

MISCONCEPTIONS HELD AND ERRORS MADE BY SOUTH AFRICAN
LEARNERS IN ANSWERING SCIENCE QUESTIONS IN THE TRENDS IN
MATHEMATICS AND SCIENCE STUDY (TIMSS)

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DECLARATION

I, Doras Sibanda, declare that this thesis is my own work and has not been submitted for any degree at any university. All sources that I used are indicated in the reference list.

Student _____

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DEDICATION

To my family

This thesis is dedicated to the memory of my father, Skubo Ngwenya, my sister Patricia and brother Mishack Ngwenya.

A B S T R A C T

This thesis presents results of a secondary analysis of South African Grade 8 learners' responses to the TIMSS 1999 Population 2 Science questions, and the results of a test and group interviews with learners from three high schools in Pietermaritzburg. The study is motivated by the need to understand the reasons for the poor performance of SA Grade 8 natural science learners in the TIMSS 1999 study. The aim of the study was to identify possible misconceptions held and errors made by SA science learners and to pinpoint possible causes and sources of these misconceptions and errors. An analysis of the SA learners' responses contained in the TIMSS 1999 Population 2 data and the test results from the Pietermaritzburg schools was used to identify possible misconceptions held and errors made by SA learners on certain science topics. The questions used in the Pietermaritzburg study were selected from the TIMSS 1999 population 2 science questions. The questions were selected based on perceived minimal levels of guessing by learners when answering these questions in the TIMSS 1999 study. The three schools selected for inclusion in this study in Pietermaritzburg were chosen based on their former classification as Indian, Coloured and Black schools. The majority of pupils at each of these three schools still reflect this racial composition that was in place at the time the TIMSS study was conducted. The Pietermaritzburg data was collected by administering a written test consisting of selected TIMSS 1999 science questions to a randomly selected group of ten learners at each school followed by interviews with the learners and the head of the Science Department at each school.

Learners' notebooks and the year planners used by teachers at the three schools were analysed primarily to check if these were in line with the SA intended curriculum and to check for any possible sources of misconceptions. The analysis of the data

was guided by the constructivist theory and the conceptual framework used in the TIMSS data. The TIMSS conceptual framework focused on the intended, the implemented and the achieved curriculum.

The study found that learners hold misconceptions on different concepts of the natural science curriculum. Some causes of misconceptions and errors among learners were identified. Some of the misconceptions highlighted indicate for instance that learners believe that boiling water is a form of a chemical reaction; a seed develops from a root; proteins are the same as vitamins, proteins and vitamins provide energy for the body.

Some possible causes of misconceptions and errors among learners were identified. These possible causes of misconceptions and errors are varied with some for example, linked to poor content coverage by teachers, learners' everyday experience, the lack of learning resources and materials at some schools.

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LIST OF ACRONYMS

ACE	Advanced Certificate in Education
ABET	Adult Basic Education Training
C2005	Curriculum 2005
DoE	Department of Education
FET	Further Education Training
FIMS	First International Mathematics Study
FISS	The First International Science Study
HoDs	Head of Departments
HSRC	Human Sciences Research Council
IEA	International Association for the Evaluation of Educational Achievement
MLA	Monitoring Learning Achievement
NQF	National Qualifications Framework
PISA	Performance in International Assessment
PMB	Pietermaritzburg
SACMEDQ	Southern Africa Consortium For Monitoring Educational Quality
SAIRR	South African Institute of Race
SAQA	South African Qualifications Authority
SISS	The Second International Science Study
TIMSS	Third International Mathematics and Science Study.
TIMSS-R	Third International Mathematics and Science Study- Repeat

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Chapter 1

INTRODUCTION

1.1 Introduction

This study aims to identify misconceptions and errors and also highlight some of the possible causes of misconceptions amongst South African Grade 8 learners when answering the Third International Mathematics and Science Study (TIMSS) science questions. The study involves a careful analysis of TIMSS 1999 science questions and the responses given by the learners to these questions. The study is based on a selection of twenty one multiple - choice questions from the TIMSS study. The topic on which each question is based was carefully selected and is in line with the South African curriculum content. The responses given by learners were analysed for possible patterns of misconceptions. In addition, interview questions were designed to find out what learners know about each science topic and then were administered to thirty learners in Grade 8 from three schools in Pietermaritzburg. The patterns of possible misconceptions and errors are identified and the possible reasons that explain the existence and origins of these misconceptions and errors are outlined.

This chapter provides a brief history of the International studies in Mathematics and Science, explains what these studies have achieved, what motivates this study and also outlines the key research questions.

1.2 The motivation for this study

International comparative studies in education are usually undertaken for various reasons. *“Such studies allow countries to compare national achievement between countries, to compare countries of special interest, to identify major determinants of national achievement country by country, and to examine to what extent the determinants are the same or different”* (Howie, TIMSS-R, Executive Summary, p.3). Participating countries believe that their nations can best compete and maintain a competitive advantage in the global economy only if their children are well educated. Wagermaker (2002) argues that comparative studies can be used by countries to indicate the possible performance of their economies in future. Some countries may also wish to compare their educational practices and systems with those of other countries so that they might set a standard measure for their education systems. It is generally believed that countries whose students excel in mathematics and science are more likely to establish a competitive advantage in an increasingly global economy (Robitaille and Beaton 2002). The findings of the Third International Mathematics and Science Study (TIMSS) and the follow up study, the TIMSS-R (TIMSS Repeat) have shown that South African learners are performing well below the international average in mathematics and science subjects. More than 8 000 Grade 8 learners from 200 South African schools took part in the TIMSS-R study that involved 38 countries including three in Africa, namely Morocco, South Africa and Tunisia.

Table 1.1 shows a selection of the top five and the worst five performers from the thirty-eight countries that participated in the TIMSS-R study of 1998/1999. South Africa’s place in this community of nations is at the

bottom of the table with the worst mean scale score of 243 (and standard error 7.8) compared to the international average scale score of 488 (standard error 0.7). The performance of South African learners in science in this study was significantly worse than that of the other African countries such as Morocco (mean score 323) and Tunisia (mean 430). Of particular concern to South Africa would be the fact that *“only the most proficient pupils in South Africa approached the level of the lowest achieving pupils from Chinese Taipei, Japan and Singapore. The South African pupils scoring around the country’s mean fell below the least proficient pupils on average from most countries with the exception of Morocco and the Philippines.”* (Howie, S. J, TIMSS-R Executive Summary, p 12).

Table 1 Distribution of TIMSS-R mean science achievement

Country	Average Scale Score (std error)	Years of Formal Schooling	Average Age
Chinese Taipei	569 (4.4)	8	14.2
Singapore	568 (8.0)	8	14.4
Hungary	552 (3.7)	8	14.4
Japan	550 (2.2)	8	14.4
Republic of Korea	549 (2.6)	8	14.4
International Average	488 (0.7)		14.4
<i>Lowest Five Achievers</i>			
Tunisia	430 (3.4)	8	14.8
Chile	420 (3.4)	8	14.4
Philippines	345(7.5)	7	14.1
Morocco	323(4.3)	7	14.2
South Africa	243(7.8)	8	15.5

Source: IEA Third International Mathematics and Science Study [TIMSS], 1998-1999.

In view of this unsatisfactory performance in international science studies by South African learners, this study seeks to identify possible misconceptions and errors made in answering TIMSS questions that could have affected the learners' performance.

The HSRC survey of school needs (Human Sciences, Research Council, 1997) showed that only 49% of South African schools had adequate provision of textbooks and even fewer had accessible library facilities within the community. In keeping with the legacy of *Apartheid*, the most deprived schools are in the township and rural settings. In the provincial analysis of the TIMSS-R data (Howie, S. J, Executive Summary), the highest scale scores were obtained by learners in the Western Cape and the Northern Cape while the more rural Eastern Cape and the Northern Province had the least scores. Pupils from well-resourced schools (which would mostly be previously white) would thus be expected to generally perform better than their rural counterparts. Van der Berg (2004) argues that despite the government's effort to allocate resources across the country the performance of the matriculants in the poorest provinces has not improved. He also insists that the poorest schools (rural and township) are struggling to attract good teachers. It has also been reported elsewhere (Blankley, 1994), that only 1 in 312 Black pupils entering the school system leaves with physical science and mathematics as final year subjects. The comparative figure for white pupils is 1 in 5. In light of these inadequacies and shortcomings in the education system, lack of basic knowledge and skills on the part of the learners to handle questions that are based on international norms and standards cannot be discounted.

There are a number of reasons that could explain the poor performance by SA learners. It is possible that at the time the TIMSS and TIMSS-R studies were conducted, the majority of the participating students, particularly those coming from poor communities, simply lacked the knowledge base to tackle the questions in the study. This view could be supported by the fact that of the 84% professionally qualified science teachers at the material time, only 42% were actually qualified to teach science, (Howie, S. J. TIMSS-R Executive Summary). This finding is quite significant since the Second International Science Study (SISS), 1979–1991 found among other things that students perform better when taught by teachers who are experienced and competent in science, Keeves (1992).

The high prevalence of unqualified and under-qualified educators in urban township and rural schools could well have given rise to the serious problem of misconceptions and errors about science concepts and terms among the learners propagated by educators whose grasp of science and scientific terms was limited. Such misconceptions and errors could result in incorrect responses being given, particularly in a study based on multiple-choice answers. In this study I therefore ask the questions;

- (1) What are the misconceptions and errors made by SA learners in answering TIMSS science questions?
- (2) What are the causes of the misconceptions and errors experienced by SA learners in answering TIMSS science questions?

1.3 International Comparative Studies in Mathematics and Science

It is now well established that science and the application of science is the main driver of human progress, “*During the past 100 years the findings of*

scientific research and the products of scientific and technological development have transformed the world in which we live. As a consequence schools throughout the world have assumed the responsibility of passing on knowledge about science to succeeding generations as well as developing a population that has an understanding of science to ensure the use of scientific knowledge for constructive ends and the betterment of life” (Keeves, 1986:19). Science literacy and the teaching of sciences in schools must be prioritized if African states are to uplift their standards of technological development to match those of the western nations and Asia. South Africa, emerging from decades of Apartheid education policies that did not provide for equitable access to education for all its citizens has a particularly difficult task of inculcating a science culture among its citizenry, particularly the young black children in township and rural schools. In advancing the teaching of science and the effectiveness of delivery of instruction in the classroom, it is vital that South African policy makers and educators have a keen understanding of education systems in other countries as a comparator. It is for this reason that international comparative studies such as those being carried out periodically by the International Association for the Evaluation of Educational Achievement (IEA), Performance in International Assessment (PISA), Monitoring Learning Achievements (MLA), and Southern Africa Consortium for Monitoring Educational Quality (SACMEDQ) are seen as of particular importance to South Africa. These studies are driven by different objectives aimed at improving the quality of teaching and learning of science by participants.

The MLA project started in 1992 and it aimed at monitoring the progress of education for ALL in participating countries. The aim of these studies depends on the needs of the participating countries, as an example, in 1999

MLA assessed grade 4 learners in the areas of life skills, reading and numeracy. PISA was first conducted in 2000 and is administered in a three year cycle. The aim of the study is to assess competencies in mathematical and scientific skills and reading literacy. SACMEDQ on the other hand aimed at monitoring education quality and achievement at different levels of learning. The programme also aimed at informing the policy makers about the need to improve the quality of education (Reddy, 2005).

The International Association for the Evaluation of Educational Achievement (IEA) was founded by a group of researchers in 1958 as an independent, international cooperative of national research institutions and governmental research agencies. Its stated primary purpose is to “*conduct large-scale comparative studies of educational achievement, with the aim of gaining a more in-depth understanding of the effects of policies and practices within and across systems of education*”, (IEA website, 2004).

The IEA has thus focused on policy issues of national concern, policy implementations and educational outcomes based on achievement. The IEA also aims to provide technical assistance to developing countries to enable them to improve their research capabilities and capacities (Wolf, 1992). By availing its data files to researchers throughout the world for secondary analysis, the IEA studies have proven over the years to be an invaluable source of data for researchers and policy makers alike who are working to improve the effectiveness of teaching and learning of mathematics, reading comprehension and science in their own countries. The cyclic nature of these studies has also provided a mechanism for monitoring progress made in policy implementation as well as identifying weakness in policy and educational practice (Robitaille and Beaton, 2002).

The First International Mathematics Study, (FIMS) was initiated in 1960 with twelve participating countries. FIMS was the first ever study undertaken by the IEA. The FIMS study focused on mathematics curriculum issues and also examined how mathematics teaching and learning might be influenced by societal and technological changes. Among the early studies in science education was the First International Science Study (FISS), 1966–1975. The study focused on the achievement in science of 10-year-old students, 14-year old-students and students in the final grade of secondary school. The FISS study also examined attitudes, methods of teaching, the development of practical skills and an understanding of the nature of science among the target student population.

The Second International Science Study (SISS) began in 1979 and continued until 1991. The study used science tests, questionnaires for students, teachers and school principals (Wolf, 1992) to examine trends in science achievement from the first testing (FISS), which took place in 1970–1971. According to Keeves (1992: 43) the major purpose of the second science study was to provide a synoptic map of the science curriculum of each participating country with respect to the three facets of the curriculum. *“It is only through an examination of the intended, the implemented and the achieved curriculum across countries that meaningful comparisons can be made of the science education programmes.”* This view is supported by Robitaille and Beaton (2002) and Postlethwaite and Wiley (1991). These facets are summarized in Figure 1.

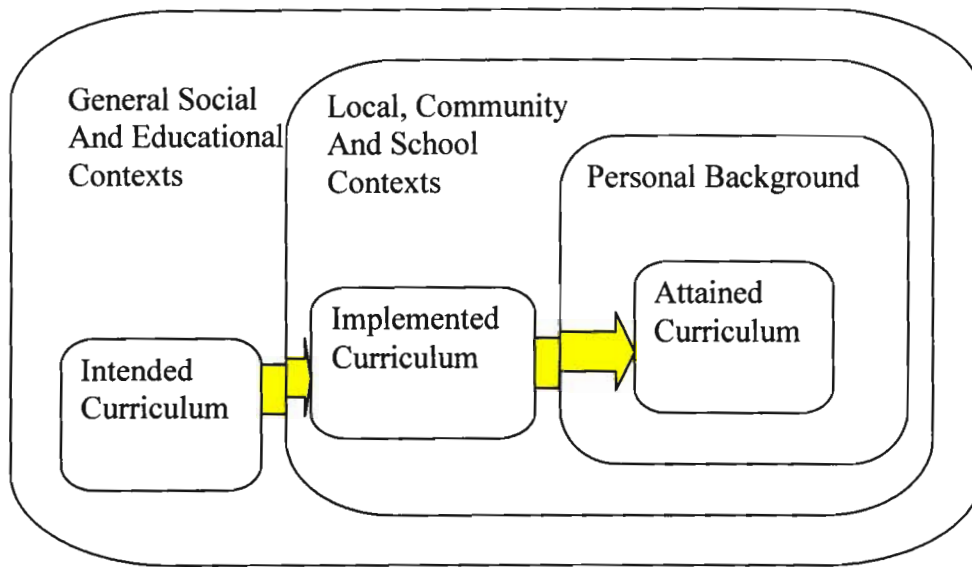


Figure 1: Conceptual framework for TIMSS (Source: Robitaille and Beaton, 2002).

The **intended curriculum** is what the education authorities and the community would like to be taught in schools. The **implemented curriculum** is what is actually taught in the classroom and is largely determined by teachers. Teachers are influenced by their own education, training and experience as well as the environment in which they teach. The **attained curriculum** is what students actually learn and is measured by their achievement.

In order for countries participating in the TIMSS study to have a common working content, curriculum documents and textbooks were analysed using the IEA Tripartite Curriculum Model. This model focuses on the intended, implemented, and attained curriculum (Valverde *et al.* 2002). Studies done by Wolf (1998) on international assessments suggest that developers must decide on the extent to which the measures should reflect a country's intended and implemented curriculum. Beaton (1998:529) argued that it was important that both the content and the processes required to answer the

questions correctly have been taught and learnt by the students. In other words the TIMSS study was meant to test the learners on the content covered at school. In keeping with the FISS, the SISS study involved learners towards the end of primary schooling (about 10 years), the lower and middle secondary schooling (about 14 years) and those at the end of secondary schooling who had about 12 years of schooling. This SISS study included, for the first time, three countries from Africa, namely Ghana, Nigeria and Zimbabwe. However, the lack of a widely publicized theoretical statement that provided a basis for the cross-cultural analysis of science education as well as a more general theoretical framework for the undertaking of IEA studies led to criticisms of plans for the analysis and reporting of the findings of the second science study (Keeves 1992:42).

The SISS study showed that many countries had adopted significant curriculum changes since the FISS with science now assuming a more prominent place in the curriculum from an early age. For these countries, there was a significant improvement in students' achievement between 1970 and 1984. However, at the upper secondary school stage, the average level of achievement in science dropped in those schools where more students remained at school and continued studying science. Significantly, the Second International Science Study (SISS) showed that students perform better when taught by teachers who are experienced and competent in science, Keeves (1992). There is a shortage of such teachers in the South African school system (Howie, S. J., TIMSS-R Executive Summary).

1.4 The Third International Mathematics and Science Study (TIMSS)

The Third International Mathematics and Science Study (TIMSS) undertaken in 1995 and its offshoot, the Third International Mathematics and Science Study-Repeat (TIMSS-R, 1999) conducted under the auspices of the International Association for the Evaluation of Educational Achievement (IEA), and in which South Africa participated for the first time, was the first in a four-year cycle of assessment of trends in students' mathematics and science achievement. According to Robitaille and Beaton (2002) the overall aim of the TIMSS study was to contribute to the improvement of the teaching and learning of mathematics and science. The TIMSS study was designed to collect data about the teaching and learning of mathematics and science. Altogether, the TIMSS study tested and gathered contextual data from more than half a million students and administered questionnaires to thousands of teachers and school principals. The TIMSS study intended to make the data and findings available so that people could learn about the kinds of curriculum and instructional practices that were associated with the highest performing nations (Robitaille and Beaton, 2002). The TIMSS international database is a rich source for various secondary analyses, particularly for investigating the conceptual understanding that students around the world have (Kjaernsli *et al*, 2002).

The TIMSS and TIMSS-R studies provided South Africa with an opportunity to compare its education system and the products of this system with the rest of the world. The comparative nature of the TIMSS studies and the poor performance of learners coming in the middle of reforms of the South African education system would have left policy makers in no doubt as to the

extent of the problems in the schooling system. The poor performance would no doubt also have emboldened the reformists to continue the education reforms in line with best practice in the world.

The TIMSS study was largely influenced by the experiences of the previous studies, such as the FIMS, FISS, SIMS and SISS. The TIMSS study was however, the first study to combine both science and mathematics. The TIMSS study is also a trend study, which makes it different from the earlier studies. The design for the study follows a regular, repeated assessment with instruments that can be linked over time. This kind of assessment allows researchers to compare the performance of learners over a period of time. One of the primary aims of the TIMSS study was to monitor the success of mathematics and science instruction and the context in which it takes place in each of the countries that participated in the project (Robitaille and Beaton, 2002).

According to Howie (Executive Summary), the TIMSS study highlighted the plight of education in developing countries where priority is often given to poverty and survival issues. In South Africa the following changes took place following the 1995 study: The Department of Education (DoE) White Paper on Education and Training of 1995 (Department of Education, 1995) amongst other issues, highlighted the importance of mathematics and science. This led to the revision of the school curriculum, resulting in the development of Curriculum 2005 (C2005). Secondly, the national audit report by Hofmeyer and Hall (1996) on the extent and size of the expenditure on teachers' salaries, which at the time consumed up to 95% of the DoE budget led to the redeployment and retrenchment of teachers starting in 1995. However, a most unfortunate consequence of the retrenchment of teachers was that many

qualified and skilled mathematics and science teachers were lost to the teaching profession. A nationwide evaluation of colleges of education also resulted in closures and mergers of colleges with universities and technical colleges. Finally, the South African Qualifications Authority (SAQA) was established in 1997. The mandate of SAQA was to implement the National Qualifications Framework (NQF) as an instrument for the transformation of education and training in South Africa.

