TIMSS 2019 SOUTH AFRICAN ITEM DIAGNOSTIC REPORT

SCIENCE

GRADE 9

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Human Sciences Research Council

IEA

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ACRONYMS

CAPS	Curriculum and Assessment Policy Statement
CRQ	Constructed Response Question
DBE	Department of Basic Education
FET	Further Education and Training
HSRC	Human Sciences Research Council
IEA	International Association for the Evaluation of Educational Achievement
MCQ	Multiple-Choice Question
TIMSS	Trends in International Mathematics and Science Study
TIMSS-SA	TIMSS in South Africa

PREFACE

The Human Sciences Research Council (HSRC) released the results of the 2019 Trends in International Mathematics and Science Study (TIMSS) in December 2020. TIMSS is a cross-national assessment of the mathematics and science knowledge and skills of Grade 4 or 5 and Grade 8 or 9 learners from the participating countries. TIMSS was developed by the International Association for the Evaluation of Educational Achievement (IEA) to allow participating nations to compare their learners' educational achievement across borders.

This report is one of four educator resource documents. Each of the four reports contains diagnostic analyses of a set of items shared by the IEA called restricted use items: Grade 5 Mathematics TIMSS restricted use items, Grade 5 Science TIMSS restricted use items, Grade 9 Mathematics TIMSS restricted use items and Grade 9 Science TIMSS restricted use items, and suggestions for remediation.

Two reports containing the highlights of the Grade 5[1] and Grade 9[2] TIMSS 2019 results were published in December 2020. Two reports with the full analyses, The South African TIMSS 2019 Grade 9 Results and The South African TIMSS 2019 Grade 5 Results, were published in January 2022.

These reports, together with additional resources, are available on the TIMSS SA website[3].

This report was compiled by Dr Edith Dempster, Dr Sharon Grussendorff and Sylvia Hannan, with Dr Palesa Sekhejane. This report is best described as a resource for educators that will contribute to their understanding of what science our Senior Phase learners know and can do and inform, through the recommendations, how to support the successful teaching and learning of science constructs.

The HSRC appreciates the support from the Department of Basic Education (DBE) in conducting TIMSS 2019 in South African schools.

Dr Vijay Reddy
Principal Investigator of TIMSS 2019, South Africa
Human Sciences Research Council

[1] https://www.timss-sa.org/publication/timss-2019-highlights-of-south-african-grade-5-results-in-mathematics-and-science
[2] https://www.timss-sa.org/publication/timss-2019-highlights-of-south-african-grade-9-results-in-mathematics-and-science
[3] https://www.timss-sa.org/

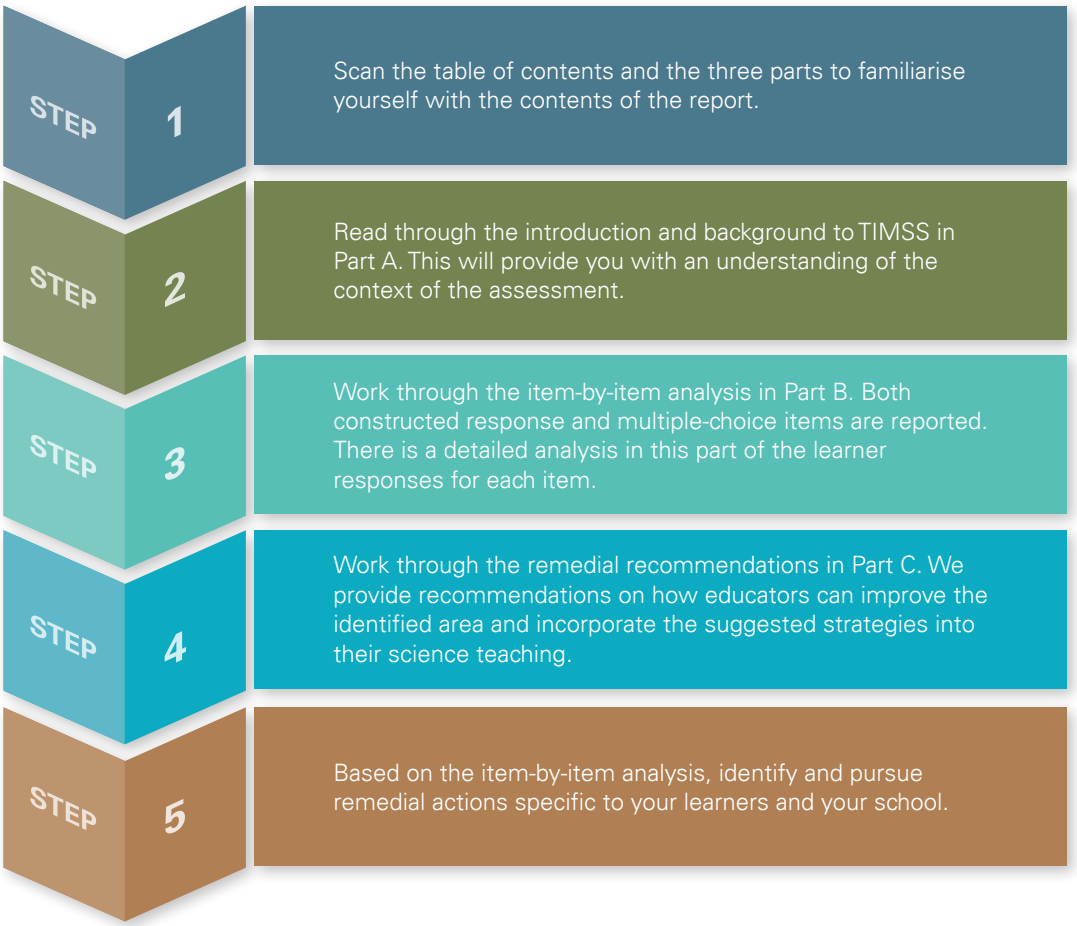
HOW DO I USE THIS REPORT?

