ teaching strategies: a case study in nuclear physics.” Data collection will involve video-recording lessons, interviewing teachers and analysing some teaching materials. Issues of confidentiality and consent will be taken care of.

For more information, please refer to the attached information letter or contact me on 09144832.

Yours faithfully,

Foster C. Lungu

Appendix 4: Information letter to Ministry of Education

Research study on investigating Malawian physical science teachers' teaching strategies: a case study in nuclear physics

My name is Foster Lungu. I am registered in the Faculty of Science of the University of the Witwatersrand in South Africa as a Doctor of Philosophy (PhD) student.

I am now conducting research on strategies physical science teachers use in teaching nuclear physics. I would like to seek your permission to involve physical science teachers from secondary schools in Malawi.

This study focuses on investigating teaching strategies employed to help students understand concepts in nuclear physics. Thus, this research project will seek answers to the following questions:

- What reasons do Malawian teachers give for classifying secondary school *nuclear physics* as one of the difficult topics to teach and learn?
- What is the nature of teaching strategies that Malawian physical science teachers use to deal with learning problems associated with the topic *Nuclear Physics?*
- What reasons do teachers give for adopting a particular teaching strategy?

I anticipate that answers to these questions will help in teachers' implementation of our new physical science curriculum in Malawi. From the findings, it will also be possible to contribute to an understanding of ways of making teachers teach the subject more effectively, and help students understand science better.

To gain understanding of the strategies employed in teaching nuclear physics, it is important to work with teachers. I would like to interview them and observe their lessons on nuclear physics. The aim is to learn from them and identify the strategies they will be using in their lessons. Some teachers who are not experienced in teaching science might learn a lot from sharing these strategies.

The interviews will take place before and after each lesson, on the same day. It is expected that each interview session will last no more than thirty minutes after teaching time. With the teacher's permission, the observations will involve some video-recording when the teacher will be teaching nuclear physics.

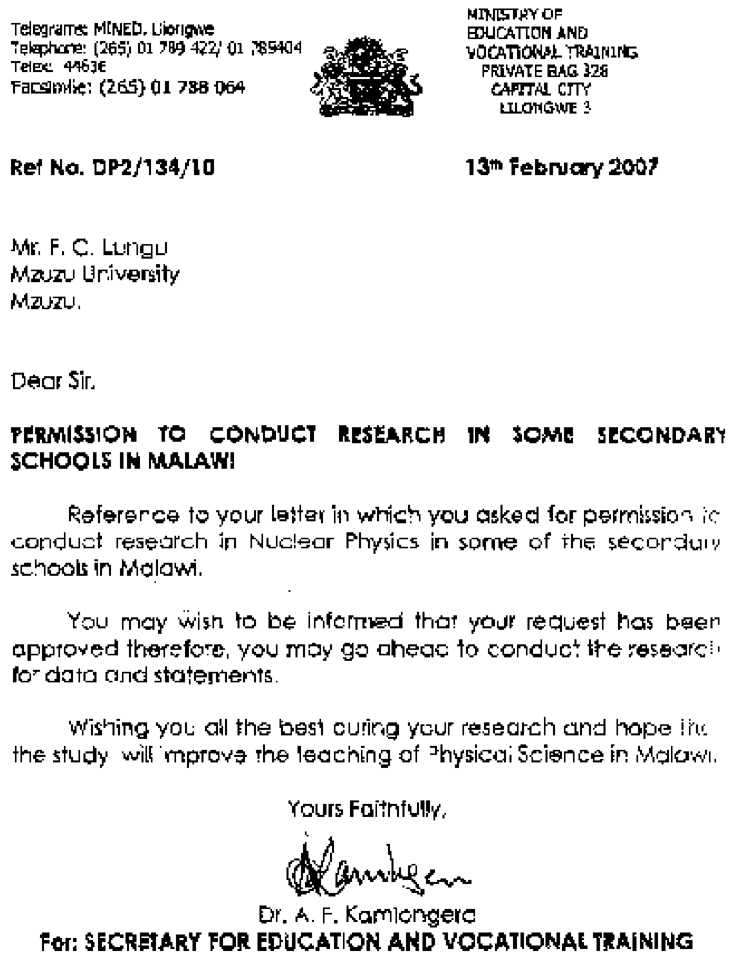
Teachers' participation in this study is entirely voluntary. All the information gained from the study will be treated confidentially and that their identities will be preserved. They will not be forced to answer any question during interviews and discussions. Teachers may withdraw from the study at any time if they so wish. I hope to publish the results of my study in teacher education journals and conferences. The identities of the participating teachers will be protected in these publications and presentations.

I will provide you with a summary of my research findings on completion of the study.

Thank you.