The education reforms implemented since 1995 have, however, yet to yield positive results in terms of enhancing learners' performance in mathematics and science subjects. A recent study by the South African Institute of Race relations (SAIRR) shows that pass rates on higher grade for mathematics remain below 10% and for physical science below 20%. The study further shows that student enrolment in Grade 12 dropped by 12% between 1991 and 2003 and notes that "*the declining number of matric candidates has been matched by a decline in the quality of matriculants as only 25% of pupils who passed matric in 2003 gained matric exemption as opposed to 33% in 1991.*" (South Africa Survey, SAIRR, 2004).

1.5 Errors and Misconceptions

A review of literature on misconceptions and errors show that researchers describe these terms in different context. For example, Sanders (1993:920) describes misconceptions as resulting from everyday experiences and the unscientific everyday language and errors as resulting from incorrect concept formation during formal learning. In other words, errors made by learners can easily be corrected through proper teaching and use of correct information, while misconceptions are resistant to change and require a constructivist

teaching approach (Driver and Oldham, 1986). This study used Sanders' ideas of misconceptions and errors.

The following studies illustrate some possible sources of misconceptions and errors amongst science students. Clerk and Rutherford (2000) argue that misconceptions exist when the structure of an individual's model differs from that of the situation it is meant to represent. They also suggest that language confusion can be mistaken for misconceptions. This is important for SA learners because many wrote the TIMSS tests in their second language and, for some, in their third language.

Hershey (2004) has categorized sources of misconceptions in learners into five critical groups:

- Oversimplification of concepts by teachers
- Overgeneralizations
- Obsolete concepts and terms
- Misidentifications
- Flawed research

The main sources of the third and fourth type of misconceptions above are textbooks and other teaching aids. The teacher is however also fingered as contributing immensely to the spread of misconceptions. A teacher whose own understanding of science is limited but is put in a situation where he or she has to deliver instruction on a subject matter whose content he or she does not fully understand is likely to spread misconceptions. In any case such a teacher is unlikely to identify his or her students' misconceptions and to remedy these in time.

A detailed analysis of student responses to selected science questions from the TIMSS 1999 data would allow for the identification of possible common misconceptions and errors made by learners on particular scientific concepts in a South African context.

1.6 Thesis Structure

The structure of this thesis is as follows:

Chapter 1 focuses on the introduction of the study, rationale and motivation.

In Chapter 2, a review of the literature related to misconceptions held by students internationally and those held by South African learners in particular will be outlined. Included in this chapter are the different learning models explaining how students learn. The theoretical framework for the study is explained.

Chapter 3 outlines the research design and methodology used to collect data for the study. The procedures and sampling techniques involved in the collection of data are described.

The secondary analysis of the TIMSS results is given in Chapter 4. This chapter focuses on the analysis of responses of SA learners and Pietermaritzburg learners to 21 selected TIMSS 1999 multiple choice science questions. Some of the study results obtained from the interviews are presented. Graphical comparison of the PMB learners' correct response and misconceptions/errors to some of the TIMSS 1999 science questions are presented.

A summary of the major findings is presented in Chapter 5. The implications for educators, limitations of the study and problems for further research are reported.

1.7 Summary

The TIMSS 199 findings provide information to participating countries about their standards on the teaching and learning of science and mathematics. The data collected by the TIMSS study can be used by each participating country to explain some of the problems faced by the country and how they can learn from other countries. According to Beaton (1998) international rankings seem not to change much even when a different set of test items are used. In other words countries at the bottom of the table tend to remain at the bottom. The TIMSS study is used as the foundation for this study because an understanding of the possible misconceptions held by the SA learners when answering the TIMSS test might help to improve the teaching and learning of science in a South African context. The improvement in the standards of teaching might lead to improvements in student performance on the TIMSS test.

Chapter 2

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

2.1 Introduction

In this chapter literature that focuses on misconceptions and errors in general, and on particular misconceptions held by learners is reviewed. These studies focus on misconceptions in chemistry, physics and biology. The researchers in these studies used different methods of data collection, for example, some used tests, textbooks and analysed examination scripts to identify misconceptions and errors. The chapter also examined various educational theories that motivate and underpin the study of student misconceptions in mathematics and science subjects. The evolution of the educational theories, in particular, Piaget's developmental theory, which has been extensively used in science education to identify misconceptions held by some learners, is discussed. The study is guided by the two research questions:

- What are the misconceptions and errors made by SA learners in answering TIMSS science questions?
- What are the possible causes of the misconceptions and errors experienced by SA learners in answering TIMSS science questions?

2.2 Student Misconceptions

Studies concerning misconceptions held by students have been carried out in different countries. Many of these misconceptions are pervasive, stable, and resistant to change (Bradley and Gerrans, 1989, Helm and Novak, 1983,

Mammen, 1996). Some of the studies, for example, Osborne and Freyberg (1985) resulted in improved instructional methods and curriculum changes in some countries. However, not much work has been done on how to alleviate or prevent misconceptions. A simplistic but perhaps effective way of avoiding misconceptions is offered by Cullen (1983) who argued that the best way to correct misconceptions is to avoid them in the first place. He proposes concept mapping as a powerful technique to help avoid the formation of conceptual misconceptions. In the conceptual change theory, learning is seen as the modification of current concepts and emphasis is placed on the role of current learning as opposed to empiricist theories of learning that emphasize the predominant role of experience in learning.

2.3 International Studies on Misconceptions

Among the many international studies that have been undertaken to identify student misconceptions in science are those of Schmidt (1997, 2000). In these studies written tests were used to identify misconceptions held by German students in various topics in chemistry. His findings highlighted the following particular examples of misconceptions held by students: (1) students limited the term isomerism to compounds of the same class, (2) students concluded from the syllable “ox” in redox that oxygen is involved in all redox reactions. (3) students held the idea that any reaction between an acid and a base would result in a neutral solution, (4) students held misconceptions that conjugate acid-base pairs consist of positively and negatively charged ions which can neutralize each other, (5) students incorrectly named oxo salts as oxide because they assumed that the naming of chemical compounds follow one single system.

In addition to identifying misconceptions, Schmidt also looked at possible causes of these misconceptions by analysing some textbooks. He found that some old fashioned terms were still used in some textbooks, for example, the term neutralization which can no longer be used to explain acid base pairs. According to Weilder (1984) and Yore and Shymansky (1985) cited in Abraham *et al* (1992), the majority of the studies concerning how textbooks have been used in the science classroom have primarily focused upon the readability of information rather than on how the textbooks can be used to develop theories, skills and classroom strategies which would promote effective science learning and reading comprehension. Studies carried out by Abraham *et al* (1992) found that the nature of misconceptions held by students indicated a general failure of textbooks to teach a reasonable understanding of chemistry concepts. They argued that the identification of possible sources of misconceptions is important because instructional strategies aimed at improving the levels of misconceptions are influenced by the type and source of misconception.

Ross and Munby (1991) studied Canadian senior high-school students' understanding of the concepts related to acids and bases. They developed a concept map model from the curriculum to identify misconceptions. They found that among other things, students' confused bases and ions, and also had problems in writing and balancing chemical equations. Some students held the notion that OH^- ions were found in acids. Their findings showed that students did not grasp all the concepts taught.

Salsona *et al* (2003) studied Spanish high school students' conceptual profiles of chemical change. They conducted their study over a period of two years. They asked students to write essays on chemical changes on two

occasions. In Spanish high schools, practical classroom sessions are not common and textbooks may not contain experimental tasks (Salsona *et al*, 2003). In their study students were taught using experiments and other methods such as problem solving. They found that most of the students' explanations were either incomplete or only partially correct. Also, students had difficulty in recalling details of experiments done in the classroom. The findings by Salsona *et al* (2003) concerning students not remembering experiments are a cause for concern in the teaching of chemistry because some studies have shown that practical work improves conceptual understanding (Harmon *et al* 1997, APU 1982). The work by Salsona *et al* however, went a long way in closing the gap left by previous researchers, who focused on unscientific responses as misconceptions.

Studies carried by Watson *et al* (1997) and BouJaoude (1991) on high school students' explanations about combustion and burning revealed that students tend to be inconsistent in their explanations, and their alternative frameworks differed from the scientific knowledge. They also found that these alternative frameworks were difficult to change. More research has to be done in order to understand how student's common sense can be incorporated into meaningful learning.

Gussarsky and Gorodetsky (1990) used word associations to study the conception of high school students concerning the concepts of chemical equilibrium. They found that students considered the left and right side of an equation as separate entities. Students also failed to identify the dynamic nature of the system at chemical equilibrium. They found that students considered the left and the right side of an equation as separate entities and

also they failed to identify the dynamic nature of the system at chemical equilibrium.

In identifying Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecules, Griffiths and Preston (1992) administered semi structured interviews to a stratified, random sample of students of differing abilities and backgrounds in science. They identified fifty-two misconceptions of which six related to the structure, composition, size, shape, weight, bonding, and energy of molecules; five related to the structure, shape, size, weight, and animistic perceptions of atoms. In summing up their findings, they state "*any misconceptions and alternative conceptions that students harbor about these concepts will impede further learning.*"

Studies on misconceptions are not only restricted to high school students, research on college students and high school teachers have shown that both teachers and college students hold misconceptions in various chemistry topics. The following studies highlight misconceptions held by teachers and college students.

Banerjee (1991) identified misconceptions experienced by Indian undergraduate chemistry students and teachers in learning concepts involving chemical equilibria. He used written diagnostic tests to identify the misconceptions. He found among other things that both students and teachers related pH directly to concentration and they then assumed that a large equilibrium value constant implies a very fast reaction. His work has shown the persistence of the level of misconceptions regardless of the level of education. In other words, misconceptions already held, may not necessarily

be removed by learning new concepts or acquiring new knowledge. His findings also indicate the complexity of these misconceptions and how they are passed from teachers to students.

Furio *et al* (2000) carried out studies on difficulties faced by teachers in teaching the concept of “amount of substance” and “mole”. In their study, they used surveys and interviews with teachers. They also analyzed textbooks. They found that teachers lacked knowledge of the socio-historical contexts of certain concepts and their meanings. Most teachers did not have updated meanings of concepts. They also found that some textbooks and syllabuses contained errors or misrepresented certain concepts. Their findings point to the need for continuous in-service courses for practicing educators.

In addressing misconceptions held by college students Sanger and Greenbowe (2000) used computer animation and conceptual change instructional methods. They found that conceptual change instruction was more effective at reducing students’ misconceptions as compared to computer animations. Their results on computers were not as effective as those of conceptual change instructions. Their findings also drew attention to the fact that no one method can be used to reduce misconception. They also encouraged the educators to teach for conceptual understanding instead of grades. There is however, need for more research in the area of appropriate teaching methods aimed at promoting conceptual change.

Pealez *et al* (2005) studied blood circulation misconceptions amongst prospective elementary teachers. They used a sample consisting of 88 students studying an introductory course in biology. The students wrote a pretest based on drawings and explanations of blood circulation and lungs.

After studying the course students were tested using an essay on how blood circulation facilitates exchange between the body and the environment. Students were also interviewed on the same diagram. They found that errors on blood circulation were persistent among undergraduate students. In the final exam they found that students held high levels of errors about the blood path. This failure to perform was due to the fact that the students did not have prior knowledge of biology before enrolling for the course. Some of the errors identified in the study were as follows:

- Waste carbon dioxide turned the lungs black
- Carbon dioxide is poisonous
- One molecule of carbon dioxide is traded for a carbon dioxide molecule in the lungs.

Westbrook and Marek (1991) studied seventh grade life science students, tenth grade biology students and college zoology students for understanding of the concept of diffusion. They used a sample of 100 students from each grade level. They used three instruments designed to collect information on gender and birth date, previous coursework and a paper and pencil task which tested students on Piaget's intellectual development stages. They found that there was no difference in the levels of misconceptions across the different age groups used in the study. Also, they found that the answers given by college students were complicated as compared to the other grades. Their findings indicated that college students' exposure to other courses like chemistry did not influence their understanding of diffusion. They concluded that science students are not comprehending science concepts in the manner they are taught in schools or colleges. These findings were confirmed in a

similar study the following year on the concept of homeostasis (Westbrook and Marek, 1992).

Lawson and Thomson (1988) studied students' formal reasoning abilities and misconceptions in genetics and natural selection using essays. Their sample consisted of 131 grade seven students. The students were taught life science by one teacher. The students were tested using a pretest aimed at testing their intellectual development. At the end of the course students were post-tested using open-ended essays that required their understanding of the concepts of genetic and natural selection. They found that more formally operational students held misconceptions that acquired characteristics can be genetically transmitted to offspring than did concretely operational students. In general formally operational students had a better understanding than the concretely operational students. They argued that it is not enough to just teach scientific concepts without addressing students' prior conceptions (misconceptions).

In studying students' understanding of electricity in simple DC circuits Shipstone (1984) used a pencil and paper test which consisted of ten questions on the concepts of current and voltage. The sample was made up of a whole class of first four years and first year sixth-forms drawn from three schools. In this study students were classed as able or weak based on their previous symbols or grades. He found that students could not discriminate between current and voltage. For example some of the students describe voltage as something which can flow.

Angell (2004) studied Norwegian students intuitive ideas based on physics specialist test items in TIMSS 1995. He analysed both multiple choice and free response questions in order to determine students' potential for

understanding, thinking and the possible nature of their misconceptions. He found that students held disjointed ideas which were inconsistent and context depended. He recommended that teachers should use the incorrect answers given by students to build correct ideas.

Joshua (1984) studied students' interpretations of simple electrical diagrams by asking students to explain the current distribution and intensities. He found amongst other things that students interpreted diagrams as figurative representations of a system and also had problems to correctly interpret the electrical diagrams.

2.4 Misconceptions Studied in South Africa

In identifying causes of misconceptions amongst South African learners, Pillay and Loonat (1993) analysed four textbooks used in schools. They also administered a questionnaire based on the concept of atomic structure three high schools. Their study concluded that the learning difficulties encountered by learners were a result of misconceptions about certain fundamental concepts like atomic structure.

Huddle and Pillay (1996) studied misconceptions in stoichiometry and chemical equilibrium held by first year chemistry students at the University of the Witwatersrand. They analysed student's examination responses for misconceptions and found that students' understanding of fundamental chemical concepts was minimal. They argued for more descriptive chemistry in schools and more time to be spent at tertiary institution for students to be able to construct concepts for themselves.

Mammen (1996) analysed first year students' test results on limiting reagents at the University of Transkei. He found that students held misconceptions on the concept of limiting reagents and also students failed to correctly apply the concept. In trying to understand the school-university gap in chemistry, Bradley and Brand (1985) administered a multiple-choice test to 750 incoming first year university students and 150 school science teachers. They found that both students and schoolteachers held similar misconceptions. They argued that part of the gap was due to the differences in the way the university lecturers and schoolteachers view some of the chemistry concepts.

Bradley and Mosimege (1998) studied misconceptions about acids and bases held by student teachers at university and at colleges of education. They administered a questionnaire consisting of multiple choice and open-ended questions. They found that university students held fewer misconceptions as compared students at a college of education. They concluded thus; "*Given the nature of the questionnaire and the levels of responses, we conclude that urgent attention needs to be given to improving the quality of science teacher training*".

The view that teacher-training colleges may be unwittingly contributing to the spread of misconceptions seems to be supported by the findings of Bradley and Gerrans (1989) and Bradley *et al* (1990). In analyzing the views of some science teachers and student teachers about chemical bonding and chemical equilibrium, they administered a multiple-choice type of questionnaire which was based on previous studies on misconceptions in the topics under study. They found that both student teachers and school science teachers held misconceptions similar to those found amongst students on chemical bonding and chemical equilibrium. From their findings they

concluded that science teacher preparation programmes were not successful in the development of scientifically correct views about chemical equilibrium. However, it is important to note that in South Africa the teacher training colleges are no-longer operational, but some of the science teachers trained by these colleges are still teaching in most township and rural schools.

Studies carried out by Sanders (1993) on high school teachers' ability to identify learners' errors on the concept of respiration in South Africa showed that many of the sampled teachers held erroneous ideas about the concept of respiration. In this study teachers were asked to mark the learners' test by ticking the correct answers and to use a cross to indicate the incorrect answers. They were also asked to make a comment on the strength and weakness of the content. She found that some of the incorrect answers were marked correct by teachers and errors made by learners were not pointed out. It is important for learners to know that they have made some scientific errors on certain concepts so that they can address these errors.

Saayman (1997) studied first year university students at the University of Stellenbosch before and after the first year semester teaching on kinematics, Newton's laws of motion, forces, motion, work energy and momentum. The sample was made up of a thousand students registered in Engineering, Medicine and Biological Sciences. Students were asked to write a pretest at the beginning of the semester and a post test at the end of the semester. His findings showed that there was about 20% gain in students' understanding between the pretest and the post test. In other words science students struggle to understand most of the concepts taught in lectures.

2.5 Education Theories Underpinning This Study

2.5.1 Piaget's Theory

Piaget's developmental theory focuses on the four stages of cognitive development. These are sensory motor (0 to 2 years), preoperational (2 to 7 years), concrete operational (7 to 11 years) and formal operational (11 + years). He used these stages to explain different tasks individuals can perform at each stage. Piaget used terms like assimilation, accommodation and equilibration to explain how children acquire new knowledge, what happens to the new knowledge and how this knowledge is used to explain and interpret events (Novak, 1977). According to Piaget, assimilation explains how repeated experiences fit into the child's existing cognitive structures. Equilibration on the other hand is maintained when the child receives similar information. However, the equilibrium is disturbed when the child receives different or new information. Whilst accommodation, on the other hand, refers to the alteration of the child's existing cognitive structures in order to fit with the new information. Wheeler and Kass (1978) used Piaget's theory as the basic framework when they studied misconceptions held by learners in chemical equilibrium. Piaget's theory views a child as being capable of constructing meaning and developing concepts internally. Piaget's theory argues that it is important to maintain equilibrium in the learner's cognitive structures. In other words, if the equilibrium is disturbed errors and misconceptions might be formed if a learner fails to relate the new information with the old. This theory provides an understanding of how errors and misconceptions are formed.

2.5.2 Ausubel's Theory

This theory assumes that the learner has some prior knowledge. The theory distinguishes between rote learning and meaningful learning where meaningful learning involves a conscious effort by the learner to relate new knowledge to relevant existing concepts. Rote learning may occur when no relevant concepts are available in the learners' cognitive structures. There is no interaction between the new knowledge and any existing relevant concepts (Novak, 1977). Ausubel's theory of meaningful learning was proposed by Novak as an alternative framework to Piaget's ideas. Albert (1979) however, argued that Ausubel's theory should be seen as complementary to Piaget's developmental theory rather than be viewed as being in conflict. The difference between Piaget's theory and Ausubel's theory is that Piaget focuses on the development of knowledge in humans while Ausubel focuses mainly on how students learn large amounts of useful concepts. However, in the 1980s emphasis shifted to focus more on conceptual change, misconceptions, alternative frameworks and prior knowledge. Researchers such as Driver, who were critical of Piaget's developmental theory, focused more on learning difficulties experienced by learners during the learning of science. Ausubel's theory assumes that prior knowledge is important in the learner's understanding of new knowledge. In other words if there is no link between the old knowledge and the new information, errors and misconceptions might be formed by the learners.

2.6 Learning Models

In this section I review various learning models and theoretical frameworks that are useful in the teaching of science and are relevant to this study

because models can help researchers understand how students learn. The use of models in trying to explain learning difficulties has been a consistent feature of research since the 1990's. Learning models can be used in planning specific lessons aimed at improving students' commonsense ideas. While many theoretical frameworks on prior knowledge, memories and the use of learners' experiences exist, (Hackling and Garnett, 1985, Pillay and Loonat, 1993), no single workable unified theory or model exists at the moment.

2.6.1 Generative Learning Model

The generative learning model is a tool that focuses on the construction of meaning from sensed experience. It can be applied to both learning and doing science. It makes use of the proposition from constructivism, which views learning as dependent on the learner generating understanding. In trying to explain why students hold views different to those of scientists, Osborne and Wittrock (1983) outlined the following model:

- Learning science is a disciplined creative process.
- Even when a teacher gives a learner an explanation on how and why something behaves as it does, the learner must still actively create meaning from that explanation.
- Teaching involves helping learners to generate appropriate meanings from incoming information, to link these meanings to other ideas in memory, and to evaluate both newly constructed ideas and the way old ideas are related in memory.