This report can be used by all science educators, although it specifically focuses on Grade 9 learners. It does not replace or contradict any official DBE policies or documents, particularly those related to assessment and the delivery of the intended curriculum.

This report is presented in three sections:

- Part A presents the Introduction and Background and highlights some broad performance trends from the analysis of the Grade 9 TIMSS 2019 restricted use science items.
- Part B presents the analysis of individual restricted use science items.
- Part C presents ideas for remediation to improve the teaching and learning of science.

When an educator or DBE official receives this resource report, an easy way to navigate it is through the steps below. This sequence of steps has been outlined to assist educators in helping their learners and/or to assist DBE officials in their mentoring, coaching, training and support of educators.



Please note, in this report, for ease of reading, the learner frequency responses were rounded to whole numbers.

PART A

INTRODUCTION AND BACKGROUND

A1. INTRODUCTION

The Trends in International Mathematics and Science Study (TIMSS) is an assessment of the mathematics and science knowledge of fourth or fifth grade (Intermediate Phase) and eighth or ninth grade (Senior Phase) learners around the world. TIMSS was developed by the International Association for the Evaluation of Educational Achievement (IEA) to allow participating nations to compare learners' educational knowledge and skills within and across borders. The goal of TIMSS is to help countries make informed decisions about how to improve teaching and learning in mathematics and science.

In South Africa, the Human Sciences Research Council (HSRC), with the support of the Department of Basic Education (DBE), has conducted TIMSS since 1995, administering the test at the Grade 8 or 9 level in 1995, 1999, 2003, 2011, 2015 and 2019. In 2015, South Africa participated in TIMSS-Numeracy at the Grade 5 level and in 2019, South Africa continued TIMSS participation at the Intermediate Phase, testing both mathematics and science.

We begin by giving you some background information about TIMSS. Further details are available on the TIMSS-SA website[4]. We go on to review what we already know about how children learn science and how they approach assessment questions. We then show you where we have identified common errors in South African learners' answers. Finally, we give you some ideas for assisting learners and improving your teaching.

A.2. WHO PARTICIPATES IN TIMSS?

TIMSS is generally written by learners in the eighth year of formal schooling, which is Grade 8 in South Africa. South African learners wrote the test when they were in Grade 9, a year later than most other countries. In September 2019, 519 schools representing a cross-section of schools across South Africa took part in TIMSS 2019. The selected schools included rural and urban schools from quintiles 1 to 5, and independent schools, from all nine provinces. Altogether 20 829 Grade 9 South African learners wrote the test in 2019 and this sample was weighted to be representative of the Grade 9 learner population.