Foster Lungu Date: 18 October 2006.

Appendix 5: Permission by Ministry of Education



Telegrams: MINED, Lilongwe
Telephone: (265) 01 789 422/ 01 789404
Telex: 44636
Facsimile: (265) 01 788 064

MINISTRY OF
EDUCATION AND
VOCATIONAL TRAINING
PRIVATE BAG 328
CAPITAL CITY
LILONGWE 3

Ref No. DP2/134/10 **13th February 2007**

Mr. F. C. Lungu
Mzuzu University
Mzuzu.

Dear Sir,

PERMISSION TO CONDUCT RESEARCH IN SOME SECONDARY SCHOOLS IN MALAWI

Reference to your letter in which you asked for permission to conduct research in Nuclear Physics in some of the secondary schools in Malawi.

You may wish to be informed that your request has been approved therefore, you may go ahead to conduct the research for data and statements.

Wishing you all the best during your research and hope the the study will improve the teaching of Physical Science in Malawi.

Yours Faithfully,

Dr. A. F. Kamlongera
For: SECRETARY FOR EDUCATION AND VOCATIONAL TRAINING

Appendix 6: Teachers' questionnaire

Dear Sir/Madam,

My name is Foster Lungu. I am a student at the University of Witwatersrand in South Africa and I am doing research in fulfillment of the requirements for the award of the degree of Doctor of Philosophy. The aim of this questionnaire is to identify the physics topic considered as most difficult to teach in the senior physical science syllabus. Thus, I would like to request you to respond to the questions below. Please note that this is not a test, thus I would appreciate if you responded as truthfully as possible. Your name and school have been included to enable me follow up on your responses. Please note that any information you provide will be treated confidentially. This questionnaire should take you about ten minutes to complete.

If you consent to participate in this research please indicate this by signing in the space provided here ____

1 Your name: ____

2 Tick your highest qualification.

M.S.C.E ______ T2 ______ DIP ED ________ BED _________

Other (Specify) ____

3 Your teaching experience (in years): ___________________________

4 Your sex: Male _________ Female ______________

5 Your School: ____

6 Below is a list of physics topics found in the Physical Science Syllabus for forms 3 and 4. Tick the topic that you find most difficult to teach.

Forces and motion
Properties of matter
Nuclear physics
Oscillations and waves
Electricity, magnetism and electromagnetic induction

7 Give as many reasons as possible for choosing this topic as the most difficult to teach.

____

____

____

____

8 What aspects of this topic make it difficult to teach?

____

____

____

____

9 Which topic would your students find most difficult to learn? Explain

____

____

____

____

Thank you for your cooperation.

Appendix 7: Letter to head teachers of schools

Mzuzu University
Private Bag 201
Luwinga
Mzuzu 2
27 March 2007

Dear Sir/Madam,

TO WHOM IT MAY CONCERN

My name is Foster Lungu, a PHd student at the University of Witwatersrand in South Africa and an employee of Mzuzu University (See enclosed copies of the letters from the University of Witwatersrand and Mzuzu University).

I have obtained permission to conduct research in some Malawian secondary schools (See enclosed letter). I write to request you to grant me permission to involve some of your physical science teachers in my research. I have enclosed an information sheet pertaining to the research.

I have also enclosed two questionnaires for two of your physical science teachers to complete.

I thank you in advance for your favourable consideration.

Yours faithfully,

Foster C. Lungu.

Appendix 8: Information letter for school principals

Research study on investigating Malawian physical science teachers' teaching strategies.

My name is Foster Lungu. I am registered in the Faculty of Science of the University of the Witwatersrand in South Africa as a Doctor of Philosophy (PhD) student.

I am now conducting research on strategies physical science teachers use in teaching physics. I would like to investigate which physics section the teachers find most difficult to teach and how they handle the difficulties. The Ministry of Education has granted me permission to carry out this study in selected Malawian schools (see attached letter). I now request your permission to involve physical science teacher(s) from your school.

This study focuses on investigating teaching strategies employed to help students understand concepts in physics. Thus, this research project will seek answers to the following questions:

- What reasons do Malawian teachers give for classifying some secondary school physics topics as difficult to teach and learn?
- What is the nature of teaching strategies that Malawian physical science teachers use to deal with learning problems associated with Physics?
- What reasons do teachers give for adopting a particular teaching strategy?

I anticipate that answers to these questions will help in designing or revising pre-service and in-service teacher development programmes for physical science teachers in Malawi. From the findings, it will also be possible to contribute to an understanding of ways of making teachers teach the subject more effectively, and help students better understand science.

To gain understanding of the strategies employed in teaching physics, it is important to work with teachers. I would like to interview them and observe their lessons on nuclear physics. The aim is to learn from them and identify the strategies they will be using in their lessons. Some teachers who are not experienced in teaching science might learn a lot from sharing these strategies.