- The successful learning of scientists' ideas is as much a restructuring of the way learners think about the world, as it is the creation of new ideas to existing ways of thinking.

This model assumes that some misconceptions and errors can be formed if learners fail to actively create meaning from the teacher's explanation. In other words learners end up making a different version of what the teacher said. This model can be used to assess the learning and teaching of science. It can also be used in the development of the curriculum and to explain some of the causes of misconceptions held by learners because it views learning as dependent on existing knowledge.

2.6.2 The Hewson-Hewson Model

Hewson and Hewson (1988) developed this model after reviewing studies on science learning. They summarized the key instructional strategies, which help students overcome their unscientific conceptions by suggesting that teachers must:

- Diagnose their students' thoughts on the topic in hand.
- Provide an opportunity for students to clarify their own thoughts.
- Directly contrast students' views and the desired view through class discussion or teacher presentation.
- Immediately provide an opportunity for students to use the desired view to explain any phenomena.
- Provide an immediate opportunity for students to apply their newly acquired understanding to different examples.

This model emphasises the application of the above stages during the teaching and learning of science so that possible misconceptions held and errors made by learners might be reduced. This model focuses on learning activities that allow the student to make an evaluation of the new conception. It also advocates for students to be given enough time to demonstrate their understanding. It is possible that these activities are part of the requirement for Curriculum C2005. This policy document gives allowance for a particular topic to be taught in different subject areas.

2.6.3 The Constructivist Model

Constructivism is a concept that focuses on how people learn from their experiences and how they formulate an understanding of their own world. In this framework, the meaning constructed by the learner is pivotal to the learning process. Learners construct knowledge through discussions and open-ended questions that are related to their everyday experiences (Carnell and Lodge, 2002). In this model:

- The teacher is seen as a facilitator.
- The responsibility for learning partly rests with the learner.
- The learner's ability is not seen as fixed, but capable of development through experience.
- The teacher's interest is to find out about each learner's abilities, skills and interest.
- The relationship between the teacher and the student remains one of expert to novice.

This model empowers the learner to be responsible for his or her own learning, whilst the teacher's responsibility is to guide the learner to find his own meanings. This model focuses on proper teaching in order to reduce the levels of errors made and misconceptions held by learners in science.

Carnell and Lodge (2002) outlined an expanded version of the constructivist model called the co-constructivist model. The essential feature of this model is that it relies on dialogue. The responsibility of learning shifts from individuals to emphasize collaboration in the construction of knowledge. It also takes into account the emotional aspects of learning, the dynamics of learning with others in groups, the significance of context and the out come of their learning. This model is not common in schools because it puts more emphasis on performance rather than learning.

2.6.4 Driver-Bell model

Driver and Bell (1986) identified six issues that emphasized the constructivist's view of the process of learning:

- Learning outcomes depend not only on the learning environment, but also on the knowledge and motivation a learner brings to the classroom.
- The process of learning involves the construction of meanings.
- The construction of meaning is a continuous and active process.
- Having constructed meanings, learners will evaluate them and consequently accept or reject them.
- Learners have the final responsibility for their learning task.
- There are commonalities in the meanings students construct.

In keeping with this theoretical viewpoint, the position of the learner must then be viewed as being pivotal when it comes to the construction of scientific meaning. This crucially explains why construction of meaning may not take place if there is no existing prior knowledge and also misconceptions and errors may be formed if learners have no previous experience of the concepts. This model was used to analyse the answers given by SA learners in the TIMSS 1999 study and the Pietermaritzburg sample.

2.6.5 Driver-Oldham Model

Driver and Oldham (1986) described a constructivist teaching sequence used in the children's learning in science as follows:

- Orientation phase: students are motivated to learn the topic.
- Elicitation phase: students make their ideas clear through discussion.
- Restructuring phase: students and teachers exchange ideas.
- Application phase: students use their ideas in familiar and unfamiliar situations.
- Review phase: students reflect on how their ideas have been changed.

The Driver-Oldham model is different from Driver-Bell model because its emphasis on the teaching approaches aimed at reducing the levels of errors and misconceptions held by learners, while the latter focuses on how learners learn new information. The Driver-Oldham model incorporates several aspects of problem solving and decision-making. This model is used as an instructional model aimed at promoting learning in science. The learner is given a chance to evaluate what happens in the classroom. If all the stages are

followed during the teaching and learning of science the levels of misconceptions and errors might be reduced.

2.6.6 The Von Glasersfeld's principle

Radical constructivists have been influenced by studies that demonstrate that knowledge is socially and culturally situated. On the other hand, the findings that intellectual practice in subject matter areas differ from one cultural community to another is consistent with radical constructivists' reflection of knowledge as a mirror of ontological reality (Husen and Postlethwaite, 1994: 1051). There is a need for elaboration of this idea so that it includes both collective activity and individual experience. According to Matthews (2000:172), von Glasersfeld's principle includes the following aspects:

- Knowledge is not about an observer independent of the world.
- Knowledge is created by individuals in a historical and cultural context.
- Knowledge refers to individual experience rather than to the world.
- Knowledge is constituted by individual conceptual structures.
- Conceptual structures constitute knowledge when individuals regard them as viable in relationship to their experience.
- There is no preferred epistemic conceptual structure.
- Knowledge is the appropriate ordering of an experiential reality.
- There is no rationally accessible, extra-experiential reality.

This assumption that individuals can create knowledge without interacting with the outside world might be difficult for people to understand. However, von Glasersfeld (1995:51) argued that knowledge is not passively received through the senses or by way of communication. He insisted that knowledge

is not actively built up by the cognizing subject since the function of cognition is adaptive and cognition serves the subject's organization of the experiential world. According to von Glasersfeld (1989) as cited in Husen and Postlethwaite (1994:1049), there are three instructional implications of constructivism:

- Priority should be given to the development of meaning and understanding rather than the training of behaviour.
- Researchers and teachers should assume that students' actions are rational given the way that they currently make sense of things.
- Students' errors and unanticipated responses should be viewed as occasions to learn about students' understanding.

This means that students should be allowed to explain their situations. Also, student's errors should be viewed as a pointer on how students learn.

Wheatley (1991) outlined two main principles of constructivism. These principles are as follows:

- Knowledge is not passively received, but is actively built up by the cognizing subject.
- The function of cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality. In other words knowledge is a process that is constructed through viable explanations of our experiences.

This model would be useful in explaining the answers given by learners because it emphasizes on the importance of culture in acquisition of knowledge. This model also suggests that knowledge is dependent on the

individual experience rather the community. This model can be used to explain the causes of some of the misconceptions identified in the study.

However, constructivism is not without its critics. Suchting, as cited in Matthews (2000:178) criticized constructivism as an unintelligible and confused doctrine. He also argued that constructivism still represented overtones of Piaget (1929) and Kuhn (1963). Similarly, Solomon (1994) argued that Driver and Easley (1978) used different words to re-describe what Piaget and Kuhn have already said.

2.7 The Theoretical / Conceptual Framework

Following a detailed examination of the literature concerning learning, I have elected to use constructivism as the most appropriate theoretical framework of this study. Constructivism is an idea that focuses on how people reflect on their experiences and how they arrive at an understanding of their own world. This theoretical perspective argues that students construct knowledge, through the interaction with the process. This might result in shared meanings of the process in a social context. For example in a particular culture, learners might have similar ideas. These ideas may differ from those of learners from a different cultural background (Geer and Rudge, 2002). The constructivist theory views learning as a process that involves the integration of new ideas with old ones. This means that ideas brought by learners to the classroom need to be exploited in order for meaningful learning to take place. This study highlights the everyday experiences of SA learners in grade eight natural science classes. This study used the ideas from Driver and Bell (1986) to interpret the way the learners answered the selected TIMSS 1999 science questions. Their ideas focus on both the individual and the context in which

the learning of science takes place. The Driver-Bell model offers a meaningful explanation for the existence of misconceptions. The theoretical framework is used as a guide for this study because it explains how experience can affect the way we arrive at conclusions in life.

2.8 Summary

This chapter discussed different learning models used by learners to understand different learning situations. However, the constructivist model of learning is the most relevant model to this study. The constructivist theory focuses on the idea that students learn by constructing their own knowledge from new ideas coupled with prior knowledge and experience of the subject at hand.

Chapter 3

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This chapter outlines the nature of the study and secondary analysis of TIMSS data. Some of the methods used in the TIMSS studies in collecting data and the methods used for collecting data for this study are presented. The characteristics of the PMB sample, selections of schools, analysis of questions and documents are also presented.

3.2 The Nature of the Study

The study is an interpretive model that seeks to explain how and why South African Grade 8 learners responded the way they did to the selected TIMSS 1999 population 2 multiple choice science questions. An interpretive model assumes that all human activity is meaningful and as a result has to be interpreted along with the social context (Scott and Usher, 1996). According to Cohen *et al* (2000:22) an interpretative paradigm seeks to understand the subjective world of human experience. Such an approach can be used to explain social actions, texts and documents (Wellington, 2000).

This study also seeks to understand some of the misconceptions held by learners in three schools in Pietermaritzburg and SA learners who participated in the TIMSS 1999 study. This study used semi-structured interviews to try and understand possible problems faced by learners when

answering the TIMSS 1999 population 2 science test items. The results of this study will be used to identify some problems faced by the learners in the sampled schools. The data collected from the schools is not for generalization, but for highlighting some of the natural science errors and misconceptions held by SA learners at grade 8 level.

The study also draws on some experiences from the conceptual framework of the TIMSS study, (see figure 1) which focuses on the intended curriculum (policy document), the implemented curriculum (notebooks) and the attained curriculum (tests). In order to understand some of the problems faced by learners this study analysed the intended curriculum, the implemented curriculum and the attained curriculum

3.3 Secondary Analysis

This study also analysed secondary data sets collected during the TIMSS 1999 study. According to Hakin (1982) cited in Dale *et al* (1988), secondary data analysis is any further analysis of an existing dataset, which presents interpretations, conclusions or knowledge additional to or different from those presented in the first report on the inquiry as a whole and its results. Dale *et al* (1988) defined secondary analysis as an empirical exercise carried out on data that has already been gathered or compiled in some way. In the study the TIMSS 1999 data was analysed in order to identify the possible patterns of misconceptions and errors made by the South African learners in answering the TIMSS science questions.

An interview schedule was designed and group interviews with learners were carried out in order to establish whether they were taught the concepts and

what they know about the topics. The questions used in the interviews are given in the *Appendix* to this thesis. The schools and number of learners involved in this study are also described.

3.4 Methodology

The TIMSS study required that National Researchers' Coordinators of each country examine the test items in line with their country's intended curriculum. In the case where the test item was not included in the national curriculum, the coordinators were supposed to judge if the item was appropriate for about 50% of the students. All the participating countries conducted the assessment and returned the information with the exception of Thailand, (Beaton, 1998). The selection of topics was based on topics covered by many countries, but not by all countries (Wolf, 1998). In other words the poor performance of SA learners could have been caused by poor coverage of the topics in the TIMSS 1999 test items. The TIMSS test items were designed in such a way that each student could only answer a certain portion of the test. This allowed the test to be written in a reasonable time frame (Wolf, 1998). Each country did a two-stage random sampling. In SA 200 schools were randomly selected from the national list and 85% of the sampled schools agreed to participate. From each school intact classes were randomly sampled. The TIMSS science items tested learners on five major topics: earth sciences, life sciences, physics, chemistry and environmental studies (Wolf, 1998).

For the purposes of this study, twenty-one questions were selected from a possible sample of thirty-seven TIMSS 1999 multiple-choice science questions. The selected science questions covered topics in chemistry (two

questions), life science (eleven questions) and physics (eight questions). Some of the study questions were trends questions, meaning that they were used both in the 1995 and 1999 TIMSS studies. The South African learners' responses were analysed for possible errors and misconceptions.

The questions were selected based on perceived minimum levels of guessing. Questions in which guessing was the only means used by learners to arrive at their responses would, statistically, exhibit almost equal frequencies of the responses or roughly 25% of learners would choose each of the possible responses, such questions were eliminated. Each selected item was then analysed for possible errors and misconceptions.

In order to obtain a better insight into the manner in which South African Grade 8 natural science learners answered the TIMSS 1999 population 2 science questions, interviews were carried out with 30 Grade 9 learners from three schools in Pietermaritzburg.

3.4.1 Sample Characteristics

The sample was made up of thirty grade nine natural science learners drawn from three different schools in Pietermaritzburg. The grade 9 learners were used in the study because they had completed a grade 8 natural science syllabus. The average age of the learners taking part in the study was about fifteen years. Ten learners were randomly selected from each school. The schools, hereafter referred to as *School A*, *School B* and *School C* respectively, were selected based on their previous status as disadvantaged (black), Indian and Coloured school rankings. A similar category was used

during the TIMSS 1999 study. The sample of learners from the coloured school that participated in this study was made up of only black learners.

3.4.2 Collection of data

The study is an analytical study and it used the secondary analysis of the TIMSS 1999 data. The constructivist theory, Pollit and Ahmed's model (see section 3.4.7) and the TIMSS conceptual framework' that focuses on the intended, the implemented and the achieved curriculum were used to analyse the learners' responses to the TIMSS test items. The twenty-one questions were administered to the thirty learners in three schools. The ten learners were drawn randomly from one class in order to minimize lesson disruption. The group interviews were administered in the three schools so as to elicit learners' understanding of the content in different scientific concepts and why they chose the answers they did in the test. The HoDs were interviewed to get an understanding of the background of the schools and the quality of the teaching and learning of science in the sampled schools. The learners' notebooks, the year planner and the intended curriculum for 1999 and C2005 were analysed in line with the content demand for each test item. The research experienced problems with the collection of data because the audio tapes from school B were damaged and also at school C the interviews were conducted under a tree. Most of the data used from interviews was in the form of written notes. Some of the interviews had to be carried outside due to shortage of suitable classroom space.

3.4.3 Design of questions for the interviews

The questions used for the interviews were constructed so as to find out:

- how the learners answered the selected TIMSS 1999 science multiple choice questions
- learners' conceptual understanding of each topic examined in the test it
- the learners' understanding of the meaning of the questions and how they arrived at their answers.

3.4.4 Interviews

Conducting interviews in order to solicit the views of learners or consumers on particular issues is a well-established research technique. It often involves a face-to-face communication between the interviewee and the researcher although telephonic interviews may be preferred in some instances. There are three types of interviews: open ended, structured and semi-structured interviews, (Verma and Mallick, 1999). Open-ended interviews allow the respondents to express themselves freely. This technique is usually used to elicit the respondent's view about certain concepts. However, there are often problems associated with the analysis of responses to open-ended questions. For example, it is difficult to quantify opinions (Cohen *et al*, 2000).

Structured interviews require the use of pre-prepared questions. These questions focus the respondent's answers on particular themes. Semi-structured interviews are usually used together with a test. The interview questions are designed so as to fill in the gaps in the data collected using a test (Verma and Mallick, 1999).

In this study semi-structured group interviews were used to establish students' understandings of scientific concepts and to determine whether the concepts were familiar to the learners. Group interviews can encourage the participants to discuss a topic amongst themselves. The participants may also feel more at ease than in a one-to-one interview. However, if the respondents are allowed to talk without any guidance, the data can be difficult to analyse (Wellington, 2000). According to Cohen *et al* (2000) the results of group interviews can be contaminated and be of little value if the researcher directs questions to only one member of the group. In this study all the learners in the group were encouraged to lead a discussion on a particular question.

3.4.5 The TIMSS Test

The TIMSS test is considered to be an achievement test because it is supposedly based on what is already covered at school by the learners. According to McMillan and Schumacher (1993) an achievement test measures what has been learnt by the learners and is not used to predict future achievement. The purpose of the TIMSS test was to measure achievement and to highlight areas of weakness and difficulties faced by the learners when answering the TIMSS science questions. This study used the content validity used in the TIMSS 1999 study. The validity of the TIMSS 1999 study involved planning of the test items, writing of the tests items and questions, piloting of the tests items and the analysis of data (Wolf, 1998). The test results were used to identify the patterns of possible errors and misconceptions held by the grade 8 natural science learners in three schools in Pietermaritzburg and the SA learners who participated in the TIMSS 1999 study.

3.4.6 Selection of schools for the study and gaining access to the schools

The schools were selected based on the previous category of black, Indian and Colored schools. It was these schools that provided the bulk of learners that took part in the TIMSS 1999 study. An introductory note was used to identify the researcher and the purpose of the study was explained by the researcher to the school principals and the participating learners. In all the schools the researcher did not experience any problems in gaining access to the schools. The principals seem to understand the need for research and its gains.

3.4.7 Analysis of questions

The analysis of the questions was guided by the need to identify particular possible patterns of misconceptions and errors common to South African grade 8 natural science learners. Scientific concepts and tools that were or should have been used by learners in answering each question were reviewed. Previous research on children's ideas relating to each question or related topics were reviewed. The theoretical framework based on the intended, implemented and attained curriculum, Pollitt and Ahmed's model and the constructivism theory were used to try and identify possible errors and misconceptions held by learners when answering TIMSS 1999 science questions.

According to Pollitt and Ahmed's (2001) model of the answering process, students answer examination questions following a process consisting of six stages. These stages are as follows:

- Learning the subject

- Reading the question
- Searching the memory
- Matching question to memory
- Generating the answer
- Writing the answer.

This model can be applicable to learners answering test or examination questions. The first stage is very important because most examinations are aimed at testing an understanding of the concepts. When answering multiple choice questions learners do not use the last two stages. This model would be helpful in interpreting how learners answered questions regarding topics that were not or inadequately taught at school at the time of the study. Pollit and Ahmed argue that students start to build up mental models of the task during the reading phase. In other words students break the sentence down based on the words used and their experiences. This model was also used to help explain how learners answered some of the TIMSS test items.

3.5 Document Analysis

The researcher collected the year planners from subject teachers at the three schools indicating which natural science topics were taught before the study was carried out. Learners' notebooks were collected from school A and school B. The researcher failed to obtain notebooks from school C. The notebooks' content represented the implemented curriculum. The implemented curriculum was analysed to check if it was in line with the intended curriculum and the attained curriculum. The notebooks were analysed for evidence of content validity of the questions and their link with the intended, the implemented and the attained curriculum.

3.6 Summary

This chapter discussed different methods used to collect the data for this study. Different methods were used in this study in order to improve validity of the results. For example interviews were used as a follow up of the results collected from the tests. The interviews with the HoDs were aimed at understanding the environmental and other factors that affect the teaching and learning of science in the three schools in Pietermaritzburg.

Chapter 4

ANALYSIS OF RESULTS AND DISCUSSION

4.1 Introduction

This chapter aims at exploring Grade 8 learners' misconceptions and errors when answering selected general science questions from the TIMSS 1999 science study. The errors made by learners are possible indicators to the misconceptions held by the learners. The responses are analysed for learners' reasoning and the nature of misconceptions held by learners are identified. The TIMSS test is both an achievement test and a diagnostic test. The diagnostic aspect of the test is used to gauge the learners' understanding and misunderstanding of science concepts (Angell, 2004).

The TIMSS study also collected data about schools' backgrounds and teacher qualifications. The questions asked in the TIMSS 1999 are analysed in line with the South African intended science curriculum for grade 8. Some results obtained from the test administered to Grade 8 natural science learners in Pietermaritzburg are presented. A comparison of the learners' correct responses to 21 questions for the three sampled schools in Pietermaritzburg is also presented.

4.2 School Profiles

This section describes background information about schools. The information would be used to understand some of the possible difficulties

experienced by learners that could result in high levels of misconceptions and errors in their learning of science.

The study found that in all the three sampled *Schools A, B and C* most of the science educators were said to be academically qualified with at least a teaching diploma in science. In the interviews with heads of science departments (HoDs) an observation was made that some educators with diplomas were upgrading themselves in other subjects that are not related to the teaching and learning of science but are seen to offer better pay prospects outside the teaching profession. This may indicate a decreased commitment to the teaching of science by such teachers.

In terms of resources, at *School A* the grade eight natural science learners did not have access to a single reference book. The teacher claimed that he used different sources of information to draw up the lessons, but these sources were not available at the school at the time this research was carried out. It was observed that he was using an old notebook as a source of information for teaching. An analysis of the notebook revealed some gaps in the content taught. The class sizes ranged from 42 to 45 learners. There was not enough space in the classrooms even to put a teacher's desk and there were no cupboards to store science equipment. The HoD at the school showed this researcher the equipment they use for teaching science. While the school had some chemicals in store, there were hardly any resources to aid the teaching and learning of biology and physics. However the instruction time of about 210 minutes per week is adequate for the learning and teaching of science at grade eight.