Worldwide, 39 countries and seven benchmarking participants participated in TIMSS 2019 at the Senior Phase. The learners were required to write both a mathematics test and a science test. South African learners did not perform very well. In fact, South Africa was one of the lowest performers of the participating countries (Reddy et al., 2020). You can read more about the South African learners' performance in the TIMSS 2019 Highlights of South African Grade 9 Results in Mathematics and Science[5] report.

[4] https://www.timss-sa.org/
[5] https://www.timss-sa.org/publication/timss-2019-highlights-of-south-african-grade-9-results-in-mathematics-and-science

The purpose of this Science Item Diagnostic Report is to support the improvement of teaching and learning and, through that, to improve learners' scientific knowledge.

A.3. WHO SETS THE TIMSS ITEMS?

The TIMSS achievement booklets contain both trend and non-trend items. The trend items are included in each cycle and form an anchor that allows for estimating achievement over time. The non-trend items are new items generated for each cycle and are subjected to extensive validation processes. For more details on the assessment frameworks and matrix design, refer to the TIMSS 2019 Assessment Frameworks[6]

The TIMSS items are set by an international panel of experts. The set of items are supplied in English and then expert translators translate the questions into the language of instruction in the participating countries (Centurino & Jones, 2017). There are two languages of learning and teaching (LoLT) in South Africa at Grade 9 level: English and Afrikaans. Most South African learners wrote the test in English, with a few writing the test in Afrikaans. Twenty-eight percent of the TIMSS Grade 9 learners reported that they 'always or almost always' spoke the language of the test at home, while 65 percent reported 'sometimes' speaking the language of the test at home.

A.4. WHAT IS THE TIMSS CURRICULUM FOR GRADE 8 OR 9 SCIENCE?

TIMSS 2019 assessed four *content areas* at the Senior Phase: 35 percent of items were devoted to biology, 20 percent to chemistry, 25 percent to physics and 20 percent to Earth science.

The TIMSS assessment items incorporate three *cognitive domains:* 35 percent of items were classified as *knowing*, and 65 percent of the items were at the higher cognitive levels of *applying* and *reasoning*. You can find more details about the science cognitive domains in the TIMSS 2019 Science Framework.[7]

There are two types of items: multiple-choice questions (MCQs) and constructed response questions (CRQs). The items are based on a curriculum decided by what is taught in most countries participating in TIMSS.

Refer to Chapter Four of the South African TIMSS 2019 Grade 9 Results[8] for a discussion of the TIMSS and CAPS curriculum match, as well as learners' performance by content and cognitive domains.

A.5. RESTRICTED USE ITEMS

After each TIMSS cycle, the IEA releases a number of TIMSS assessment items – called 'restricted use' items. Twenty-eight Grade 8 or 9 items were released after the TIMSS 2019 cycle. Three items had two questions (Parts A and B), while the remaining items had only one question each. Hence, we report on 31 items (16 MCQs and 15 CRQs).

Eight of the 28 items were from the biology content area, six were chemistry items, eight were physics and six were related to Earth science.

The restricted use items will not be used again in the TIMSS assessment, but the analysis of learner performance at an item level can help us understand what types of difficulties learners have and where they have gaps in their knowledge.

[6] https://timssandpirls.bc.edu/timss2019/frameworks/
[7] https://timssandpirls.bc.edu/timss2019/frameworks/framework-chapters/science-framework/
[8] Reddy, V., Winnaar, L., Arends, A., Juan, A., Harvey, J., Hannan. S. & Isdale, K. (2022). *The South African TIMSS 2019 Grade 9 Results: Building achievement and achievement gaps*. Cape Town: HSRC Press. Available at https://www.timss-sa.org/publications/timss-national-reports

A.6. COUNTRIES THAT FORM THE 'INTERNATIONAL' AVERAGE

The international average is the average percentage correct of a group of 17 countries that participated in the paper[9] version of TIMSS 2019 at Grade 8 or 9. The countries included a few high-scoring countries, but were mostly countries with an average achievement below the centrepoint of 500. Table 1 shows the countries, the languages in which they wrote the test and their achievement scores. In every country, the language of the test was the same as at least one of the languages of instruction.