The interviews will take place before and after each lesson. It is expected that each interview session will last no more than thirty minutes after teaching time. With the teacher's permission, the observations will involve some video-recording when the teacher will be teaching nuclear physics.

Teachers' participation in this study is entirely voluntary. All the information gained from the study will be treated confidentially and their identity will be preserved. They will not be forced to answer any question during interviews and discussions. Teachers may withdraw from the study at any time if they so wish. I hope to publish the results of my study in teacher education journals and conferences. The identities of the participating teachers will be protected in these publications and presentations.

I will provide you with a summary of my research findings on completion of the study.

Thank you.

Foster Lungu Date: 18 October 2006.

Appendix 9: Information sheet for participating teachers

Research study on investigating Malawian physical science teachers' teaching strategies: a case study in nuclear physics

My name is Foster Lungu. I am registered in the Faculty of Science of the University of the Witwatersrand in South Africa as a Doctor of Philosophy (PhD) student.

I am now conducting research on strategies physical science teachers use in teaching nuclear physics. The Ministry of Education has granted me permission to carry out this study in selected Malawian schools. The head teacher has granted me permission to involve one physical science teacher from this school.

This study focuses on investigating teaching strategies employed to help students understand concepts in nuclear physics. Thus, this research project will seek answers to the following questions:

1. What reasons do Malawian teachers give for classifying secondary school *nuclear physics* as one of the difficult topics to teach and learn?
2. What is the nature of teaching strategies that Malawian physical science teachers use to deal with learning problems associated with the topic *Nuclear Physics?*
3. What reasons do teachers give for adopting a particular teaching strategy?

I anticipate that answers to these questions will help in designing or revising pre-service and in-service teacher development programmes for physical science teachers in Malawi. From the findings, it will also be possible to contribute to an understanding of ways of making teachers teach the subject more effectively, and help students better understand science.

To gain understanding of the strategies employed in teaching nuclear physics, it is important to work with some of the teachers. I would like to interview you and observe your lessons on nuclear physics. The aim is to learn from you and identify the strategies you will be using in your lessons. Some teachers who are not experienced in teaching science might learn a lot from sharing these strategies.

The interviews will take place before and after each lesson on the day the lesson is held. It is expected that each interview session will last no more than thirty minutes. With your permission, the observations will involve video recording when you will be teaching nuclear physics.

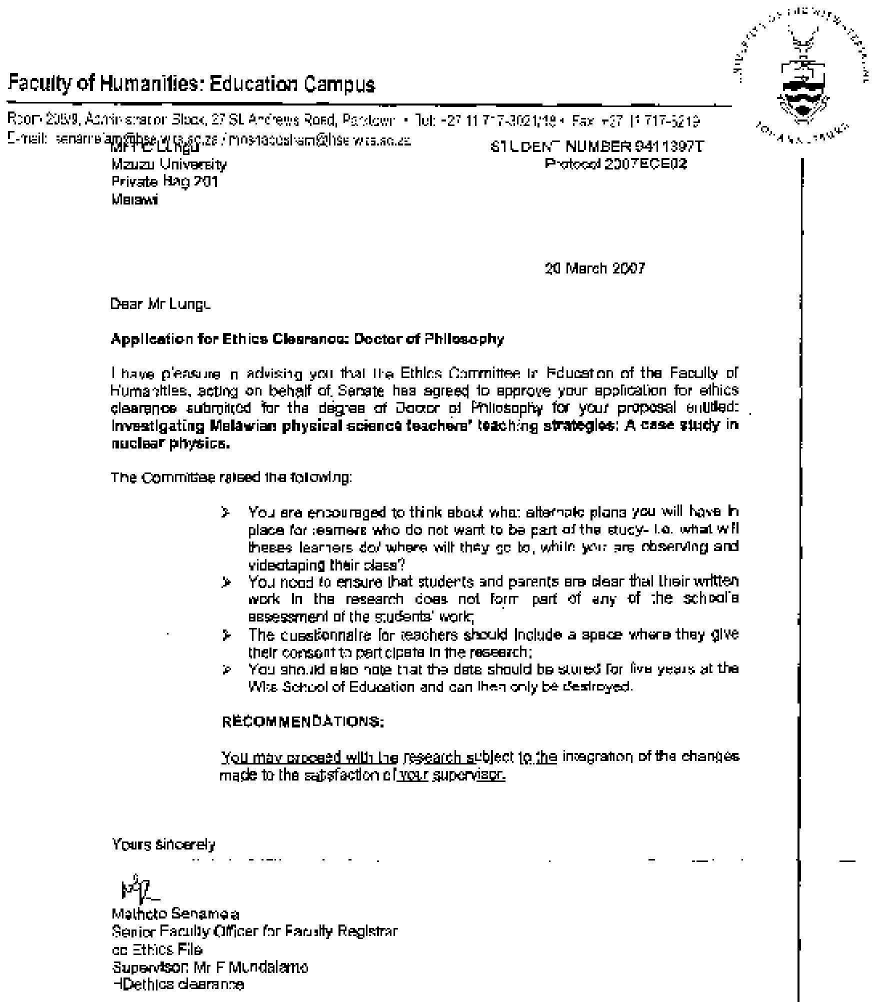
Your participation in this study is entirely voluntary. All the information gained from the study will be treated confidentially and that your identity will remain anonymous. No staff member or member of management will have any access to the information you provide. I hope to publish the results of my study in academic journals. In order to protect confidentiality, I will not use your real names.