At *School B* the grade eight learners did not have textbooks but relied on learning support materials supplied by the Department of Education (DoE). These materials are valuable sources of information. They are however not suitable for use as a primary source of information because some of the concepts are not explained in detail. An analysis of these materials show that the information given was not detailed at all for learners to gain adequate understanding of certain concepts as required by the international studies. For example, the concept of matter only focused on the properties and not the changes of state. The class size at this school is about 42 learners per class. The instruction time is about 215 minutes per week, which is in line with the DoE requirements. At *School B* it was observed that a language specialist was teaching grade 9 natural science lessons.

At *School C* there are five science laboratories in total. However, the school does not have the equipment required to adequately teach science and these specialist rooms are now used as ordinary classrooms. The class sizes at this school range from 45 to 50 learners per class. The class sizes are however much smaller in grades 11 and 12 because of high drop out levels at grade 10. The school uses an eight-day teaching cycle and learners do science for six days in a cycle. The lessons are about one hour per session. The school does not have textbooks for all the grades except for grade 12, but teachers in lower grades do have some resource books. The researcher did not see the textbooks used by teachers at this school. It was observed that the DoE supplies the grade 12 textbooks. The science teachers at this school hold diplomas in science and degrees in other subjects that are not related to science. Only one science teacher at *School C* is a university science graduate. Despite its lack of adequate resources, the school is classified as privileged by the DoE because it has among other things, a fence and tarred

roads leading to it. This precludes the school from getting extra funding from the department of education to purchase equipment and supplies for the science laboratories.

4.3 Content Topics

The question numbers used in this study are the original TIMSS-R population 2 labels. The selected questions were grouped under the following topics:

- Animals and insects (L03, J02, L05)
- Chemical phenomena (N07)
- Density and mathematical formula (B03, P01)
- Electricity (N01)
- Energy transformations (B02, H06)
- Light (D01, F02, J08)
- Nervous system (D05, F03)
- Nutrition and diet (J07, H02)
- Physical phenomena (J04)
- Plants (H05, N05, D06, L02)

4.4 Secondary Analysis of Selected Science Questions

In this section the students' responses to the selected questions are presented and discussed item by item. The main focus was to identify the nature of the students' misconceptions and errors in conceptual understanding of scientific concepts. The data on percentages and the numbers of learners who attempted particular questions is based on the TIMSS 1999 data and the 2005 Pietermaritzburg sample. Some earlier studies on similar concepts or topics are reviewed. It is however important to note that none of the questions used in this study has been used as a tool to identify misconceptions in the reviewed literature. It is also important to note that this study only focused on the SA learners' responses to the TIMSS 1999 selected questions. The level of difficulty of each question was determined based on the percentage correct, questions with a percentage of correct responses less than 50% were identified as difficult questions. The international averages for each question will be stated for the purpose of comparison.

The analysis of learner's responses in the TIMSS 1999 study is supplemented by the results obtained from three schools in Pietermaritzburg. These results were collected using a multiple choice test and group interviews. The interviews were aimed at eliciting learner's understanding of certain scientific concepts and to establish whether the content was taught or not.

This chapter seeks to provide answers to the following research questions:

1. What are the misconceptions and errors made by SA learners in answering TIMSS science questions?
2. What are the causes of the misconceptions and errors experienced by SA learners in answering TIMSS science questions?

4.4.1 Animals and Insects (J02, L03, L05)

In this section learner's responses in the TIMSS study and the Pietermaritzburg sample to three questions relating to animals and insects are analysed for any possible patterns of misconceptions and errors made by learners when answering the questions.

QJ02. What feature is shared by ALL insects?

- A. External skeleton
- B. Two pairs of wings
- C. Jumping legs
- D. Stinging mechanism

The international average correct for this test item: 49%.

The correct answer is A. This question requires learners to understand simple information. Question J02 required learners to state a feature shared by all insects. All insects have an exoskeleton that is thick and immovable. They are the only winged invertebrates, but not all have two pairs of wings. If the question did not emphasize the word ALL, the response B to the question could have been correct. All the responses are true for some insects, but the question requires that the response must be true for all insects. The question proved to be difficult for the SA learners and learners in other countries who participated in the TIMSS 1999 study. In the interviews it was established that the PMB cohort was taught this topic at primary school. This is reflected in the higher percentage correct (56%) of learners that got the answer correct in the PMB sample (see Table 4.1).

The way in which students responded in TIMSS 1999 and from the PMB sample is shown in Table 4.1 below.

Table 4. 1 Percentage of learners selecting each response for question J02

Study	Learners' responses			
	A*	B	C	D
TIMSS 1999	41.2	27.0	19.3	11.2
PMB Sample	56.0	6.0	23.3	10.2

* represents the correct answer

Only one PMB learner did not respond to this question. There is a significant difference in the percentage of learners who gave the incorrect responses B and C in the studies. In the TIMSS study 41.2% of the learners chose the correct answer. A higher percentage (56%) of the PMB sample selected the correct answer. 27.0% of the learners who selected B in the TIMSS study assumed that all insects have two wings. In the PMB sample a much smaller percentage (6%) of learners selected this response. It could be argued that the difference could be due to the differences in sample sizes. It is possible that the large number of learners in the TIMSS study who selected B overlooked the word **all**, which would make B the correct answer. Similarly Naidoo (2003) in her study on teachers' scientific literacy reported that 7/15 of students enrolled in the Advanced Certificate in Education Programme (ACE) chose response B in the pretest. A significant number of learners in the TIMSS study and the PMB sample selected responses C and D. This could imply that once again learners misinterpreted the question by overlooking the word **all**. In the interviews learners failed to explain the meaning of the question. Also, in the interviews it became clear that many learners who selected B, C and D overlooked the word ALL in the question. When the learners were asked to identify the correct answer one of the learners was adamant that B was one of the correct answers because 80% of the insects have two pairs of wings. We cannot overlook the possibility that some learners might have possible misconceptions about the features

of insects. For example in the interviews one of the learners suggested that all insects have four jumping legs. Here is a sample of some of the responses given by learners during the interviews in response to the question:

What is an insect?

Student 1: insect has four legs, jumping legs.

Student 2: two pair of wings.

Students: An insect is like a fly, mosquitoes, lady bird, spider, locust and fly.

Some of the students are clearly not directly answering the interview question but are using the option from the TIMSS question to answer. Some students tried to answer the question by giving examples of insects with wings. The students were unable to define what an insect is but, from their answers it is clear that they do have some fragmented (disjointed) ideas about insects.

QL03. Which one of the following characteristics is most likely to be found in mammals that are preyed on by other mammals for food?

- A. **Eyes on their sides of the head.**
- B. Teeth that are long and pointed
- C. Claws on the feet
- D. Ears that cannot move

The international average correct for this test item: 37%.

The correct answer is A. Question L03 required students to know the physical characteristics of prey mammals. They should also know that animals that are preyed on by others have their eyes positioned at the sides so that they have a better view of the predator. The question requires learners to understand complex information. The

question was difficult for SA learners and learners in other countries who participated in the TIMSS 1999 study, on the other hand the PMB sample scored better on this question. In the interviews it was established that this topic was taught at primary school. This is reflected in the percentage correct responses in table 4.2.

The manner in which students responded in the TIMSS 1999 and the PMB sample is shown in Table 4.2 below.

Table 4. 2 Percentage of learners selecting each response for question L03

Study	Learners' responses			
	A*	B	C	D
TIMSS 1999	28.3	36.1	19.4	15.2
PMB Sample	46.7	36.7	16.7	0.0

* represents the correct answer

In the TIMSS test 28.3% of the SA learners selected the correct answer (A) and a significantly higher percentage of the sample (46.7%) were correct. From Table 4.2 a similar pattern in which the learners in both studies selected the incorrect responses B and C is observed. About 36.1% of the learners from the TIMSS study selected B and 36.7% of the PMB sample selected B. Perhaps learners in both studies were confused by the terms prey and preyed on. From their everyday experiences most learners would associate teeth with the eating of food and this could explain why some learners chose response B. The choice of C by almost the same percentage of students in both studies indicates a somewhat similar confusion. In other words, one might justifiably suspect that terminology or key word thinking might have affected the learners' choices of responses B and C. According to Harlow and Jones (2004: 233), key word thinking is when a student recognizes a word or part of a word in the item and links the response to their understanding of this word. It is possible that

learners know from everyday experience that animals that prey on and not preyed on have claws to catch the prey. The results of this item might seem interesting in the sense that none of the sampled learners were attracted to response D while in the TIMSS study 15.2% of the learners selected this response. The results obtained by Naidoo (2003: 69) showed that 7/15 of the student teachers in both the pretests and posttests selected the correct response A. In the interviews it however became clear that most of the sampled learners did not know the meaning of the word prey. Some of the responses given by learners are as follows:

What is prey?

Student 1: A prey is an animal.

Student 2: Lion is a prey.

Student 3: No, a buck is the lion's prey.

These responses show that some learners misinterpreted the question because they did not understand the meaning of the word “prey” or there is confusion between the meanings of preyed on or prey on.

QL05. When male wolves place their scent on trees, they are most likely doing this in order to

- A. attract female wolves
- B. attract prey
- C. mark their territory against other wolves**
- D. mark the location of food supplies

The international average correct for this test item: 60%.

The correct answer is C. Question L05 asked learners to give a reason why wolves mark their territory. Animals such as wolves communicate their feelings and needs to others by marking their territory. Wolves use scent marking to delineate territorial boundaries between packs, so that a series of scent marks serves as a warning to other wolves to keep away. Scent marks may be used as a kind of road map to enable wolves to find their way. The question requires learners to show an understanding of simple information, but this was difficult for the PMB sampled learners because this topic had not been taught at the time of the interviews. This question was only difficult for SA grade 8 natural science learners in both studies but, not for other learners in other countries who participated in the TIMSS 1999 study.

The way in which students responded in TIMSS 1999 and from the PMB sample is shown in Table 4.3 below.

Table 4. 3 Percentage of learners selecting each response for question L05

Study	Learners' responses			
	A	B	C*	D
TIMSS 1999	49.1	9.8	26.2	13.3
PMB Sample	43.3	10.0	30.0	13.3

* represents the correct answer

The results shown above indicate that there is a similar pattern in the selection of all the responses by learners in TIMSS 1999 and the 2005 sample. One PMB learner did not respond to this question. In the TIMSS study 26.2% of the learners selected the correct answer and 30% of the PMB sample chose the correct answer. In the TIMSS study a high percentage of respondents, 49.1% in all selected the incorrect response A. A similar pattern was observed with the learners in the PMB sampled learners where 43.3% of the learners selected the incorrect answer A. Similarly, Naidoo

(2003) found that a high number of students teachers selected response A in both the pretests and posttests. A lesser number of learners selected the incorrect responses B and D. The PMB sample did not know the meaning of prey in the previous question as a result response B was not popular with them. This is indicated by the results in Table 4.3. In the interviews learners could not give a reasonable description or explanation of what a wolf is. It is possible that the term male in the question was used by learners as a key word to help them select the response A. Also it is possible that learners know from everyday experiences that opposite or unlike objects attract. And they also know from the television adverts that perfume or scent is portrayed as a way of attracting the opposite sex. Therefore the most obvious choice would be A which implies female wolves are attracted to the males by their scent.

In the interviews it became clear that the word attract was used by learners to mean attracting the opposite sex. In all the three sampled schools most learners identified A and C as being the most correct answers. When the learners were asked why A was correct, answers like ‘it is the one that makes sense’ was given. In the interviews learners could not give reasonable explanations as to why they were choosing a particular alternative instead of the other. Similar findings were made by Taylor (1991) cited in Pollitt and Ahmed (2001:2) where students could not explain how they arrived at an answer in a multiple choice test and students indicated that an answer “just popped into their heads”. As a possible example, when learners were asked to describe a wolf they gave the following answers:

What is a wolf?

Student 1: It stays in the forest.

Student 2: Looks similar to a dog.

The responses show that some learners lack basic knowledge about the characteristics of wolves. It is evident that learners used their everyday experience to

answer the above question. It is possible to infer that the poor performance of learners observed in the TIMSS 1999 study was partly due to the fact that some of the content had not been taught or had been partially taught in grade 7. For example, the intended curriculum for 1999 emphasized that features of animals should be related to the suitability of every organism to survive in its particular habitat. What was supposed to be taught would not be relevant to this question. Also the SA intended curriculum C2005 does not specify what should be studied on animals. An analysis of the PMB sample learners' notebooks, which represents the implemented curriculum, showed that this topic had not been taught at grade 8 at the time the study was conducted. This raises the issue of the appropriateness of questions to the target population. While the sampled learners may not be familiar with the habits of wild wolves, it is however true that many African big cats such as leopards, cheetahs and even family dogs display the same behavioural traits as wolves.

This study has shown that some learners made errors when answering some life science some questions because they were unfamiliar with the terminology used in the questions. In this instance they also lacked a context, that is they were not familiar with wolves and their behavioural traits and as result they used key word linking to answer the question. It has also been shown that some learners have fragmented (disjointed) ideas about some of the concepts they have not been properly taught.

4.4.2 Chemical Phenomena

In this section learner's responses in the TIMSS study and the Pietermaritzburg sample to a question relating to chemical reaction is analysed for any possible patterns of misconceptions held and errors made by learners when answering the questions.

QN07. Which is an example of a chemical reaction?

- A. Water boiling
- B. Sugar dissolving
- C. Nail rusting**
- D. Wax melting

The international average correct for this test item: 47%.

The correct answer is C. Question N07 examined the learners on their understanding of a chemical change. In answering this question learners were expected to know the difference between the concepts of chemical and physical transformation. In a physical transformation of matter, the identity of the substances, which are taking part in the process, is conserved. In a chemical transformation of matter, the identity of substances that are taking part in the processes is altered and the microscopic units undergo change. A chemical reaction may occur when two or more elements are chemically joined. This change may result in a change in colour, smell or gas being given off or even the formation of new substances. This question requires learners to know examples of chemical reactions. This topic was difficult for SA learners and learners in other countries who participated in the TIMSS 1999 study. This topic had been taught at two schools at the time the study was conducted. But this is not reflected in their percentage correct results in Table 4.4.

The way in which students responded in TIMSS 1999 and from the PMB sample is shown in Table 4.4 below.

Table 4. 4 Percentage of learners selecting each response for question N07

Study	Learners' responses			
	A	B	C*	D
TIMSS 1999	32.5	28.9	17.8	19.1
PMB Sample	30.0	13.3	33.3	23.3

* represents the correct answer

There is a similar pattern in which the learners in both studies selected incorrect responses A and D. About 32.5% of the TIMSS respondents chose A compared with 30% of the sampled learners. 19.1% of the respondents from the TIMSS study selected D and 23.3% of the sampled learners selected D. The selection of responses A and D could also suggest that learners do not know the difference between the change of state as opposed to a chemical change or chemical reaction. It is possible that the variation observed in the choices of B and C could be due to the difference in the size of the sample.

In the TIMSS study a very small percentage of SA learners 17.8% selected the correct answer. While 33.3% of the PMB sample were correct. It is possible that the PMB sample knew that water boils and became steam and wax changes to liquid when it melts. Heat is involved in both processes could possibly explain the choices of the PMB sample. On the other hand the rusting of nail and dissolving of sugar requires the presence of water. Also most of the incorrect learners failed to view rusting of nail as a chemical reaction. About twenty nine percent of the respondents in the TIMSS study selected B suggested that learners think that dissolving sugar involve a chemical change, but only 13.3% of the sampled learners selected B. The high percentage of incorrect responses could suggest that learners have

misconceptions about chemical changes. In the interviews it became clear that most learners did not know or understand the concept of change of state. When learners were asked some questions in the interviews they gave the following responses:

What is chemical change?

Student 1: Something observed to react something out of it.

Student 2: I think it means two solutions react together.

Give some examples of a chemical change?

Student 1: Sugar and water dissolving

Student 2: Particles of sugar disappear.

Student 3: Water boiling

What is change of state?

None of the interviewed learners were able to respond to this question.

The responses given by learners suggest that learners hold the following possible misconceptions/errors about chemical changes: that the boiling of water, sugar dissolving, and melting of wax are examples of chemical change.

Starvidou and Solomoniadou (1989: 89), observed that when children aged 13 -14 years were asked to categorize change as either physical or chemical, children classified dissolution of salt or sugar in water as chemical phenomena because they felt that two substances were involved (water + sugar or water + salt) to produce only one “visible” substance. In the Starvidou and Solomoniadou (1989) study, the rusting of a nail was correctly classified as a chemical phenomenon. However, the reason proffered was that only one substance was changing. The same group of learners also classified the boiling of water as a chemical phenomenon. Starvidou and Solomoniadou concluded from their study that students categorized processes based on a few concepts directly related to static representation of everyday life.

Their findings are similar to the findings of this study where students identified dissolving of sugar and boiling water as examples of chemical change.

4.4.3 Density and Mathematical Formula (QB03, QP01)

In this section learner's responses in the TIMSS study and the Pietermaritzburg sample to two questions relating to mathematical equations are analysed for any possible patterns of misconceptions held and errors made by learners when answering the questions.

QB03. Which object listed in the table has the greatest density?

Object	Mass of Object	Volume of Object
W	11.0 grams	24 cubic centimetres
X	11.0 grams	12 cubic centimetres
Y	5.5 grams	4 cubic centimetres
Z	5.5 grams	11 cubic centimetres

- A. W
- B. X
- C. Y**
- D. Z

The international average correct for this test item: 28%.

The correct answer is C. Question B03 required students to calculate the density of an object given the object's mass and volume. The test item requires learners to apply a formula involving the mass and volume of the object analyse the data and

then provide a solution. The question was difficult for SA grade 8 natural science learners and learners in other countries who participated in the TIMSS 1999 study. This posed a challenge to most of the learners in the Pietermaritzburg study because they did not have a knowledge base to refer to since the work was not yet taught at two schools at the time the study was conducted. The concept of density has been shown in earlier studies to present major conceptual challenges for learners (Hewson (1986) and Demenech *et al* (1993)). In order to fully grasp the concept of density, learners were required to understand the concepts of mass and volume. Volume is commonly defined, as the amount of space that is occupied by matter and mass is the quantity of matter in a body. The density of a substance is the ratio of its mass in kg's to the volume in cubic metres of that substance.

The way in which students responded in TIMSS 1999 and from the PMB sample is shown in Table 4.5 below.

Table 4. 5 Percentage of learners selecting each response for question B03

Study	Learners' responses			
	A	B	C*	D
TIMSS 1999	57.5	14.5	17.2	9.0
PMB Sample	56.7	13.3	16.7	10.0

* represents the correct answer

One PMB learner did not respond to this question. There is a similar pattern in the manner in which learners selected the four alternatives in both studies. The results from the TIMSS study show that only 17.2% of the SA learners and about 16.7% of the PMB learners selected the correct answer C. A high percentage, 57.5% of the SA learners selected the incorrect response A and a similar percentage of 56.7% of the sampled learners selected response A. This high percentage of incorrect responses

would indicate that learners did not use the scientific formula relating mass, density and volume, in arriving at their answers. The learners seem to have used the idea that largest object with the largest volume equals largest density. In the interviews one learner said that he arrived at the correct answer by adding the greatest mass plus greatest volume and that gave him the greatest density. Results of the TIMSS study and the PMB sample indicate that most of the learners seem to have used this idea in arriving at their answers.

In the interviews it was established that learners at one of the schools had been taught the concept of density, but very few could apply the formula, only 3 learners from *School B* where the topic was taught were able to identify the correct answer. The notebook from school B confirmed that this topic was taught at school. Only 1 learner from each of the other two schools where the topic was not taught was correct. This topic can not be easily related to everyday experience by learners because people rarely use the concept of density. The concept of density is also not explicitly mentioned in the intended curriculum C2005 as content to be taught at grade 8 natural science. An important observation during the interviews was that learners had problems in correctly defining scientific or technical terms. Learners were asked to explain the precise meaning of mass, volume and density. These are some of the student responses to a density question:

What is mass, volume and density?

Student 1: Mass is weight.

Student 2: Mass is density of something like 12.5kg.