Table 1: Countries that made up the 'international average' in Grade 8/9 science

Country	Language of test	Science scale score	Language of instruction
Japan	Japanese	570	Japanese
Australia	English	528	English
Ireland	English/Irish	523	English/Irish
New Zealand	English	499	English
Bahrain	English/Arabic	486	Arabic
Cyprus	Greek/English	484	Greek/English
Kazakhstan	Kazakh/Russian	478	Kazakh/Russian
Romania	Romanian	470	Romanian
Oman	Arabic/English	457	Arabic/English
Jordan	Arabic/English	452	Arabic
Iran, Islamic Republic of	Farsi	449	Farsi
Kuwait	Arabic/English	444	Arabic
Saudi Arabia	Arabic/English	431	Arabic
Morocco	Arabic/French	394	Arabic/French
Egypt	Arabic/English	389	Arabic
Lebanon	English/French	377	English/French
South Africa	**English/Afrikaans**	**370**	**English/Afrikaans**

Source: Exhibit 3 (in Kelly et al., 2020).

A.7. BROAD LEARNER PERFORMANCE TRENDS

South African Grade 9 learners performed poorly in the TIMSS science study. We must look for reasons why levels of science knowledge and skills are poor in South Africa so that we can improve teaching and learning in science. In this section, we report on:

- The link between TIMSS restricted use items and the South African Curriculum and Assessment Policy Statement (CAPS) for the Senior Phase;
- Common patterns between South African and international performance on restricted use items;
- Performance by cognitive domains;
- The role of language and, in particular, the readability of items;
- Performance in Multiple-Choice vs Constructed Response Questions;
- Questions not answered or incorrectly answered; and
- Performance differences between boys and girls.

[9] Countries took the TIMSS 2019 assessment either as an e-version or a paper version. South Africa was one of 17 countries that participated in the paper version of the assessment.

A.7.1. Do the TIMSS restricted use items match our CAPS curriculum?

To answer this question, we matched each TIMSS restricted use item against the South African Natural Sciences curriculum for Grades 8 and 9, up to the time the TIMSS assessment was written (Table 2). We graded the match on a scale of 0 to 3:

0 = no match (the topic of the TIMSS item does not appear in the South African curriculum);
1 = weak match;
2 = partial match;
3 = full match.

Table 2: Level of match between TIMSS restricted use items and the South African Natural Sciences curriculum for Grades 8 to 9

	No match (0)	Weak match (1)	Partial match (2)	Full match (3)	Average match*
CRQ	2	2	0	11	2.3
MCQ	4	4	5	3	1.4
TOTAL	**6**	**6**	**5**	**14**	**1.9**

*An average match of 3 would be a perfect match, 0 would be no match.

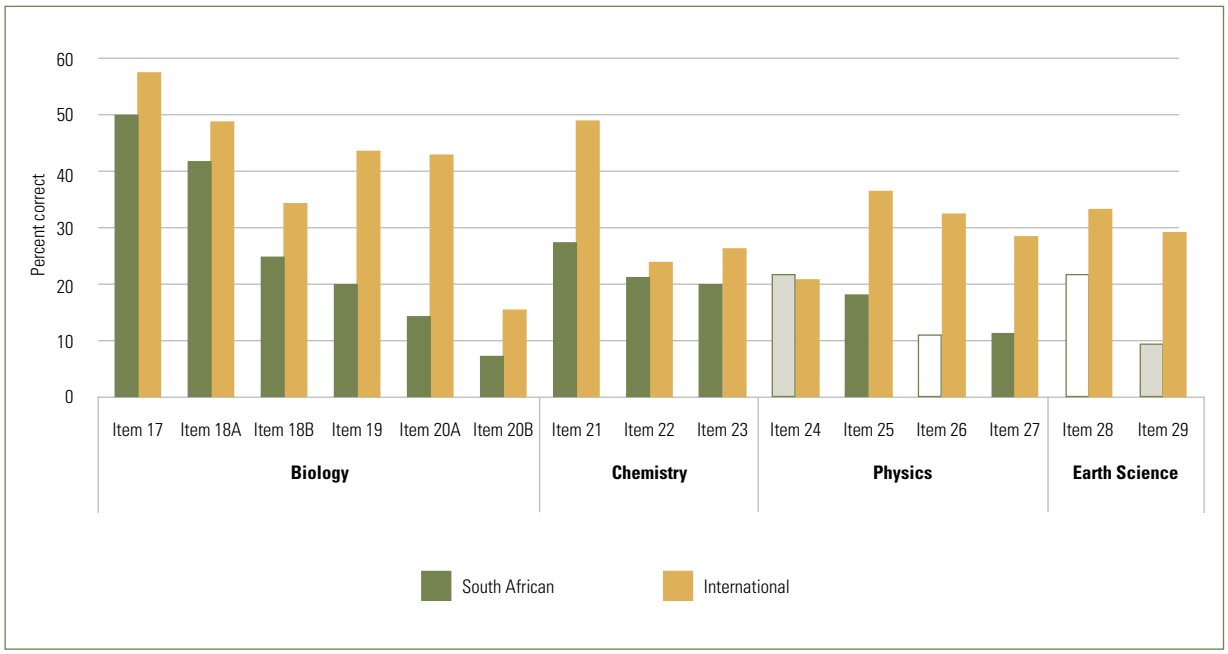
Table 2 shows that the South African school curriculum matches well with the TIMSS restricted use items for CRQs (average of 2.3), but weakly with MCQs (average of 1.4).