I will provide you with a summary of my research findings on completion of the study.

Thank you.

Foster Lungu Date: 18 October 2006.

Appendix 10: Ethics clearance



Faculty of Humanities: Education Campus

Room 2059, Administration Block, 27 St Andrews Road, Parktown • Tel: +27 11 717-3021/18 • Fax +27 11 717-3219
E-mail: senamelam@hse.wits.ac.za / mosiaoushem@hse.wits.ac.za

Mr C Lungu
Mzuzu University
Private Bag 201
Malawi

STUDENT NUMBER 9411397T
Protocol 2007ECE02

20 March 2007

Dear Mr Lungu

Application for Ethics Clearance: Doctor of Philosophy

I have pleasure in advising you that the Ethics Committee in Education of the Faculty of Humanities, acting on behalf of Senate has agreed to approve your application for ethics clearance submitted for the degree of Doctor of Philosophy for your proposal entitled: **Investigating Malawian physical science teachers' teaching strategies: A case study in nuclear physics.**

The Committee raised the following:

- You are encouraged to think about what alternate plans you will have in place for learners who do not want to be part of the study- i.e. what will theses learners do/ where will they go to, while you are observing and videotaping their class?
- You need to ensure that students and parents are clear that their written work in the research does not form part of any of the school's assessment of the students' work;
- The questionnaire for teachers should include a space where they give their consent to participate in the research;
- You should also note that the data should be stored for five years at the Wits School of Education and can then only be destroyed.

RECOMMENDATIONS:

You may proceed with the research subject to the integration of the changes made to the satisfaction of your supervisor.

Yours sincerely

Mathoto Senamela
Senior Faculty Officer for Faculty Registrar
cc Ethics File
Supervisor: Mr F Mundalamo
HDethics clearance

Appendix 11: Consent form for teachers' participation

Title of Research Project: Investigating Malawian physical science teachers' teaching strategies: case of nuclear physics

I, ________________________________, consent to participate in this study conducted by Mr. Foster Lungu, a PhD student of the University of the Witwatersrand, for his research on strategies Malawian physical science teachers use in teaching nuclear physics.

- I realize that there are no risks attached to my involvement in this study, and that the study is being conducted for educational purposes only.
- I understand that I participate voluntarily in the study.
- I further consent to being audio/video recorded as part of the study.
- I also understand that everything I say will be kept confidential and I will only be identified by a pseudonym in the transcript.
- I also consent that verbatim quotes from me may be used in the research report, but they will be reported so that my identity is anonymous.

Name: ____

Signature: ____

Date: ____ ______

Appendix 12: Consent form for teachers

Title of Research Project: Investigating Malawian physical science teachers' teaching strategies: case of nuclear physics

I, ________________________________, give my consent for the researcher, Mr. Foster Lungu, a PhD student of the University of the Witwatersrand, to audiotape the interviews conducted with me or video record my lessons in nuclear physics for his research on teaching strategies Malawian physical science teachers use in teaching nuclear physics.

- I realize that there are no risks attached to my involvement in this study, and that the study is being conducted for educational purposes only.
- I understand that I participate voluntarily in the study.
- I consent that the audio/video recording will be done by the researcher.
- I understand that the contents of the audio or videotapes will be used only for the purposes of this research and only by the researcher and be kept strictly confidential.
- I understand that the only the researcher will have access to the audio or videotapes..
- I understand that the interviews will be recorded in about 30 minutes..
- I understand that the audio or videotapes of the interviews will be completely destroyed once the study is completed.

Name: ____

Signature: ____

Date: ____

Appendix 13: Information letter for students

Research study on investigating Malawian physical science teachers' teaching strategies: a case study in nuclear physics

Hi! My name is Foster Lungu. I am studying for a degree of Doctor of Philosophy at the University of Witwatersrand in South Africa.