Student 3: Mass is just something like grams and weight.

Student 4: Mass is pushing action, attracting something.

Student 5: Volume is space of an object.

Student 6: Density is the amount of space.

Student 7: Volume is loud and low.

In general students used their everyday understanding of the terms for example mass and volume but they were not able to relate to “density” because in everyday language the concept of density is rarely used. The answers given by learners are in line with the findings of Demenech *et al* (1993). In their study they found that high school students could not give a correct scientific definition of mass. When asked about the relationship between mass, volume and density the expected response was the formula:

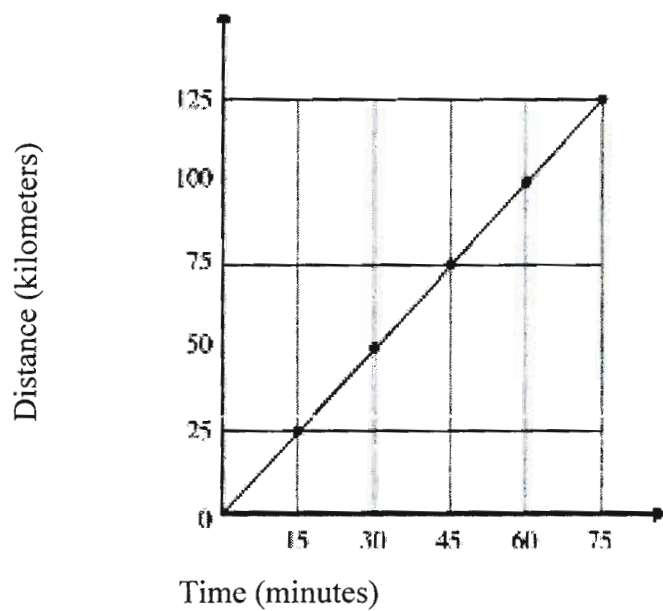
$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Most learners from *School B* were able to give the correct formula in the interviews. However, very few learners actually applied this formula when confronted with a question that required a numerical computation of density in the test. When asked why they did not use the formula to calculate the correct answer they could not give any rational explanation. Hewson (1986) in his study on children’s ideas on floating and sinking found that students could not come up with one general reason as to why some objects float while others sink. Some of the students explained density as the packing of particles. Demenech *et al* (1993) observed that most Spanish high school students could also not give a scientific definition of mass. Demenech *et al* (1993) argued that students’ failure to grasp certain concepts may be due to the formal quantitative numerical reasoning used by scientists and less to do with their inability to learn the vocabulary and fundamental knowledge involved. It was also interesting to note that some learners understood the word “volume” within the context of

'sound' i.e. being 'loud' or 'low' and so were relating the concept to a more everyday understanding of the word. This study has confirmed that learners have problems in explaining or defining the concepts of mass, volume and density.

Question P01

The graph shows the progress made by a car traveling along a straight road



What is the speed of the car?

25 kilometers per hour

50kilometres per hour

75 kilometers

100 kilometers.

The international average correct for this test item: 54%.

The correct answer is D. Question P01 requires learners to determine the speed of an object from a distance – time graph. The distance time graph shows the distance covered by moving object in a given time. In answering this question learners were expected to use the relationship between distance, speed and time in working out their answers. Also they needed to be able to read off the graph. In particular, average speed is defined using the mathematical formula: $\text{average speed} = \text{distance} / \text{time}$. This test item requires learners to theorize, analyse and solve problems. The item requires learners to interpret or understand the meaning of the graph before working out a possible solution. The question was difficult for SA learners but was not difficult for learners in other countries who participated in the TIMSS 1999 study. In the interviews it was established that this topic had not been taught at two schools at the time the interviews were conducted. This is reflected in the low percentage correct results in Table 4.6.

The way in which students responded in TIMSS 1999 and from the PMB sample is shown in Table 4.6 below.

Table 4. 6 Percentage of learners selecting each response for question P01

Study	Learners' responses			
	A	B	C	D*
TIMSS 1999	17.3	8.9	25.6	46.9
PMB Sample	16.7	26.7	40.0	13.3

* represent the correct answer

One PMB learner did not respond to this question. In the TIMSS study 46.9% of the learners selected the correct response and only 13.3% of the PMB learners were correct. There is a different pattern in answering the question. The difference could be due to the fact that the 1999 SA syllabus suggests that this topic was supposed to

be taught at grade 7. But, curriculum C2005 which the PMB sample used does not mention this topic directly. 25.6% of the respondents in the TIMSS study chose the response C and 40% of the PMB learners chose C, possibly meaning that learners read off the answer from the graph. In the interviews learners in all three sampled schools failed to interpret the meaning of the graph. For example, some of the responses given by learners when asked about graphs are as follows:

What does this graph represent or show?

Student 1: Pie chart.

Student 2: The graph is about constant speed.

What is speed?

Student 1: 'Constant space'.

Student 2: "Speed" is similar to a watch.

What is the relationship between speed, distance and time?

Student 1: speed = Time/ Distance.

None of the learners were able to respond correctly to the above questions. It is interesting to note however that the student who referred to 'speed' as a 'constant space', is actually referring to it within the context of the graph and the fact that the space between the different points on the graph is constant and is not defining the term 'speed'. Also, the hand of a watch moves at a constant 'speed' hence the reference to speed being similar to a watch. The learners' responses suggest that they lack basic knowledge or skills about graphs and about the concept of speed. Beichner (1994) in his study of students' interpretation of kinematics (motion) graphs found that some students described graphs as photographs. Osbourne and Freyberg (1985) found that many children in junior secondary school do not have the appropriate mental ability to understand line graphs. According to Berg and Phillips

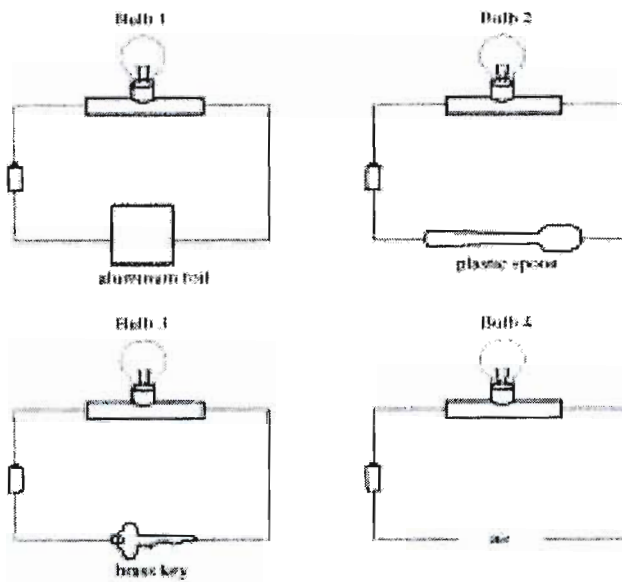
(1994) literature on graphing showed that students in different age levels have problems with the construction and interpretation of graphs.

4.4.4 Electrical Circuit (N01)

In this section learner's responses in the TIMSS study and the Pietermaritzburg sample to a question relating to electric circuit are analysed for any possible patterns of misconceptions held and errors made by learners when answering the questions.

Question N01

The following diagrams show a battery and a bulb connected by wires to various materials.



Which of the bulbs will light?

- A. 1 only
- B. 2 and 3 only
- C. 1 and 3 only**

D. 1, 3 and 4 only

E. 1, 2 and 3 only.

The international average correct for this test item: 54%.

The correct answer is C. This question requires learners to know that in a complete circuit, electrical current flows. If the light glows it means that current is flowing. Conductors are substances, which allow current to flow through them whilst insulators do not allow current to flow through them. This question will be a problem to learners with little or no exposure to experimental tasks relating to electricity. The test item requires learners to understand complex information. This question was difficult for SA learners, but it was not difficult for learners in other countries who participated in the TIMSS 1999 study. This topic on electricity had been taught in all the three schools studied. This is reflected in the percentage correct results in Table 4.7.

The way in which students responded in TIMSS 1999 and from the PMB sample is shown in Table 4.7 below.

Table 4.7 Percentage of learners selecting each response for question N01

Study	Learners' responses				
	A	B	C*	D	E
TIMSS 1999	32.4	11.0	32.6	14.3	8.2
PMB Sample	23.3	0.0	46.7	10.0	23.3

* represents the correct answer

There is no pattern in the manner in which the learners selected the four alternatives in both studies. In the TIMSS study 32.6% of the learners selected the correct response. In contrast, the results obtained from the three sampled schools show a

better understanding with 46.7% of the learners being correct. 32.4% of the learners in the TIMSS study chose A and only 23.3% of the sampled learners chose A. Learners in both studies failed to perceive the brass key to be a metal or a conductor. 23.3% of the sampled learners chose E and only 8.2% of the learners in the TIMSS study chose this response. It is evident that learners used their every experience that electricity is transmitted by a medium to select the incorrect responses in Table 4.7. Some of the answers given by learners when they were asked to state the correct answer are as follows:

Give some examples of metals.

Students: copper, iron, steel.

Which one is the correct answer?

Students: C, you need a conductor for electricity.

Student 2: Air will not conduct electricity.

Student 3: Air is not a wire.

Student 4: You need a wire to conduct electricity, key is not a wire.

From their answers it is clear that from their everyday experience the students know that electricity is conducted through wires. The students' answers to the interview questions also show that they can give adequate examples of metals and understand that air does not conduct electricity but are not necessarily making the connection between metals and their ability to conduct electricity regardless of their shape. An analysis of the learners' notebooks however revealed that in school A no explicit mention of insulators and conductors was made. In *School B* where adequate work was taught on the topic compared to the other two schools, the study revealed a better performance by the learners. In his study on students' interpretation of simple electric diagrams, Joshua (1984) found that both high school and university students

had problems in interpreting circuit diagrams. Shipstone (1984) found that learners thought that current was used up in a circuit.

4.4.5 Energy Transformation (QH06, QB02)

In this section learner's responses in the TIMSS study and the Pietermaritzburg cohort to two questions relating to energy transformations are analysed for any possible patterns of misconceptions held and errors made by learners when answering the questions.

QH06. If you are burning wood, the reaction will

- A. **release energy**
- B. absorb energy
- C. neither absorb nor release energy
- D. Sometimes release and sometimes absorb energy, depending on the kind of wood.

The international average correct for this test item: 55%.

The correct answer is A. This question deals with a broad issue of energy change and or conservation. The fundamental principle of conservation of energy states that energy cannot be destroyed but can be converted from one form to the other. The knowledge of energy conversion and types or forms of energy is necessary in answering this question. Burning means combustion. A lot of energy is released in burning and flames are usually seen. Carbon dioxide and water are the common products of burning. The learners were supposed to link burning and combustion and use the relationship in arriving at their answers. The test item required learners to understand simple information. The wording of the question is not easy for a second

language learner to understand. The question was difficult for the SA learners but was not for learners in other countries who participated in the TIMSS 1999 study. An analysis of the year planner and notebooks revealed that the topic had been taught at the three schools at the time the study was carried out. This is reflected in the percentage correct results in Table 4.8.

The way in which students responded in TIMSS 1999 and the PMB sample is shown in table 4.8 below

Table 4. 8 Percentage of learners selecting each response for question H06

Sample	Learners' responses			
	A*	B	C	D
TIMSS 1999	19.6	24.2	10.4	42.8
PMB Sample	40.0	13.3	13.3	30.0

* represents the correct answer

There is no obvious relationship in the manner the question was answered in 1999 and in 2005. In the TIMSS study about 19.6% of the students were able to identify the correct answer and 40% of the sampled learners were correct. 42.8% of the students in the TIMSS study selected D as the correct answer and 30% of the sample learners selected D. It is possible that from everyday experience learners know that when one is making fire the burning of the wood depends on the kind of wood used. If the wood is wet it does not burn easily but absorbs energy. For example planks and wood shavings burn faster and give off heat. Also, it could be possible that learners do not understand the meaning of the term reaction within the context it is used in the question. In the interviews, learners failed to explain the meaning of the question and the concept of energy changes, but an analysis of the learners' notebooks and planners revealed that the topic had been taught at schools. The implication here is

that learners have problems in understanding the concept of energy changes. In other words this could imply that learners do not understand some of the concepts taught. As an example, when learners were asked some general questions about energy, the following responses were given:

Give some examples of energy changes.

Student 1: When car is off.

Student 2: A radio.

Student 3: When you switch the lights

Give some examples of types of energy.

Students: Food, kinetic energy, potential energy, heat energy, sound energy, light energy and elastic energy.

Students were able to list types of energy but had no clear understanding of what is involved in energy change. The examples of energy changes given by learners possibly suggest that learners used their everyday experiences of how an object works and only those examples of objects that learners interact with at home were given. For example, most examples given are of objects in which observable energy changes occur and where the effect of the presence or absence of energy is observed when the object or appliance is 'on' or 'off'. These ideas are not related to what is learnt at school. Studies carried out by Bliss and Ogborn (1985) also confirm that learners have problems with the concept of energy. In their study learners classified cars, aircrafts, ships, and drills as having energy. On the other hand they viewed a falling book and rain from clouds as not having energy. The study showed that objects used by learners at home made more sense to them in terms of explaining the concept of energy than unfamiliar objects. Their findings are similar to the findings of this study where learners view cars, radios and lights as examples of energy change.

QB02. Most of the chemical energy released when gasoline (petrol) burns in a car engine is not used to move the car, but is changed into

A. electricity

B. heat

C. magnetism

D. sound

The international average correct for this test item: 58%.

The correct answer is B. The test item requires learners to understand simple information about multiple energy changes and that most chemical energy is released as heat. The topic was difficult for the SA learners but it was not difficult for the PMB sample and the learners in other countries who participated in the TIMSS 1999 study. The learners' notebooks and year planners indicated that the topic had been taught in schools at the time the study was carried out. This is reflected in the percentage correct results of the sampled learners in Table 4.9.

The way in which students responded in TIMSS 1999 and from the PMB sample is shown in Table 4.9 below.

Table 4. 9 Percentage of learners selecting each response for question B02

Study	Learners' responses			
	A	B*	C	D
TIMSS 1999	27.0	39.7	11.5	18.6
PMB Sample	10.0	50.0	23.3	16.7

* represents the correct answers

In the TIMSS study less than two out of five or 39.7% of the learners chose the correct answer and 50% of the PMB learners were correct. A relatively large number of learners in the TIMSS study (27.0%) selected A; this response attracted few (10%) of the PMB learners. The choice of A could have been influenced by the fact that a car has lights. 11.5% of the learners from the TIMSS study compared with 23.3% of the sampled learners selected C. 18.6% of the learners from the TIMSS study chose D and 16.7% of the PMB learners selected D. It is possible that from everyday experience learners know that when a car is moving sound is produced and magnetism is associated with electric motors.

In the interviews learners could not give any reasonable explanation as to what energy changes entail. This confirms the findings of Driver (1985). In her study of 10-11 year-olds reported that students had problems with the concept of energy change. In so far as some of learners in this group are concerned, chemical potential energy changed into electrical energy. This could be true when looking at the changes in an electric circuit, where a battery is used as the source of energy. Some students are aware of this fact from their everyday experiences and this could explain the confusion in answering this question. As an example, when learners were asked the question:

Is petrol a source of energy?

Student 1: No, because the car is not a living thing.

Student 2: Yes a car cannot go without petrol.

Student 1 associates energy with food and living things. This indicates a possible misconception. These results are however, not unexpected, as a number of previous studies would confirm. A study by Ault *et al* (1988:539) found among other things that learners did not consider energy to exist unless it is being used. Potential energy

was thus not seen as a form of energy. The study found that although learners had ideas about energy conversions most could not explain the conversion processes and the resultant energy forms.

4.4.6 Fluid Evaporation (QJ04)

In this section learner's responses in the TIMSS study and the Pietermaritzburg sample to a question relating to the rate of fluid evaporation is analysed for any possible patterns of misconceptions held and errors made by learners when answering the questions.

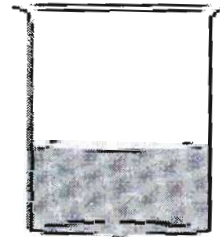
Question J04

A student put 100mL of water in each of the open containers and let them stand in the sun for one day. Which container would probably lose most water due to evaporation?

A.



B.



C.



D.



The international average correct for this test item: 84%.

The correct answer is C. The test item requires learners to understand complex information. Evaporation occurs when water changes from a liquid to water vapour. In practice, the larger the surface area, the more water escapes as water vapour compared

to a small surface area. The learners were expected to link surface area to the rate of evaporation. This question was not difficult for SA learners and learners in other countries who participated in the TIMSS 1999 study. In the interviews it was established that the PMB cohort was taught this topic at primary school. This is reflected in the percentage correct results in Table 4.10.

The way in which students responded in TIMSS 1999 and from the PMB sample is shown in Table 4.10 below.

Table 4. 10 Percentage of learners selecting each response for question J04

Study	Learners' responses			
	A	B	C*	D
TIMSS 1999	8.2	13.3	53.3	23.0
PMB Sample	0.0	6.6	80.0	13.3

* represents the correct answer

In the TIMSS study a high percentage 53.3% of correct responses would suggest a reasonable understanding of the process of evaporation. The results obtained in the three sampled schools show that a high percentage of 80% chose the correct answer. It is possible that from everyday experience learners know that a saucer cools tea faster than a cup. However, the selection of D by 23.0% of the learners in the TIMSS study and 13.3% of the sampled learners would suggest a misinterpretation of the question by some learners. It is clearly stated that the amount of water is the same in all cases. To the learners however, D contained more water because of height. Also the choice D could suggest that learners used their senses of sight. In the interviews learners in all the schools indicated that a similar experiment was done at primary school. Nevertheless, learners failed to give a correct definition of evaporation. Some of the responses given by the learners are as follows:

What is evaporation?

Student 1: Water goes up into the air.

Student 2: Water vapour from the dam to the cloud.

Student 3: The sun makes the water to go up.

What are the factors affecting the rate of evaporation?

Student 1: Water, Sun.

Student 2: The sun.

What is wrong with A?

Students: A is wrong you need a bigger surface area like a dam.

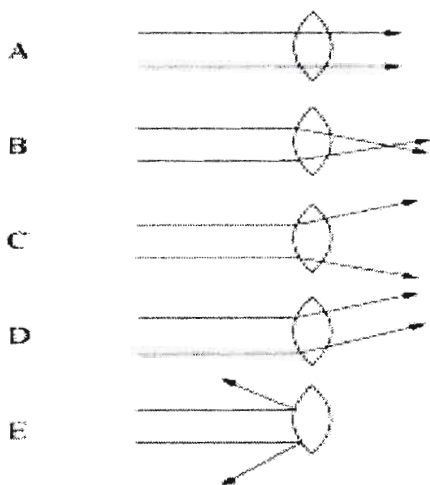
The responses given by the learners show some understanding that the heat from the sun causes water to go up and the need for a larger surface area for more water to evaporate. But there was no mention of the change of state. These responses show that learners view water as being removed from the source and not water vapour. Research carried out by Stavy (1990) and Bar and Travis (1991) show that learners have difficulties in explaining the concept of evaporation. Studies carried out by Russell *et al.* (1989) on eliciting children's ideas on evaporation showed that students explained the drop in the level of water as due to removal by a person or an animal. Some learners thought that the sun had sucked up some of the water. When the learners were asked to represent their ideas on a diagram, they did not show the change of states. Further research carried out by Stavy (1990), Bar and Travis (1991) on evaporation clearly shows that learners have problems in explaining this concept. Their findings are similar to the findings of this study.

4.4.7 Light and Solar Radiation QD01, QF02, QJ08.

In this section learner's responses in the TIMSS study and the Pietermaritzburg sample to three questions relating to light and solar radiation are analysed for any possible patterns of misconceptions and errors made by learners when answering the questions.

Question D01

Which diagram best shows what happens when light passes through a magnifying glass?



The international average correct for this test item: 42%.

The correct answer is B. D01 requires learners to understand complex information. Learners are required to apply the concept of refraction in order to answer this question. In space light travels in straight lines. When light passes through a lens it is refracted (bent). If the lens is a convex the light ray is focused at the focal point. This

question was difficult for SA learners and learners in other countries who participated in the TIMSS 1999 study. An analysis of the learners' notebooks and the year planners revealed that the topic had not been taught in schools at the time of the study was carried out. This is reflected by the low percentage correct responses in Table 4.11.

The way in which students responded in TIMSS 1999 and from the PMB sample is shown in Table 4.11 below.

Table 4. 11 Percentage of learners selecting each response for question D01

Study	Learners' responses				
	A	B*	C	D	E
TIMSS 1999	31.4	13.5	23.9	4.5	23.8
PMB Sample	33.3	13.3	30.0	6.7	13.3

* represents the correct answer

One PMB learner did not respond to this question. In the TIMSS study only a small percentage, 13.5% of learners were able to identify the correct answer and similar percentage, 13.3% of the sampled learners were correct. Of particular interest is that 31.4% of the learners chose A as the correct response and similar observations were made in the findings of the three sampled schools is that 33.3% of the learners chose A. This group believed that light travels in a straight line, even when it passes through transparent objects. In keeping with the findings in Guesne (1985), by choosing C as the correct response, 23.9% of the learners in the TIMSS study thought that a magnifying glass enlarges the light rays and 30% of the sampled learners chose C. In Guesne (1985), it was found that learners interpreted the idea that a magnifying glass sets a sheet of paper alight to mean that a magnifying glass makes the light rays bigger. However some correctly thought the magnifying glass

concentrated the light rays, but when asked to draw the diagrams they failed to show the aspect of bending of light.

In the interviews when learners at school B were asked to draw a diagram to represent how light travels as it passes through a lens. Most of the diagrams drawn by learners were similar to those in the TIMSS test items but none of the diagrams resembled the focusing of light as it passed through the lens. These results are similar to those of Guesne (1985) where students failed to show the aspect of bending of light. The choice of A by a large number of learners clearly shows that the concept of refraction is alien to the learners. It was established during interviews that learners used their everyday experience that light travels in a straight line in arriving at their answer. For example some of the responses given by learners are as follows:

What is light?

Student 1: Something that can allow you to see.

Student 2: Makes things brighter.

What is the correct answer?

Students: C; the light is spreading out so that you can see properly, arrows bend get bigger, the sun's rays go through the magnifying glass, rays spread out.

Students: A; arrows straight, straight lines. .

The learners are defining light within the context of its enabling them to see and to see things better. They are unable to give a scientific definition but rather relate it to their everyday observation of the function of light. The responses given by learners also suggest that learners used their everyday experiences that light travels in a straight line and also the fact that a magnifying glass makes things bigger meant that to them the lens made the rays bigger. These findings are similar to those of Guesne (1985).

QF02. On a warm day, you will feel cooler wearing light-coloured clothes because

- A. reflect more radiation**
- B. prevent sweating
- C. are not as heavy as dark clothes
- D. let more air in

The international average correct for this test item: 65%.

The correct answer is A. The test item requires learners to understand complex information. This test item is challenging because it requires learners to correctly interpret the given information and deduce the meaning from it. To respond correctly to this test item, learners needed to understand that when light falls on a body some of the energy is reflected and some is absorbed. The absorbed energy heats up the object whose temperature then rises. Dark or black bodies are good heat absorbers and emitters. On the other hand, highly polished or light-coloured bodies are good reflectors of heat. In arriving at their correct answers learners were expected to apply this scientific knowledge. The topic was difficult for SA learners but was not difficult for learner in other countries who participated in the TIMSS 1999 study. In the interviews it was established that the topic had not been taught in schools at the time the study was carried out. This is reflected in the low percentage correct in Table 4.12.

The way in which students responded in TIMSS 1999 and from the PMB sample is shown in table 4.12 below.

Table 4. 12 Percentage of learners selecting each response for question F02

Study	Learners' responses			
	A*	B	C	D
TIMSS 1999	18.2	11.2	37.1	31.5
PMB Sample	10.0	3.3	36.7	50.0

* represents the correct answer

In the TIMSS study 18.2% of the learners selected the correct answer compared with only 10% of the sampled learners. A selection of C by a large percentage of learners in both studies would imply that learners did not understand the meaning of the question. In the interviews learners failed to explain the question. It is some of these learners used key word thinking to link the word light to mean the opposite of heavy. In other words the wording of the question confused them as second English language speakers. About 31.5% of the learners in the TIMSS study chose D as compared to 50% of the sampled learners. It is possible that from everyday experience learners have experienced that on a warm day people feel cooler in lighter clothes. However, in the interviews it became clear that although the topic was not taught at the time this study was carried out, the majority of learners knew the meaning of light coloured because learners gave correct examples of light coloured objects. However, these answers were not linked to the content demand of the question. Some of the answers given by learners are as follows:

Give examples of light-coloured objects.

Students: yellow, white, pink, blue, orange.

What is the correct answer?

Student 1 C is the correct answer because it gives better understanding they do not take in light.

Student 2: D lets more air in, when air blows on you it makes you cool, more air means cooler.

This study has found that some of the conceptual problems experienced by learners during the TIMSS 1999 study and the PMB study might be due to the fact that learners were not taught some of the topics and the language used in the question.

Q J08 Sunscreen is used to protect the skin from exposure to which type of solar radiation?

- A. visible
- B. X-rays
- C. Infrared
- D. Ultraviolet**
- E. Microwaves

The international average correct for this test item: 62%.

The correct answer is D. The test item requires learners to understand simple information. This question probes the learners' knowledge of the electromagnetic spectrum. The electromagnetic spectrum covers a wide range of wavelengths and photon energies. Also found in the electromagnetic spectrum are common electromagnetic waves like radio waves, microwaves, infrared, visible, ultraviolet, X-rays and gamma rays. Too much exposure to ultraviolet rays can cause severe damage to the skin, commonly known as sunburn. Sunscreen is applied to the skin as a preventative measure to avoid sunburn. This question was difficult for SA learners but, not for learners in other countries who participated in the TIMSS 1999 study. An analysis of the notebooks and the year planners revealed that the topic had not been

taught in schools at the time the study was conducted. This is reflected in the low percentage correct in Table 4.13.

The way in which students responded in TIMSS 1999 and from the PMB sample is shown in table 4.13 below.

Table 4. 13 Percentage of learners selecting each response for question J08

Study	Learners' responses				
	A	B	C	D*	E
TIMSS 1999	16.9	30.8	6.6	18.0	26.0
PMB Sample	16.7	23.3	10.0	36.7	6.7

* represents the correct answer

Two PMB learners did not respond to this question. The results indicate that learners' choices of incorrect responses A and C are similar for both studies. In the TIMSS study only 18% of the respondents identified the correct answer. The results of the PMB sample were better with 36.7% of the learners being correct. However, almost a third of SA learners in the TIMSS study selected the response B. A similar pattern was obtained from the sampled schools. It is possible that the concept of X-rays would be the most familiar form of radiation to most learners because of their use in hospitals. A second group of learners in the TIMSS study, 26.0% chose E compared with a small percentage (6.7%) of the sampled learners who chose this response. It is possible that the sampled learners are familiar with the use of microwaves in homes and they could not associate it with the skin. The observed difference is due to the fact that the PMB sample consisted of city schools whilst the TIMSS study included rural schools. It is possible that these learners lacked relevant basic knowledge on the concepts of solar radiation and ultraviolet light. In the interviews, learners could not give correct examples of sunscreen products

suggesting that they have not used sunscreen before or do not know what sunscreen is. One learner said that sunscreen was ‘something bad for the body and it comes from the sun. This implies that some learners understood the word ‘sunscreen’ to mean ‘sunburn’. Some of the answers given by learners when asked about radiation are as follows:

What is solar radiation?

Student 1: A signal

Student 2: To move backwards.

The answers given by learners suggest that learners do not know the concept of solar radiation or understand its implications with respect to the human body. This question might be perceived to be irrelevant to most of the learners in the PMB sample due to a widely held misconception that black people do not need to use sunscreen because the skin is dark already, as a result most black people do not usually use sunscreen products. It is also interesting to note that most of the correct learners were from *School B* who knew about sunscreen, most pupils at this school are of Indian origin and probably use sunscreen. From the learner’s responses, it is possible to infer that the poor performance of the SA learners observed in the TIMSS 1999 study on this and other questions might have been caused by the fact that the context was not relevant to the majority of learners. The intended SA Curriculum 1999 indicates that the concept of light should be covered in Grade 9. This study has shown that learners lacked basic knowledge on the concept of light and solar radiation.

4.4.8 Nervous System QD05, QF03

In this section learner's responses in the TIMSS study and the Pietermaritzburg sample to two questions relating to nervous system are analysed for any possible patterns of misconceptions held and errors made by learners when answering the questions.

QD05. Sensory messages are taken to the brain by

- A. arteries and veins
- B. arteries and hormone
- C. nerves and hormones**
- D. muscles and veins

The international average correct for this test item: 69%.

The correct answer is C. The test item requires learners to understand simple information. This question is a simple recall type of question and those learners with no prior knowledge cannot, in general, be expected to respond correctly. Learners are expected to know that the nervous system helps to co-ordinate the activities of the body of an organism. Nerve cells are specialized to "carry messages" between different parts of the body and that hormones are substances which are synthesized in the body and affect processes in the body. This topic was difficult for SA learners, but not for learners in other countries who participated in the TIMSS 1999 study. In the interviews it was established that the PMB sample had been taught this topic at primary school at the time the study was carried out. This is reflected in the percentage correct results in Table 4.14.

The way in which students responded in TIMSS 1999 and from the PMB sample is shown in Table 4.14 below.

Table 4. 14 Percentage of learners selecting each response for question D05

Study	Learners' responses			
	A	B	C*	D
TIMSS 1999	16.2	13.9	35.7	30.7
PMB Sample	20.0	10.0	40.0	26.7

* represents the correct answer

One PMB learner did not respond to this question. There is a similar pattern of answering in both studies. In the TIMSS study 35.7% of the learners selected the correct response and 40.0% of the sampled learners chose C. The selection of D by 30.7% of the learners in the TIMSS study and 26.7% of the sampled learners could suggest that some learners do not know the difference between the nervous system, skeletal and circulatory systems. In the interviews learners failed to describe or define the circulatory system and only one student was able to give a partial answer when asked to say what the nervous system was. Some of the responses given by learners are as follows:

What is a nervous system?

Student 1: transmit messages

Which is the correct answer?

Students: D, Muscles and veins.

Students: C, nerves and hormones.

Student: arteries are everywhere in the body

Student: arteries and veins have blood

The students clearly do not know the meaning of the word sensory and cannot relate it to the nervous system (that they cannot define anyway). It makes sense to them that messages are carried to the brain by the circulatory system because it goes everywhere in the body. Reiss and Tunnicliffe (2001) on their study of students' understanding of human organs and organs systems found that most biology students did not understand the organ systems. They reported that students' drawings did not resemble a proper nervous system and also students failed to link the connections between different organs.

QF03. Humans interpret seeing, hearing tasting and smelling in the

- A. **brain**
- B. spinal cord
- C. receptors
- D. skin

The international average correct for this test item: 65%.

The correct answer is A. The test item required learners to understand simple information. Question F03 requires learners to know or recall that when a multi-cellular animal responds to a stimulus, certain cells receive the stimulus while others respond to it. The brain interpret and co-ordinates these activities in the nervous system. Sense organs such the eye, the ear, the tongue, nose and the skin contain sensory cells. This topic was difficult for SA learners, but not for the PMB sample and learners in other countries who participated in the TIMSS 1999 study. In the interviews it was established that the PMB sample had been taught this topic at primary school. This is reflected in the percentage correct results in Table 4.15.

The way in which students responded in TIMSS 1999 and in the PMB sample is Table 4.15 below.

Table 4. 15 Percentage of learners selecting each response for question F03

Study	Learners' responses			
	A*	B	C	D
TIMSS 1999	32.4	16.8	14.1	34.3
PMB Sample	53.0	6.7	10.0	20.0

* represents the correct answer

Three PMB learners did not respond to this question. In the TIMSS study the percentage of correct responses was 32.4% compared with 53% of the sampled learners. A further 34.3% of learners chose D as compared to about 20% of the sampled learners. It is possible that these learners could have jumped to conclusion that D is the correct answer because it is the sense organ associated with touch which is the only sense missing in the question or they did not know the meaning of 'interpret' used in the question. Also from everyday experience learners know that skin is one organ that covers the enter body and is constantly in touch with the environment and it easily senses changes. In the interviews students were asked the following questions:

What are senses?

Student 1: Sense is what guides you like the skin.

Name the senses and their organs.

Students: smell, taste, sight, touch and hearing.

Students: nose, tongue, eyes, skin and ears.

Which part of the body controls the function of senses?

Student 1: Muscle and veins. (Did you learn that at school?) No I used my head.

Students: Brain controls everything in your body.

It is evident that some learners have knowledge about senses and the organs associated with them. But they did not have a clear understanding how different organs work in relation to each other. The majority of learners in this study were aware though that the brain controls the body's activities. The findings of this study are similar those of Johnson and Wellman (1982) who found that children aged 10-11 years are aware that the brain is involved in most sensory motor activities.

4.4.9 Nutrition and Diet (H02, J07)

In this section learner's responses in the TIMSS study and the Pietermaritzburg sample to two questions relating to nutrition and diet are analysed for any possible patterns of misconceptions held and errors made by learners when answering the questions.

QH02. What are vitamins?

- A. Substances that break down food
- B. Bacteria that people get when they eat some foods
- C. Substances that people make from protein
- D. Substances that people need in small amounts in order for their bodies to function normally.**

The international average correct for this test item: 78%.

The correct answer is D. The test item requires learners to understand simple information. Question H02 requires learners to have knowledge of vitamins. Vitamins are organic substances needed in the diet in tiny amounts. They are

required by the body to remain healthy and also help some organs to function. The expectation is that most learners would find the concept of food in general and vitamins in particular, simple to deal with since learners interact with food daily. But the TIMSS 1999 results indicate otherwise. This topic was difficult for the SA learners, but not for the PMB sample and learners in other countries who participated in the TIMSS 1999 study. In the interviews it was established that this topic was taught at primary school and *School B* learners were also taught this topic at grade 8 at the time this study was carried out. This is reflected in the percentage correct results in table 4.16.

The way in which students responded in TIMSS 1999 and in the PMB sample is shown in table 4.16 below.

Table 4. 16 Percentage of learners selecting each response for question H02

Study	Learners' responses			
	A	B	C	D*
TIMSS 1999	8.6	22.7	31.1	34.9
PMB Sample	3.3	6.7	23.3	63.3

* represents the correct answer

Only one PMB learner did not respond to this question. In the TIMSS study, the fact that less than four out of ten or 34.9% of learners responded correctly would suggest that some of the learners either did not have the basic knowledge to tackle this question or more likely, that there are possible misconceptions held by learners on the nature and the role of vitamins in human nutrition. The results of the sampled schools however show that 63.3% of the learners chose D. In the TIMSS study 22.7% of the learners selected B and only 6.7% of the PMB learners selected B. This difference could be due to the difference in sample size. 31.1% of the respondents in

the TIMSS study chose C and 23.3% of the sampled learners could imply that although some of the learners might be aware of vitamins, they are however unsure of the source and the role of vitamins. This could also indicate possible misconceptions where learners view proteins to be the same as vitamins and energy. In the interviews learners failed to give examples of the sources of protein and vitamins. Some of the answers given by learners in the interviews are as follows:

What are vitamins?

Student 1: A vitamin is a protein

Student 2: Substance which people make from protein.

Which is the correct answer?

Students: D is the correct answer.

Students: C is the correct answer.

These responses show that some learners view vitamins as being the same as proteins or view proteins as a source of vitamins. This topic is not only difficult for children, Lucas (1987) cited in Driver *et al* (1994) found that most adults were familiar with the dietary components but not with the function of each component. Most people in his study thought that proteins provided the energy needs of the human body and about 19% of the sample thought that vitamins provided the body energy.

QJ07. The BEST reason for including protein in a healthy diet is because it is the main source of

- A. energy for the body
- B. fibre for digestion
- C. raw materials for cell growth and repair**
- D. vitamins

The international average correct for this test item: 33%.

The correct answer is C. The test item required learners to understand simple information. The question probed learners on their understanding of the reasons for including proteins in their diets. Learners should have been aware that diet refers to constituents of food a person eats. Proteins are broken down to amino acids. Organisms use these amino acids at a later stage to make their own protein requirements. The body requires proteins for growth; regeneration and repair of damaged and worn out tissue. The question was difficult for SA learners and for learners in other countries who participated in the TIMSS 1999 study. An analysis of the year planners and notebooks revealed that the topic had not been taught at the time the study was carried out. This is reflected in the low percentage correct results in table 4.17.

The way in which students responded in TIMSS 1999 and in the PMB sample is shown in Table 4.17 below.

Table 4. 17 Percentage of learners selecting each response for question J07

Study	Learners' responses			
	A	B	C*	D
TIMSS 1999	51.4	6.8	10.9	30.0
PMB Sample	60.0	3.3	3.3	30.0

* represents the correct answer

One PMB learner did not respond to this question. There is a similar pattern of answering this question in both studies. In the TIMSS study only 10.9% of the learners chose the correct response. The results from the sampled schools were equally poor with only one out of thirty (3.3%) learners choosing the correct answer.

51. 4% of the learners in the TIMSS study chose A and 60% of the sampled learners chose A. 30% of the learners in both studies chose D. The high percentage of incorrect responses is a reflection of possible misconceptions held by learners regarding the nature and the role of these substances in our diets. For example in television adverts vitamin supplements are often portrayed as a form of energy booster e.g. Supradyn is portrayed as such. Singleton and Rhoads (1984) cited in Hart et al (2002) found that children's nutritional information were largely drawn from informal sources such as television adverts, books and school.

This topic is mentioned in the intended SA curriculum C2005 as part of the content to be taught to Grade 8 natural science learners. In the interviews it became clear that most of the learners thought that proteins were a source of energy. Some of the learners' responses to some questions on protein:

What are proteins?

Student 1: Like food, give energy.

Student 2: proteins are energy.

Student 3: Proteins are vitamins.

What is the source of energy in foods?

Student 1: Vegetables and fruits.

Most of the learners could not answer the last questions on sources of energy in foods. This study has found that most of learners thought that protein is a source of energy because food is a source of energy and proteins are a food group.

4.4.10 Plants and Plant Nutrition (D06, H05, L02 N05)

In this section learner's responses in the TIMSS study and the Pietermaritzburg sample to four questions relating to plant and plant nutrition on are analysed for any possible patterns of misconceptions held and errors made by learners when answering the questions.

D06. Seeds develop from which part of a plant?

- A. Flower
- B. Leaf
- C. Root
- D. Stem

The international average correct for this test item: 71%.

The correct answer is A. This item requires learners to understand simple information about flowering plant anatomy. The question required learners know the parts of plants and their functions. This question was difficult for SA learners but not for learners in other countries who participated in the TIMSS 1999 study. An analysis of the year planners and notebooks revealed that the topic was not taught at grade 8 at the time the study was carried out. This is reflected in the low percentage correct results in Table 4.18.

The way in which students responded in TIMSS 1999 and in the PMB sample is shown in Table 4.18 below.

Table 4. 18 Percentage of learners selecting each response for question D06

Study	Learners' responses			
	A*	B	C	D
TIMSS 1999	36.3	8.0	38.4	14.1
PMB Sample	20.0	6.6	60.0	10.0

*represents the correct answer

One PMB learner did not respond to this question. In the TIMSS study 36.3% of the learners were able to identify the correct response and only 20% of the sampled learners were correct. 38.4% of the learners in the TIMSS study chose C and 60% of the sampled learners chose the response C. From the answers given during the interviews it is clear that learners linked the stages of germination with the development of seeds in plants. In that case, C would appear to be correct and would appeal to anyone without adequate scientific knowledge since the root is usually the first structure to be seen when a plant develops. The choice of C also suggests that learners hold possible misconceptions about seed development and the function of a root. Also the language used in this question is not easy for second language English users to clearly understand. In the interviews one learner said that the reason for choosing the root was because it is the first part to grow on a plant and it gives food to the plant. This shows that learners misinterpreted the question. Also in the interviews learners at School A translated the word “develop” into Zulu which brought in more errors associated with translation. However, during the interviews some learners were able to identify the parts of plants, but most learners did not understand the concept of seed development. The following are some of the answers suggested by learners during the interviews:

What are seeds?

Student 1: Things that you plant, for example mealies, flowers and plant seeds.

Student 2: Something that makes plants to grow.