As part of my studies, I am conducting research on how science teachers teach physical science. I would like to seek your permission to involve you in my research. This research focuses on how teachers teach science and help students understand ideas about physics.

To know more about how ideas about nuclear physics are taught and learnt, it is important to work with you and your teachers. I would like to attend some of your lessons. In addition, I would like, with your permission, to look at some of the notes that you make during lessons. In order to make accurate observations of your important lessons, I would also like to video-record the lessons. This information will help me to understand more about the teaching of science in schools and to find ways of making students learn science better. All the information gained from the study will be treated in confidence.

Your participation in this research will add important information about how students learn science in Malawi.

Thank you.

Foster Lungu　　　　Date: 18 October 2006.

Appendix 14: Information letter for parents

Research study on investigating Malawian physical science teachers' teaching strategies: a case study in nuclear physics

My name is Foster Lungu. I am registered in the Faculty of Science of the University of the Witwatersrand in South Africa as a Doctor of Philosophy (PhD) student. This research focuses on how teachers help students understand physics concepts perceived as difficult.

To know more about how nuclear physics ideas are taught and learnt, it is important to work with teachers and students. I will be attending some of lessons on nuclear physics. In addition, I would like, with your permission, to look at some of the notes that your child will be making during lessons. In order to make accurate observations of lessons, I would also like to video-record the lessons. This information will help me better understand the teaching of science in schools in Malawi and to find ways of making students learn science better. All information gained from the study will be treated in confidence.

Your child's participation in this research will add very useful information about how students learn science in Malawi.

If you agree to your child's participation in this research, please complete the form attached.

Thank you.

Foster Lungu.

Appendix 15: Consent form for parents

Title of Research Project: Investigating Malawian physical science teachers' teaching strategies: a case study in nuclear physics

I, _________________________________, give my consent for the researcher, Mr. Foster Lungu, a PhD student of the University of the Witwatersrand, to video record lessons where my child will be learning physical science.

- I realize that there are no risks attached to my child's involvement in this study, and that the notes collected from my child will be used for research purposes only.
- I consent that the video recording will be done by the researcher.
- I understand that the contents of the videotapes will be used only for the purposes of this research and only by the researcher and be kept strictly confidential.
- I understand that the videotapes will be kept in a safely locked cabinet, to which only the researcher has access.
- I understand that the videotapes of the lessons will be destroyed once the study is completed.

Name: ____

Signature: ____

Date: ____

Appendix 16: Guiding interview questions

Pre-observation interview questions

What is today’s lesson about?

What main ideas are you going to cover?

What difficulties are associated with the teaching of this lesson?

What teaching strategies will you use? Explain.

What else can you tell me about today’s lesson?

Post-observation interview questions

I saw that you used this teaching strategy. Could you explain?

Why did you change the strategy when covering this (*name the idea*) idea?

Students seemed to understand this idea (*name the idea*). Why was the case?

If you were to re-teach the lesson, would you use the same approach? Explain.

Is there anything you would like to add about today’s lesson?