Student 3: Plants produce seeds.

Where do seeds come from?

Student 1: They come from the roots; roots absorb water from the soil.

Student 2: Roots make plants grow. You see the roots first. The roots give food to the plant.

Student 3: Seeds come from compost.

The answers given by learners suggest that some learners lack basic knowledge of basic plant anatomy and the function of each part. It is also that some learners hold possible misconceptions on seed development and functions of different parts of a plant.

QH05. People get energy from the food they eat. Where does the energy stored in food come from?

A. fertilizers

B. The Sun

C. Vitamins

D. The soil.

The international average correct for this test item: 24%

The correct answer is B. The test item requires learners to understand simple information. Question H05 examined learners on their understanding of source of the energy stored in food. This question required learners to have knowledge of energy conversion in the environment. The sun was supposed to be identified as the source of energy. This question was difficult for both SA learners and learners in other countries who participated in the TIMSS 1999 study. In the interviews it was established that the topic had not been taught at grade 8 in all the three schools at the

time the study was carried out. This is reflected in the low percentage correct results in Table 4.19.

The way in which students responded in TIMSS 1999 and from the PMB sample is shown in Table 4.19 below.

Table 4. 19 Percentage of learners selecting each response for question H05

Study	Learners' responses			
	A	B*	C	D
TIMSS 1999	6.9	15.4	44.5	30.6
PMB Sample	3.3	26.7	50.0	23.3

*represents the correct answer

In the TIMSS study 15.4% of the learners were able to identify the sun as the ultimate source of energy stored in food. Only 26.7% of the sampled learners chose the correct answer. However, 44.5% of the learners in the TIMSS study chose C and 50% of the sampled learners chose C. About 30.6% of the learners in the TIMSS study selected D and 23.3% of the sampled learners selected D, suggesting that they view plants as feeding from the soil via the roots or else they misinterpreted the question to mean the root as tuber that contains stored energy and is found in the soil.. It is possible that most of learners in both studies hold misconceptions about the source of energy stored in plants.

QL02. What is the primary function of the large leaves found on seedlings growing in a forest?

A. To provide shade for the root systems

- B. To get rid of excess water that is entering through the roots
- C. To allow for leaf damage by insects
- D. To gather as much light as possible for photosynthesis**

The international average correct for this test item: 72%.

The correct answer is D. The item requires learners to understand complex information in order to answer the question. A foliage leaf is well adapted for photosynthesis. It is broad and flat, which means that a large surface area is exposed to sunlight and air. Learners were expected to apply their knowledge of plant structure and function in answering this question. Also they needed to know that if the seedlings were growing under canopy in the forest they would be competition for light and therefore the need for larger leaves. This question was difficult for SA learners but was not for learners in other countries who participated in the TIMSS 1999 study. In the interviews it was established that the topic had not been taught at the schools at the time the study was carried out. This is reflected in the low percentage correct results in Table 4.20.

The way in which students responded in TIMSS 1999 and in the PMB sample is shown in Table 4.20 below.

Table 4. 20 Percentage of learners selecting each response for question L02

Study	Learners' responses			
	A	B	C	D*
TIMSS 1999	23.7	19.7	17.7	37.8
PMB Sample	20.0	33.3	6.7	33.3

* represents the correct answer

Two PMB learners did not respond to this question. There is a pattern in the selection of responses A and D. In the TIMSS study 37.8% of the learners selected the correct response and 33.3% of the sampled learners were correct. It is possible that learners hold misconceptions that the large leaves provide shade for the root systems and thus help prevent the loss of moisture from the soil, the choice of response A by 23.7% of the learners in the TIMSS study and 20.0% of the sampled learners show that in both studies the learners overlooked or misunderstood the phrase “primary function” of the leaves. In the interviews, it became clear that learners sometimes do not understand the meaning of some questions because they failed explain the question. The following are some of the answers given by learners in response to the interview question:

What are leaves?

Student 1: Things that protect plant from the sun.

Student 2: They produce energy for people.

Student 3: They are from the plant

What are the functions of leaves?

Student 1: Leaves produce energy from the sun to the plant

Student 2: Leaves make food for the plant

In these responses some of the learners could not make a clear distinction between the description of a leaf and the function of the leaf. The findings of this study are similar to those of Smith and Anderson (1984), Wandersee (1983), Arnold and Simpson (1980) and Bell (1985), who found that students believed that plants needed food. Most of the students suggested air, soil, light, water and fertilizers as plant food. Similarly Arnold and Simpson (1982) reported that the majority of learners in their sample were aware that plants need energy but they thought that the food

supplying this energy came from the soil via the roots. Similarly, Wandersee (1983) found that students described the role of the leaf as:

- To capture the rain and the water vapour in the air.
- To capture the sun's warmth.
- Leaves drink in the dew
- Rain goes in the holes of the leaves.
- Leaves changes colour because they cannot breathe.

QN05. Some plants grow better if bone meal (ground –up bones) is spread around their roots. What does bone meal supply to plants that make them grow better?

A. Energy

B. Minerals

C. Vitamins

D. Carbon dioxide

E. Water

The international average correct for this test item: 65%.

The correct answer is B. This test item requires learners to understand simple information. In relation to plant nutrition learners were asked about the role of bone meal in plant growth. In addition to a bulk supply of carbon, hydrogen, and oxygen from carbon dioxide and water, plants take in small amounts of "food" in the form of inorganic salts like nitrate, phosphate, magnesium and potassium ions. Land plants obtain these elements from the soil where they occur as mineral salts. These salts are soluble and dissolve in water. Bone meal contains trace amounts of mineral salts. These salts are essential in ensuring the proper growth of plants. The question proved to be difficult for SA learners, but not for learners in other countries who participated

in the TIMSS study. An analysis of the year planners and notebooks revealed that the topic had been taught in two schools at the time the study was carried out, but this is not reflected in their percentage correct in Table 4.21.

The way in which students responded in TIMSS 1999 and in the PMB is shown in Table 4.21 below.

Table 4. 21 Percentage of learners selecting each response for question N05

Study	Learners' responses				
	A	B*	C	D	E
TIMSS 1999	12.5	26.6	12.5	8.4	37.5
PMB Sample	13.3	20.0	0.0	13.3	53.3

* represents the correct answer

In the TIMSS study only 26.5% of the learners selected the correct response and only 20% of the sampled learners were correct. The choice of E by 37.5% of the learners in the TIMSS study and 53.3 % of the PMB learners suggest that learners view water as essential to plant growth. In the interviews learners at school C knew the meaning of bone-meal, but this is not reflected in their choice of answers in table 4.21. In the TIMSS study 12.5% Of the learners selected C and none of the sampled learners chose this response. This shift in answering could be due to the fact the PMB sample would not select C because they associate vitamins with proteins and energy (see QH05, QJ07). The choice of E by a large number of students could be a possible misconception that water is plant food. In reality water provides the transportation system for minerals and trace elements. It is possible that most learners have experienced drought at home and at school. In other words learners know that water is needed for plant growth. The following responses further illustrate some of the

possible misconceptions among the sampled learners. The sampled learners were asked the following questions:

What is bone-meal?

Student 1: Minerals

What are plant nutrients?

Students: Water, chlorophyll and green things in the tree.

What is the use of water in plants?

Student 1: Water is for plant growth, and energy.

Student 2: Water is the food for the plant.

Student 3: Water makes the plants to grow.

If you just water a plant will it grow?

Student 1: No it needs energy from the sun as well as water.

Most learners did not know what bone meal was and probably used key word thinking to answer the question. From the previous questions it is clear that they associate roots with water and plant growth. It is possible that learners hold misconceptions about roots, water and plant growth. These findings are similar to those of Bell (1985) who found that most of the students regarded plant food as anything taken in by the plant from the surround. Some of the respondents thought that chlorophyll was plant food. Johnstone and Mahmoud (1980) used high school learners, teachers and undergraduate students to isolate difficult topics in school biology. The topics which involved plants, osmosis, water balance in living organisms, chemical energy and chemistry of photosynthesis and respiration, were found to be amongst the most difficult topics.

In addition to the analysis of the performance of the SA learners and the PMB sample, this study tried to identify the possible causes of some errors and misconceptions observed in the study by analyzing documents such as learners' notebooks.

4.5 Possible sources of errors and misconceptions

In this section findings of the possible sources of misconceptions are reported. The findings are based on analysis of learners' note books, year planners and on interviews with the heads of science departments. The actual teaching was not observed during this study.

An analysis of the learners' notebooks and interviews with teachers showed that some topics included in this and the TIMSS studies had not been taught in grade eight in all three schools at the time the study was conducted. The actual topics that learners had been exposed to in the classroom in grade eight also differed substantially from school to school. The latter can be attributed to curriculum C2005 which does not specify in detail what should be taught and when. It was found that only five of the ten selected study topics were taught in all the three schools. The topics that were taught at all three schools covered the following aspects of the curriculum: energy and energy changes, electricity, matter, animal and plant cells. The following topics were only partially taught or not taught: Light, plants, graphs (distance, velocity and time graphs), animal nutrition (taught at *School B* only) and animals (characteristics of animals). It is interesting to note however that even in those topics that had been taught in schools learners still had some problems answering the questions correctly. A case in point is that learners in all three schools could not explain the process of energy changes. It was observed that in *School A*, electricity had been studied for a longer period of time than at the other schools but

very few learners were able to identify the correct answer in the test. An analysis of the learners' note books revealed that electricity was taught from January to August 2004. Also it was observed that learners in *School C* had been taught about plant nutrients and were to some extent able to relate bone-meal to minerals used by plants. However the learners could not give examples of such minerals. This could probably mean that learners were not taught examples of minerals in grade 8 in natural science.

It was found that in one of the schools, the science content taught in Grade 8, in the researcher's opinion, amounted to less than half of the expected yearly content. The learners' notebooks revealed that work amounting to thirty pages of written notes was recorded for the whole year. It was also noticed that in *School A*, a lesson on cameras had just been completed with a diagram of a pinhole camera still on the chalkboard when the interviews were being conducted. When learners were asked about lenses they could not however explain what a lens was.

In the interviews with the HoD in one of the schools it became clear that learners are taught concepts, but they do not understand most of the concepts. The HoD at school B lamented the learners' lack of ability to think on their own. He argued that OBE teaching styles do not prepare learners to think on their own and that some parents do most of the take-home projects submitted by learners, so as a result learners do not develop a deep understanding of the subject. There is also an apparent confusion among some educators about the implementation of the OBE curriculum. Rogan and Aldous (2005) observed that learners were in some cases asked to work in groups on unfamiliar topics without any reference materials in some schools in Mpumalanga. An interview with the Head of the Science Department in *School C* elicited the response that OBE teaching is premised on using learners' everyday experiences in the teaching of science. While this is a noble idea, these everyday experiences must

however be used to elicit and expand on what learners know about certain concepts rather than be viewed as end in themselves and a complete source of information. There may also be a need to investigate if teachers are over emphasizing group work because they believe it is the right approach to teach the new curriculum without first or subsequently laying a firm theoretical foundation for the learner's experiences.

The learners participating in this study failed to show a sufficient level of academic competence expected of them on those topics that were reflected as having been taught at school. This is similar to the findings of the TIMSS study which found that learners of all ages lacked knowledge and skills to answer the study questions (Roth and Barton, 2004). Based on their notebooks it was clear that learners' notes on the topic on states of matter only focused on the properties of the states of matter. No references to or examples of the changes of states of matter were mentioned in the note books. It would be difficult for these learners to answer questions in international studies where they are supposed to demonstrate a good understanding of these concepts. Inaccurate marking (and possibly teaching) was also noted as a possible cause of misconceptions. For instance in a class exercise a learner correctly classified boiling as an example of a physical change, but this answer was marked incorrect. An analysis of the learner's notebook showed that most of the marking was done by other learners. This is an indication that teachers are over emphasizing the use of learners for assessing their own work or other learners' work. This is one of the aspects of C2005. It was also noted that learners at *School B* were taught how to write chemical equations using symbols when pre-requisite topics to this concept like bonding were not taught. A learner incorrectly drew the molecular structure of carbon dioxide suggesting that the carbon atom forms a single bond with each oxygen atom. These incorrect representations could be sources of misconception when these learners study organic chemistry or carbon bonding at a latter stage.

In the absence of formal learning or because of inadequate instruction, learners used their everyday experiences and understanding to answer some of the questions in this study, and one assumes the same for the TIMSS study. The answers given by the learners however, show that learners hold some basic ideas about some science concepts without any formal teaching. For instance, in this study learners were able to relate water with plant growth. This is one of the topics that it would appear had not been taught formally in class at grade 8. In this instance the findings of this study are different to those of Finley *et al* (1982) in which students failed to link water to plant growth even though they understood that water was essential for plants. However concepts that did not relate to everyday experiences and required learners to have fully grasped certain fundamental concepts in order for them to give correct scientific responses, posed major challenges for the learners. In such cases when responding to the problems posed in the test learners inevitably used other strategies such as key word thinking.

4.6 Summary of problems associated with Misconceptions and Errors

This study has identified possible problems in the school system that could have contributed to the errors made and the misconceptions held by learners in grade 8 natural science. These problems possibly hindered the learning and teaching of science in grade 8 natural science level. The problems are summarised as follows:

- Science content partially taught
- Lack of resources
- Poor teacher quality
- English as a second language
- Lack of proficiency in scientific language
- Uneven implementation and interpretation of the new curriculum C2005.

- Some of the topics asked in the TIMSS 1999 study were not taught in the sampled schools during the time the study was carried out.

Similar observations were made by Chamberlain *et al* (1998) cited in Harlow and Jones (2004) who found that in New Zealand some of the population 2 test items were targeted at a higher level group of learners. These problems possibly caused learners to use their everyday experience and other strategies to try and answer and that contributed to high levels of errors and misconceptions.

4.7 Summary of Misconceptions Identified by this study

In this section learner's misconceptions held by learners and errors made by learners in answering the selected TIMSS 1999 science questions are summarized.

This study has identified eleven possible misconceptions that might have affected the performance of the learners in the TIMSS 1999 study and the PMB sample. These misconceptions are as follows:

- Boiling water, sugar dissolving and wax melting are forms of chemical reactions, QN07 (Starvidou and Solomoniadou 1989)
- Proteins are a source of energy, QH02, QJ07,
- Proteins are vitamins, QH02, QJ07
- The energy stored in food comes from vitamins, QH05.
- Vitamins give us energy, QH02, QJ07
(<http://www.huntel.net/rsweetland/science/misconceptions/personal>, November 2005),
- A seed develops from a root, QD06.
- Energy is a food substance, QB02
- Leaves serve the purpose of providing shade for the root systems, QL02.
- Water is plants' food, N05 (Wandersee 1983; Wood-Robinson, 1991)

- Light always travels in a straight line, QD01
(See also <http://www.amasci.com/miscon/oppphys.html>, 22 July 2005)
- A magnifying glass makes light rays bigger, QD01 (Guesne, 1985)

This study has also identified the following errors made by SA learners in the TIMSS study and the PMB cohort in answering the selected TIMSS 1999 population 2 science questions. These errors are possibly due to problems associated with language and lack of basic knowledge.

- Incomplete ideas about concepts. (QJ02, QH06)
- Questions were not fully understood and were misinterpreted in some cases QL05, QB03, QJ04,
- Meaning of sentences was changed because of the exclusion of some terms in a sentence. (QJ02, QF02, QJ08, QD05, QF02, QD06)
- Key words from the sentences were linked to everyday experience without fully understanding the meaning of the whole sentence. (QN05, QL02, QH05, L05)
- Interpretation of scientific terms into everyday language, for example scent and volume.

This study has confirmed that in questions where misconceptions and errors abound, the performance of SA learners in the TIMSS 1999 study and the PMB sample was poor.

Apart from the misconceptions held and errors made by the learners in the TIMSS 1999 study and the PMB sample, the study has also found amongst other things that:

- Some of the topics asked in the TIMSS 1999 science questions had not been taught in school during the time of the study. (The concept of light should be

taught in Grade 9 according to the intended SA curriculum for 1999).

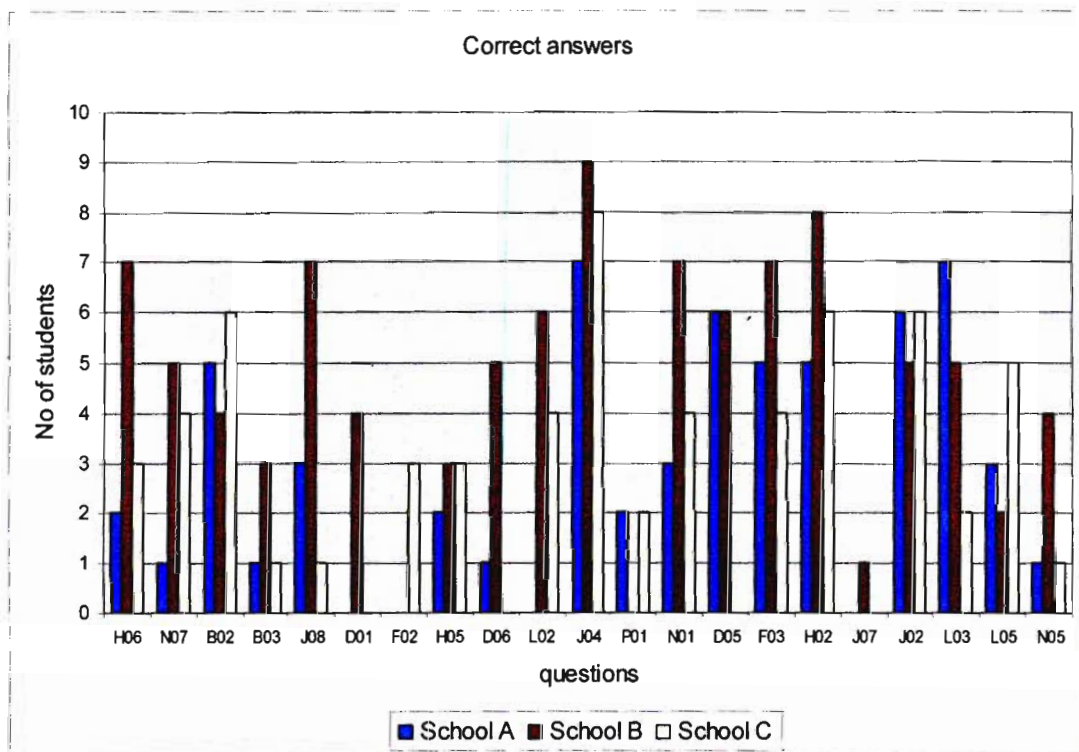
- Learners use their everyday experiences and own understanding when faced with unfamiliar tasks.
- Learners had problems in applying scientific formulae and interpreting graphs.
- Most learners did not understand fully some of the concepts taught at grade 8 natural science.
- The learners used a number of strategies such as key word thinking to try and answer questions if they did not fully understand the question or the concept being dealt with in the question.

There is need to investigate the teaching and learning of science in a broader context focusing on instructional methods, resource allocation, teacher quality, language issues and assessment methods in schools in Pietermaritzburg.

4.8 Comparison of the performance of PMB learners

This section uses tables to compare learners' correct responses obtained from the three sampled schools. It is however, important to note that the purpose of this study is not to compare the performance of the sampled schools. The questions where patterns of possible misconceptions were identified as possible causes for the poor performance of the sampled learners in the three schools will be presented. The topics which proved to be difficult to the sampled learners and learners in the TIMSS 1999 study will be reported on. In the graphs that follow a comparison of the performance of learners from the three Pietermaritzburg schools was made.

Figure 2: Correct responses scored by learners in *Schools A, B and C*.



The results in figure 2 indicate that *School B* had the most correct answers followed by *School C* and lastly *School A*. The results indicate that out of 21 questions, half of the learners at *School B* scored correct on 12 questions, while half of the learners at *School C* were correct on 7 questions. At *School A*, half of the learners were correct on 5 questions. In general, *School B* has better results compared to the other schools. It was observed that at school B learners had access to the Department of Education's learner support materials and they were taught more content as compared to the other two schools. However, it is important to note that although the learners at *School B* performed better as compared to the other schools, their performance was not consistent.

In this study, the answering of the following questions was found to be influenced by possible errors and misconceptions held by the sampled learners: questions N07, D01, H05, D06, L02, J07 and N05. It is possible that the incorrect answers given by learners represented possible errors and misconceptions held by learners on each question. The graph below represents levels of possible misconceptions identified in the PMB study.

Figure 3: Representation of possible misconceptions on selected questions.

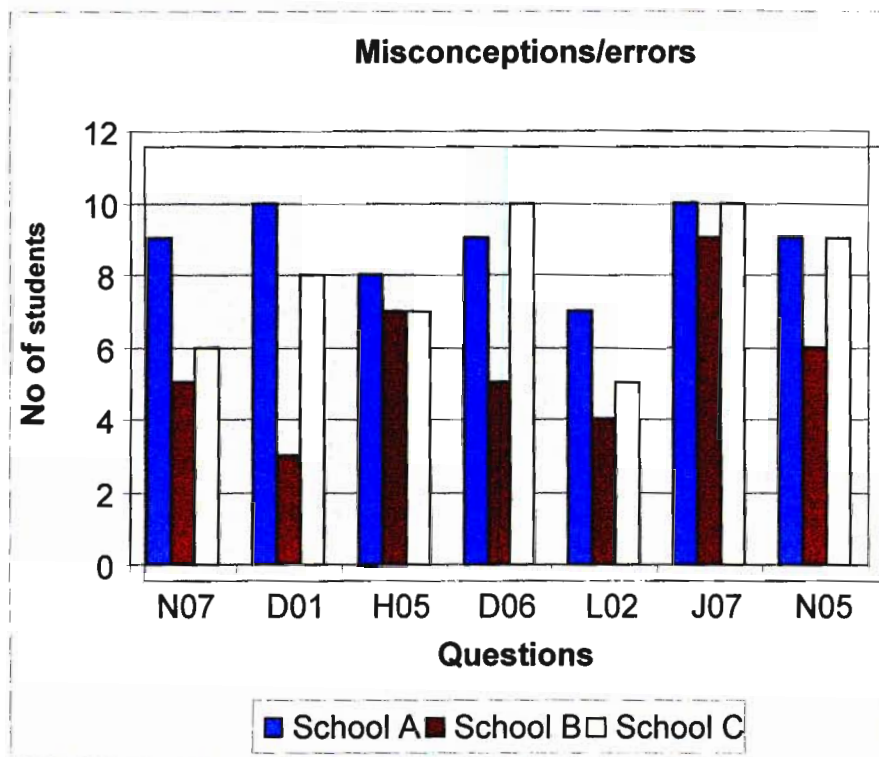


Figure 3 shows the number of learners per school with possible errors and misconception on the seven questions. The results on figure 3 show that the learners at *School B* held fewer misconceptions and errors compared to other two schools possibly because at school B learners are first English language speakers. Also at *School B* learners had been taught more topics and in greater detail as compared to the other two schools. It was also observed that at school B most of the teachers were

university graduates. It is possible to infer that most university science graduates are competent in the science content

This study also found the following topics to be difficult for learners in both the Pietermaritzburg and in the TIMSS 1999 studies.

- Density.
- Light.
- Plants
- Distance-time graphs.
- Animal nutrition.
- Plant nutrition.

These topics were only partially taught or not taught at all in grade 8 at the time the study was carried out. The fact, that some of the topics had not been taught at schools at the time of the interviews could only suggest that most of the learners used their everyday experiences, a number of strategies such as key word thinking to try and answer the questions when faced with new concepts. The learners managed to respond incorrectly to some of the question asked in the interviews on the concept of light, although the topics were not taught at school at the time of the interviews.

Chapter 5

SUMMARY, RECOMMENDATIONS AND CONCLUSIONS

5.1 Introduction

The secondary analysis of the TIMSS data provides valuable information that among other issues highlights possible misconceptions held and errors made by South African Grade 8 natural science learners when answering the TIMSS test. The information provided by the secondary analysis of this data could be a very valuable resource in the training of science teachers. During teacher training educators can be exposed to the misconceptions learners bring to class on each topic and be taught how to change the way their learners think about the various concepts involved. The findings of this study could be used to further develop the TIMSS study in terms of context validity with reference to the South African curriculum. However, it is important to note that the secondary analysis of the TIMSS data alone cannot be used to identify possible misconceptions and errors applicable to a South African context because other factors such as poor teacher quality, lack of basic knowledge and lack of resources influence the levels of learning and teaching of science in SA schools. To gain further understanding of what is happening there is a need to interrogate the ways in which the learners' understand and therefore answer the TIMSS questions, as well as a need to find out what actually goes on in the classrooms. An in-depth understanding of the effect of these factors could lead to the development of ways and means to reduce the levels of these misconceptions and errors.

The aim of this research was to provide some answers to the following research questions:

- (1) What are the misconceptions and errors made by SA learners in answering TIMSS science questions?
- (2) What are the causes of the misconceptions and errors experienced by SA learners in answering TIMSS science questions?

This chapter reports on the key findings of the study, critiques it, discusses the implications for educators and educational policy makers, and also makes recommendations for future studies.

5.2 Summary of major findings

There is evidence that learners' poor performance in the TIMSS 1999 was caused by their use of everyday experiences and other strategies in an attempt to try and answer questions that they were inadequately equipped to answer. This was due to a number of factors including the fact that they lacked the basic knowledge and language skills (English grammar and scientific) needed to answer the questions. Other factors such as poor teacher quality, lack of relevant resources and the uneven implementation of C2005 also contributed to the problem. All these problems have probably contributed to the development of misconceptions and the making of errors when answering the TIMSS 1999 questions. One could say that the misconceptions and errors found in this study seem to be associated with the problems facing learners in the majority of South African classrooms in general. It should be noted however that some of the TIMSS questions were set at an inappropriate grade level for South African learners.

5.2.1 Misconceptions and errors

The study found that learners held possible misconceptions and errors in the following content areas:

- Chemical reactions (QN07)
- Light (QD01)
- Plants (QH05, QL02, QD06, QN05)
- Animal Nutrition (QJ07)

These topics are not only problematic for SA learners but, they seem to pose learning difficulties across countries. For example the international average correct for question H05 was 24%. In both the TIMSS 1999 and Pietermaritzburg sample the grade 8 learner performed poorly on these topics. The percentage correct for these topics ranges from 3.3% to 37.8% for both TIMSS 1999 study and Pietermaritzburg study. The reviewed literature showed that students across different age groups held possible misconceptions and made errors on these topics (Starvidou and Solomoniaduo, 1989; Guesne, 1985; Wood-Robinson, 1991).

The ideas of Driver and Bell (1986) helped me understand the causes of some of the errors made and misconceptions held by learners. For example when learners were asked the question: What are proteins? They gave answers such as proteins are energy, proteins are vitamins and proteins give energy. The learners' responses are based on their everyday experience rather than on scientific information learnt at school. These findings are inline with the theoretical framework which suggests that learners bring some unscientific ideas to science classes and these ideas can hinder meaningful learning from taking place (Driver and Bell, 1986).

5.2.2 Content not taught and relevance of question to grade level

The study has shown that the poor performance of SA learners in international studies could be linked to a lack of basic scientific knowledge and skills required to answer some of the questions asked in international studies. This is similar to the findings of the TIMSS study (Roth and Barton, 2004). It was found that some of the questions asked in the TIMSS 1999 study had not been taught at some schools at the time of this study and some of the topics were to be taught in grade 9. For example the South African 1999 syllabus indicated that the concept of light should be taught in grade 9. Similarly Chamberlain *et al* (1998) cited in Harlow and Jones (2004) observed that in New Zealand most of the TIMSS population 2 science questions targeted higher grade. This study found that learners performed badly in most of the unfamiliar topics. There is need for further investigation on the appropriateness of some of the questions asked in international studies at grade 8 level.

5.2.3 Second Language and Scientific Language Issues

This study also found that the poor performance of learners in the TIMSS 1999 study and the Pietermaritzburg sample was due to the language used in some of the questions. Some of the words used in the questions had more than one meaning, a confusing prospect for second language English users. Also some learners translated scientific terms into everyday language, for example, terms such as volume, light, mass and scent. Learners translated some of the words into their mother language which brought in more errors into their understanding of the questions. Some of the questions or topics where language confusion interfered with the meaning cover the following topics:

- Animals and insects (QL03, QJ02, QL05)

- Energy transformations (QB02, QH06)
- Nervous system (QD05, QF03)

Similarly, Howie (2002) found that language affected mathematics achievement in the TIMSS 1999 study. She found that learners who used English as their first language performed better followed by Afrikaans speaking learners. She also found that the Tswana and southern-Sotho learners scored higher than other African language speakers. This difference was due to the fact that in South Africa the Tswana originate from the former Bophuthatswana, where English language and communication skills were prioritized in the school curriculum. Redish (2003: 27) argues that students' difficulties with a particular problem might not be associated with the student's knowledge but with the student's framing (expectations) of the situation. In other words, learners reword the sentence to suit what they already know. Millar et al (1994) cited in Monk and Osborne (2000:65) in their study on investigative work found that students demonstrated four different frames. They:

- engage in an activity without a plan
- try to model a desired solution
- try to optimize an effect
- use unscientific frames.

They also found that most students at the age of 14 could not apply scientific frames. This is similar to the findings of this study, because most learners used unscientific strategies such, as key word thinking, matching of words in the sentences to the ones in the answers. For example learners answered most of the interview questions using their everyday experience. There is a need to investigate if the strategies observed in this study are also used by learners in their daily learning at school.

5.2.4 Poor teacher quality/Lack of knowledge

The study has shown that the poor performance of SA learners in international studies could be linked to poor teacher quality. According to Yip (1998) cited in Pelaez et al (2005:3) most teacher education programmes fail to foster an understanding of science amongst teachers. In one of the schools studied the work taught in grade 8 natural science classes did not cover most of the content for that particular grade. It was found that learners' lack of knowledge affected their performance in the following topics:

- Density (QB03)
- Distance time graphs and the formula (QP01)
- Light and solar radiation (QD01, QF02, QJ08)

This study also found that teachers with diplomas in science are primarily occupied with advancing themselves in subjects not related to science. These other subjects are viewed by teachers as an alternative career path. This indicates a lack of commitment on the part of these teachers to the teaching and learning of science and it is possible that these teachers are not putting much energy into improving their teaching and learning of science. In the TIMSS-R it was reported that about half of the South African science teachers felt unprepared to teach science at grade 8 level (Howie (2001). Rogan and Aldous (2005) found that teacher development but not teacher qualification was a factor that affected curriculum implementation. Most of the learners in the Pietermaritzburg study failed to give correct answers in the test and in the interviews. In other words learners do not know or have difficulties in explaining most of the scientific concepts asked in the TIMSS test. Bradley and Mosimege (1998) found that college student teachers held more misconceptions compared to university student teachers. Similarly, Bradely and Gerrans (1989), Bradely, Gerrans

and Long (1990) found that the patterns of misconceptions held by students were similar to those held by school teachers. There is need for policy makers to encourage advancement in science subjects and also reward science teachers adequately so that they choose to stay in the teaching profession. For example science teachers with diplomas should be encouraged and given incentives to acquire higher qualifications in science education.

In this study it was observed that a lot of marking of class and home work exercises is done by learners. Peer assessment is one of the assessment components in C2005. This is a noble idea but learners can not correct any incorrect ideas apart from identifying the correct and wrong answers. In South Africa most learners depend on their notebooks as the only source of information. It is therefore critical that these notebooks contain correct information. There is therefore need for further investigation into the extent to which learners can mark their own or their friends' work in the teaching and learning of science where errors made by learners might develop into misconception if they are not corrected promptly.

5.2.5 Implementation of curriculum C2005.

This study was carried out during a phase when a new curriculum C2005 was still being implemented. The implementation has caused a lot of confusion amongst the science educators. The curriculum allows for educators to select relevant topics to be taught and allows for interaction of different disciplines. However, the curriculum document does not specify in great detail what needs to be taught. This resulted in teachers teaching different topics within the same grade in a year. The poor teacher quality has also affected the implementation of this curriculum. This study found that at one school learners studied electricity from January 2004 to August 2004 but this did not improve their level of understanding of concepts. Rogan (2003) cited in

Rogan and Aldous (2005:16), observed that teachers were confused about the new curriculum because teaching is now focused on group work although curriculum C2005 does not advocate group work as the principal method of teaching. Rogan (2003) also observed that learners were asked to discuss unfamiliar tasks without the guidance of the teacher. In other words very little learning takes place and learners are forced to use their everyday experience to try and complete the tasks set out for them. In science these everyday experiences might be possible sources of errors and misconceptions. There is still a need for teachers to use the traditional methods of teaching by planning learning activities which challenge learners to learn new information. There is also need to investigate the use of group work and the extent to which learners are given unfamiliar tasks for homework with inadequate enabling support.

5.3 Implications for Educators

Previous research has shown that learner's misconceptions act as barrier to learning new concepts and are resistant to change (Wood-Robinson 1991; Solomon 1983 and Wandersee 1983). There are a number of major implications for educators identified by this study. Firstly, errors made by learners need to be identified and corrected by the science educators by providing learners with the correct information and regular feedback. These errors have the potential to contribute to the development of misconceptions that are difficult to dislodge. Secondly, learners come to science classes with preconceived ideas or notions of the concept to be learnt. These ideas may also develop into long term misconceptions that may hinder the learning of new information. Learners have a variety of misconceptions on different concepts taught at schools. For example learners view proteins as vitamins and as energy. Teaching these learners new information cannot easily change these misconceptions and so the challenge for educators is to identify these misconceptions and then use their

understanding of these misconceptions to build up learning activities that use constructivist teaching approaches that can bring about conceptual change.

In order to reduce levels of misconceptions learning activities must be planned in such a way as to challenge learners' misconceptions (Driver and Oldham, 1986). The misconceptions identified in this study could help teachers to understand how learners think using their 'self taught ideas'. These ideas need to be confronted at all levels of teaching by educators who are constantly updating themselves in science related areas. These implications have been confirmed by previous research such as that by Driver *et al* (1994), Solomon (1983), Wood-Robinson (1991), and Wandersee (1983).

5.4 Critique of the Study

This study is an interpretive study, which seeks to make meaning out of learner's responses to Grade 8 natural science questions. The strength of the study draws from its source of data, the TIMSS 1999 data. This data was drawn from a large sample that represented over 8000 SA grade 8 natural science learners. The TIMSS data was supplemented with local school-based tests and interviews in order to improve the validity of the secondary data. However, despite these strengths, the study has the following limitations:

1. Only twenty-one questions from the TIMSS study were used instead of the possible thirty-seven multi-choice questions. It should be noted however that in retrospect having found that the students in general are not guessing but are using a variety of other strategies to try and answer the questions, it is possible that there may have been more to learn about student errors and misconception from interrogating the sixteen questions that were originally eliminated.

2. A larger number of questions would have allowed for statistical correlation of learners' responses to be analysed. A better approach would have been to select the questions using correlation or other statistical tools. A possible improvement on this study could be to focus on questions that relate to only one or two aspects of the curriculum.
3. The sample size of thirty learners drawn from only three different schools is too small for generalization of results. Also, the results of the sampled schools could not be accurately compared because of the different environments in which learning took place. A larger sample in terms of schools and learners involved could have given a clearer picture of the levels of misconceptions held and errors made by SA grade 8 natural science learners.

5.5 Suggestion for further studies

An more in-depth study involving a larger sample of schools and a deeper interrogation of why and how the grade eight learners in South African Schools answer the TIMSS Natural Science multiple choice questions the way they do. This would help to shed more light on student misconceptions and errors in this regard. This knowledge could then be used to make recommendations to educators on how conceptual change associated with the learning of Natural Science could be addressed in South African classrooms. There is also a need to investigate further how the OBE curriculum C2005 is being implemented in the teaching and learning of science in South African schools and how this is impacting on student performance in the TIMSS and on student performance in general. An analysis of curricula used by other countries participating in the TIMSS study could be undertaken and a comparison made so as to try and determine why these learners are performing better than SA learners when answering the TIMSS.

These findings are informed by the constructivist theory, which argues that children already know some science before any formal teaching takes place. This view argues that learners construct knowledge through interaction with the environment (Driver and Oldham, 1986). According to Driver *et al* (1994b), children's ideas change due to experience and social orientation into commonsense. Learners cannot easily dismiss their commonsense when confronted with scientific teaching (Solomon, 1983). According to Bennett (2003:35), "*... research has provided overwhelming evidence that children arrive in science lessons with ideas which they have formed in making sense of the world around them.*"

5.6 Summary

In this study I set out to identify possible misconceptions and errors made by learners in answering the TIMSS 1999 population 2 questions and to highlight some of the possible causes of these misconceptions and errors. I have shown that SA learners and the Pietermaritzburg sample hold possible misconceptions and made errors when answering the TIMSS 1999 science questions. The results revealed that learners used their everyday experiences (common sense science) and a number of strategies to try and answer most of the questions derived from unfamiliar topics. This study found that learners performed badly on most of the topics that were not yet taught at school at the time the study was carried out. However, this study could not infer that the misconceptions held and errors made by learners were the ultimate causes of the poor performance of grade 8 natural science in the TIMSS study because other factors like poor teacher quality, implementation of the new curriculum and language influenced the results of this study. These findings show that what happens in science classrooms is not isolated to other broader political, social and economic issues that affect schools. Therefore in trying to address issues of performance, the context within which teaching and learning of science is located should be

considered. In the SA case this would mean looking into issues like teacher education, teacher development, resources, language and the socioeconomic status of schools. There is need to improve the quality of science teachers and resources required for the smooth delivery and learning of science in schools. Scientist can not be grown but, they can be nurtured by good scientific teaching methods at an early age up to high school.

South Africa participated in the TIMSS in order to measure its own learners' achievement in maths and science against that of other countries. Its poor performance in relation to other countries is alarming but there is a lot that can be learned from studies such as this that can be used to influence the direction of educational policies and what happens and needs to happen in South African classrooms. In order to understand and thus benefit from studies such as these there is clearly a need to interrogate the secondary data even further. Thus it becomes very clear that conclusions drawn from international assessment studies such as TIMSS should be understood within the context of what is happening in the schools that take part in such studies.

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A P P E N D I X

INTERVIEW QUESTIONS

J02

What is an insect?

Did you learn that at school?

What is the meaning of this sentence?

Which is the correct answer?

L03

What is a mammal?

Give examples of characteristics of mammals.

What is prey?

Which is the correct answer?

L05

What is a wolf?

What characteristics of wolves?

Which is the correct answer?

N07

What is chemical change?

Give examples of chemical change.

What is a change of state?

Give examples of change of state

Which is the correct answer?

B03

What is mass?

What is volume?

What is density?

What are the relationship between mass, volume and density?

Write down the formula that links mass, volume and density.

What is the correct answer?

P01

What is the meaning of the graph?

What is speed?

What is the relationship between speed, distance and time?

Which is the correct answer?

N01

What is a metal?

Give examples of metals

Which is the correct answer?

H06

What is energy change?

Does energy have more than one form?

Give some examples of types of energy.

Give examples of energy change?

Did you learn that at school?

B02

What is energy?

Name the sources of energy.

What are some of the uses of energy?

Is petrol a source of energy?

What kind of energy is contained in petrol?

J04

What is the meaning of this question?

What is evaporation?

What are the factors affecting the rate of evaporation?

What is wrong with A?

D01

What is light?

What is a lens?

What is the use of a lens?

Is a magnifying glass a lens?

Which is the correct answer?

F02

What is light-colored?

Give examples of light colored objects.

What is the correct answer?

J08

Name the components of electromagnetic waves.

What is sun screen?

What is solar radiation?

D05

What is a nervous system?

What is circulatory system?

Which is the correct answer?

F03

What are senses?

Name senses and their organs?

Which part of the human body works with senses?

No answer

Which is the correct answer?

H02 and J07

What are vitamins?

What are proteins?

Name sources of vitamins

Name sources of proteins.

Which is the correct answer?

D06

What are seeds?

Where do seeds come from?

Which part of a plant develops seeds?

Which is the correct answer?

H05

Name the different parts of a plant.

Do plants need food?

What is the source of energy?

What is the main source of energy on earth?

L02

What are leaves?

What are the functions of leaves?

Which is the correct answer?

N05

What is bone-meal?

Give examples of plant food?

What are plant nutrients?

Give examples of plant nutrients.

Which is the correct answer?

What is the use of water in plants?

If you just water a plant will it grow?