Appendix 17: Results on nuclear physics as most difficult topic

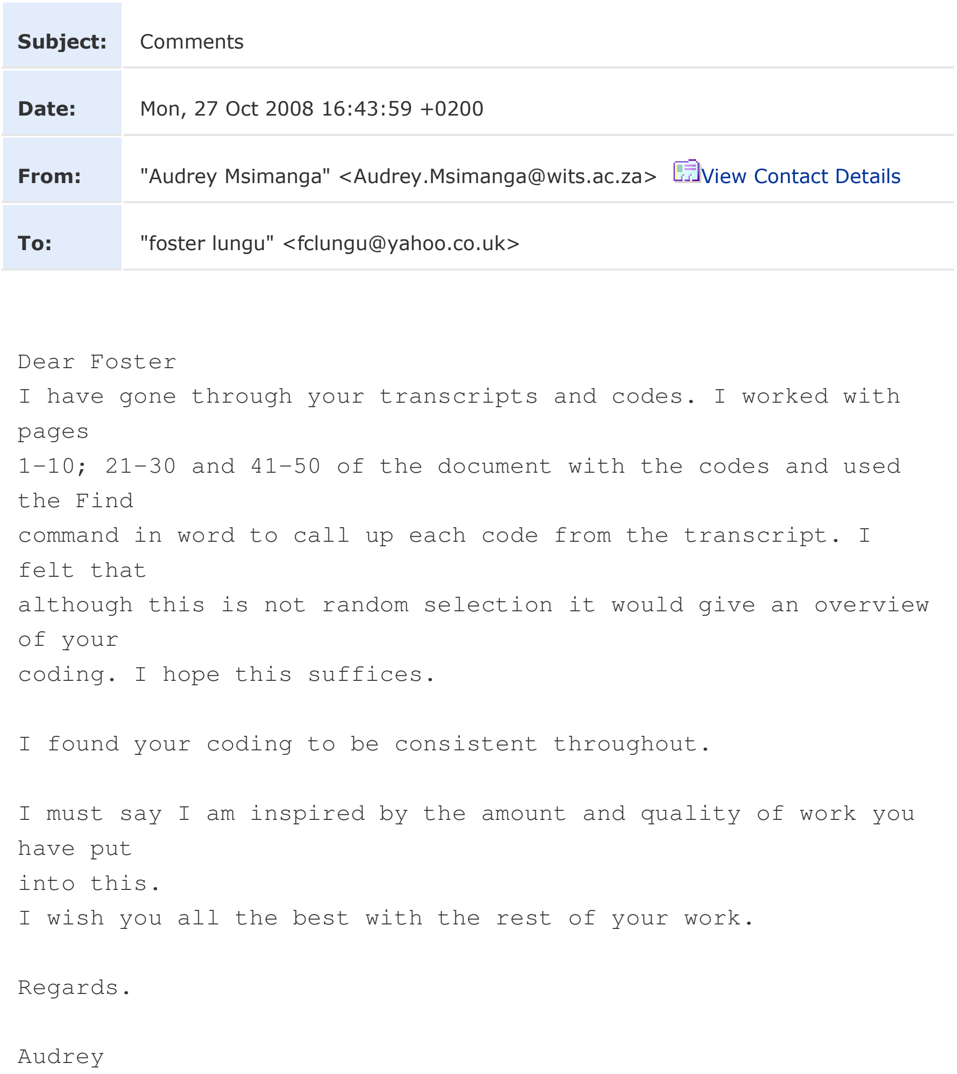
*REASONS GIVEN FOR LABELLING NUCLEAR PHYSICS AS MDT	*ASPECTS OF NUCLEAR PHYSICS THAT ARE MDT	*REASONS FOR LABELLING NUCLEAR PHYSICS AS MDL
1. Lack of teaching materials (8) 2. Most concepts are abstract (7) 3. The topic is new (5) 4. Difficult to do experiments at this level (3) 5. Deals with dangerous substances (2) 6. Lack of relevant textbooks (2) 7. It is complex for students (2) 8. Teacher inadequacies (2) 9. Difficult to apply to real life situation (1)	1. Radioactive decay process (8) 2. Nuclear calculations (5) 3. Nature of gamma rays, beta & alpha particles (4) 4. Nuclear fission & fusion (2) 5. Half life (2) 6. Detectors of radioactivity (2) 7. Forms or isotopes of elements (1) 8. The elements involved are out side the first 20 in the periodic table that are recommended (1) 9. Balancing nuclear reactions (1) 10. Transfer nuclear energy to various working field (1)	1. Some ideas are hard to understand (8). 2. Lack of teaching materials like detectors (4) 3. Preconceived ideas from periodic table (1) 4. Students take the topic as irrelevant (1). 5. Needs high class reasoning (1) 6. Poor teacher presentation (1) 7. Lack of basic knowledge from forms 1 and 2 (1)

*Numbers in brackets represent frequencies of occurrence or number of respondents who mentioned it

Notes

1. The following were interpreted to mean the same thing: concepts are abstract, the topic is theoretical and it is difficult to do experiments.
2. Reason 8 has implications for confidence of the concerned teachers; where a teacher feels inadequate, confidence is likely to be low.
3. Under aspects that are MDT, the following responses, perceived as irrelevant by the researcher, were left out: teachers' lack of understanding of subject matter, lack of teaching approaches, lack of apparatus, the topic is very scientific
4. Compare responses on aspects that are most difficult to teach (MDT) with difficulties from examiners reports

Appendix 18: Comments on the coding system



Subject:	Comments
Date:	Mon, 27 Oct 2008 16:43:59 +0200
From:	"Audrey Msimanga" <Audrey.Msimanga@wits.ac.za> View Contact Details
To:	"foster lungu" <fclungu@yahoo.co.uk>

Dear Foster
I have gone through your transcripts and codes. I worked with pages 1-10; 21-30 and 41-50 of the document with the codes and used the Find command in word to call up each code from the transcript. I felt that although this is not random selection it would give an overview of your coding. I hope this suffices.

I found your coding to be consistent throughout.

I must say I am inspired by the amount and quality of work you have put into this.
I wish you all the best with the rest of your work.

Regards.

Audrey

Appendix 19: Codes about planned content and anticipated difficulties

```
------------------------------------------------------------------
                         PRIMARY DOCUMENTS
CODES                    10     11     12     13     14     15     16     17
------------------------------------------------------------------
Atom Pre                 0      0      3      0      3      1      0      0
Atomic mass Pre          0      0      0      0      0      1      0      2
Calculation Pre          0      0      0      0      0      1      0      0
Chem change Pre          0      0      1      0      0      0      0      0
Detection Pre            0      0      1      0      0      0      0      0
Diff abstract Pre        0      0      1      0      2      0      0      0
Diff aids Pre            0      0      0      0      4      0      0      0
Diff Defn Pre            0      0      0      0      0      0      0      2
Diff disintegrate Pre0          0      1      0      0      0      0      0
Diff nutronprot Pre      0      3      0      0      0      0      0      0
Diff rad details Pre     0      0      1      0      0      0      0      0
Easy expect Pre          0      1      0      0      0      0      0      0
Electric field Pre       1      0      1      0      0      0      0      0
Electron Pre             0      1      1      0      1      0      0      1
Guidelines Pre           0      0      0      0      0      0      1      0
Isotope Pre              0      1      2      0      0      1      0      3
Magnetic field Pre       1      0      1      0      0      0      0      0
Neutron Pre              0      2      1      0      0      1      1      1
No diff Pre              1      0      0      0      0      0      1      0
Nuclear reaction Pre     0      1      2      0      0      0      0      0
Nucleons Pre              0     0     0      0      0       1      0      0
Nucleus Pre              0      0      0      0      1      1      1      0
Periodic table Pre       0      0      0      0      1      0      0      0
Positive charge Pre      0      0      1      0      0      0      0      0
Proton Pre               0      1      1      0      1      0      1      1
Rad alpha Pre            2      4      3      0      0      0      0      0
Rad beta Pre             1      5      3      0      0      0      0      0
Rad emission Pre         0      0      1      0      0      0      0      0
Rad gamma Pre            1      1      3      0      0      0      0      0
Rad substances Pre       1      0      1      0      0      0      0      0
Radioactivity Pre        0      1      4      0      0      0      0      0
Stability Pre            0      0      0      0      0      0      2      0
Std notation Pre         0      0      0      0      0      1      0      0
Teach underst Pre        0      3      6      0      3      0      0      0
Types radiation Pre      1      0      1      0      0      0      0      0
What to do Pre           1      1      5      0      1      2      1      2
```

Appendix 20: Frequencies of codes for observed learning difficulties

```
-----------------------------------------------------------------
                         PRIMARY DOCUMENTS
CODES                10    11    12    13    14    15    16    17
-----------------------------------------------------------------
Diff atom split Vi   0     0     0     6     0     0     0     0
Diff calculation St  0     2     0     1     0     1     0     0
Diff calculation Vi  0     5     1     0     0     0     0     1
Diff conception St   5     3     0     3     2     0     1     0
Diff conception Vi   1     0     3     2     1     3     0     2
Diff defn Vi         0     0     0     0     0     0     0     1
Diff diagram St      3     0     0     0     0     0     0     0
Diff experiment St   0     0     1     0     1     0     0     0
Diff explain St      0     0     2     0     0     0     0     0
Diff explain Vi      0     0     1     0     0     0     0     0
Diff fields St       2     0     0     0     0     0     0     0
Diff guidelines Vi   0     0     0     0     0     0     3     0
Diff isotope St      0     0     1     1     0     0     0     2
Diff limit Vi        0     0     0     0     0     0     1     0
Diff mass no Vi      1     2     2     0     0     0     0     0
Diff mass St         0     0     0     0     1     0     0     1
Diff new topic Vi    0     0     0     1     0     0     0     0
Diff nutronprot St   2     2     0     0     0     0     0     0
Diff nutronprot Vi   1     5     0     0     0     0     0     0
Diff principle Vi    0     0     1     0     0     0     0     0
Diff proton no Vi    0     0     0     0     0     0     0     1
Diff rad effect St   3     1     0     0     0     0     0     0
Diff average mass Vi 0     0     1     0     0     0     0     0
Diff Stability Vi    0     0     0     0     0     0     5     0
Diff symbol St       0     0     0     0     1     2     0     0
Diff symbol Vi       0     1     0     0     2     0     0     1
St diff numbers Vi   1     0     0     0     0     0     0     0
```

Appendix 21: Distribution of teaching strategies codes

	PRIMARY DOCUMENTS							
CODES	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Meth call quests Vi	0	0	0	0	0	1	5	0
Meth caution Vi	2	0	0	0	0	0	0	0
Meth chart Pre	3	0	1	0	0	0	0	0
Meth chart Vi	6	0	5	1	1	4	3	0
Meth clas discus Vi	0	0	0	0	0	0	4	0
Meth compare Vi	1	2	0	1	0	0	0	0
Meth demo Vi	2	0	0	5	0	0	0	0
Meth diagram Vi	20	26	9	14	4	2	0	1
Meth discuss Pre	1	2	1	0	0	2	0	0
Meth example Vi	6	7	20	2	4	8	0	7
Meth exercise Pre	0	0	1	0	0	0	1	0
Meth exercise Vi	0	0	0	0	0	0	2	0
Meth expose Pre	3	2	4	0	1	0	0	1
Meth expose Vi	43	48	29	31	14	12	11	7
Meth gestures Vi	1	1	0	2	0	0	0	0
Meth group Pre	0	0	0	0	1	1	1	1
Meth group Vi	0	8	0	0	2	2	1	3
Meth history Pre	0	0	1	0	0	0	0	0
Meth history Vi	1	0	0	5	0	0	0	0
Meth preview Vi	0	0	0	0	0	1	1	0
Meth question Pre	0	3	1	0	0	2	0	0
Meth question Vi	36	52	53	15	23	23	10	20
Meth reps Pre	0	0	2	0	0	0	0	0
Meth reps Vi	19	22	18	3	6	6	1	4
Meth review Pre	1	0	0	0	1	0	0	1
Meth review Vi	5	1	1	2	5	1	1	0
Meth roleplay Pre	0	0	0	0	0	0	1	0
Meth roleplay Vi	0	0	0	0	0	0	2	0
Meth rpt phrase Vi	11	8	10	5	4	4	1	3
Meth rpt respose Vi	11	18	15	3	2	6	1	15
Meth st help Vi	0	3	0	0	0	0	0	0
Meth st to board Vi	3	6	2	1	0	0	0	0
Meth vernacular Vi	13	4	0	0	0	0	0	0
Meth write board Vi	21	25	20	17	9	5	5	9
Reason - exercise Pre	0	0	0	0	0	0	1	0
Reason diff reps Po	5	1	4	2	1	0	0	1
Reason al resorce Po	1	0	0	0	0	0	0	0
Reason all meths Po	0	0	0	0	0	1	0	0
Reason calculate Po	1	0	0	0	0	0	0	0
Reason call quest Po	0	0	0	0	0	1	1	0
Reason chart Po	3	0	0	1	0	2	1	0
Reason diagram Po	5	0	1	2	0	2	0	0
Reason diffr reps Pr	0	0	1	0	0	0	0	0
Reason discussion Po	0	2	0	0	0	0	1	0
Reason discussion Pr	0	1	1	0	0	1	0	0
Reason examples Po	0	1	2	1	0	2	1	4
Reason exercis Pre	0	0	1	0	0	0	0	0
Reason expose Po	0	0	0	1	1	0	0	1
Reason expose Pre	2	1	1	0	1	0	0	0
Reason group Po	0	0	0	0	2	0	0	1
Reason group Pre	0	0	0	0	1	0	1	1
Reason history Po	1	0	0	2	0	0	0	0

Reason history Pre	0	0	2	0	0	0	0	0
Reason history St	0	0	0	1	0	0	0	0
Reason history Vi	0	0	0	1	0	0	0	0
Reason ignore Po	0	0	0	0	0	1	0	0
Reason just pick Po	0	0	1	0	0	0	0	0
Reason meth quest Po	8	2	0	0	0	0	0	0
Reason meth quest Pr	1	0	0	0	0	0	0	0
Reason names Po	0	1	0	0	0	0	0	0
Reason no detail Po	0	0	0	0	0	0	1	0
Reason no exampl Po	0	0	0	1	0	0	0	0
Reason omission Po	2	0	0	0	3	1	5	3
Reason omission Vi	1	0	1	0	0	0	0	0
Reason Preview Po	0	0	0	0	1	1	0	1
Reason question Po	2	0	3	3	2	1	0	3
Reason question Pre	0	1	1	0	0	1	0	0
Reason question Vi	1	0	2	0	0	0	0	0
Reason read ahead Po	0	0	0	0	0	0	1	0
Reason repeat Po	0	1	1	0	0	0	0	0
Reason review Po	2	0	2	0	0	0	1	1
Reason review Pre	0	0	0	0	1	0	0	0
Reason roleplay Po	0	0	0	0	0	0	3	0
Reason roleplay Pre	0	0	0	0	0	0	1	0
Reason same time Po	0	0	0	1	0	0	0	0
Reason st 2 bod Po	0	2	1	0	0	0	0	0
Reason st help Po	0	0	1	0	0	0	0	0
Reason Table Po	0	0	1	0	0	0	0	0
Reason venarcular Po	2	0	0	0	0	0	0	0
Reason write bod Po	0	0	2	0	1	0	0	3

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