Next, we explored whether learners' performance was related to the observed curriculum match. Figures 1 and 2 show learners' performance for individual questions and the extent of the curriculum match. Focus on the green bars (on the left) in each graph.

Key for South African curriculum match

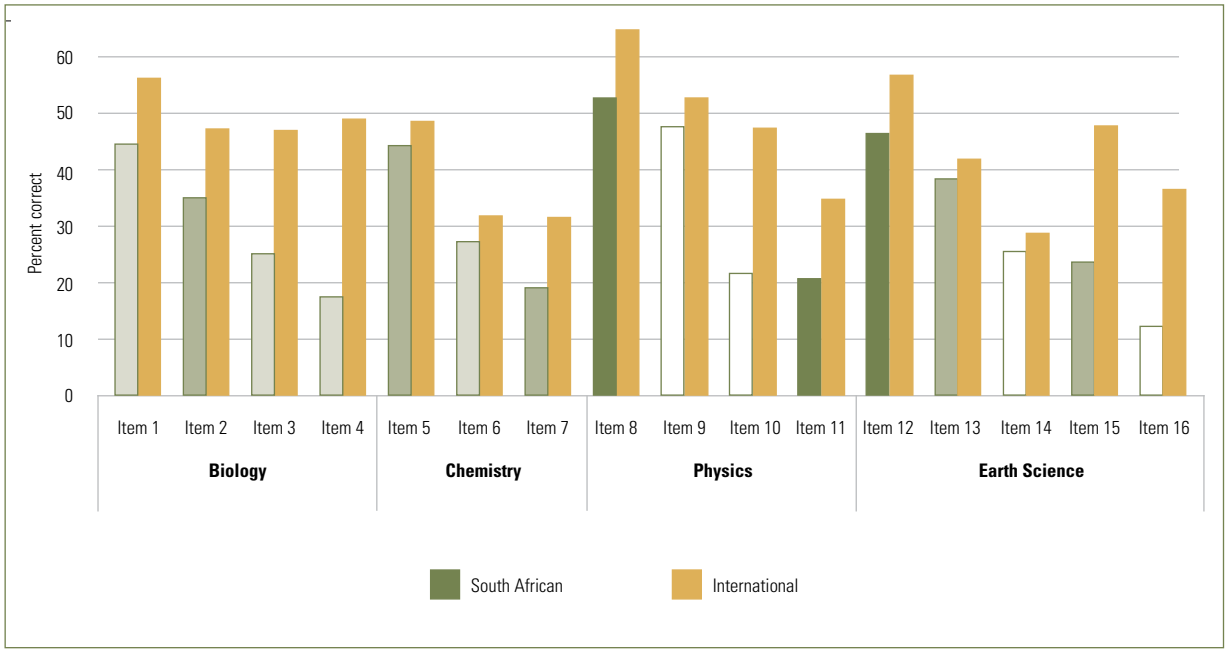
3 = full match 2 = partial match 1 = weak match 0 = no match

Figure 1: Constructed response items: Percentages correct + partially correct, and curriculum match, by content domain



Eleven restricted use constructed response items had a close match with the South African curriculum and learners performed relatively well on just over half the items. There was no match between **ITEM 26** and **ITEM 28** and the South African curriculum.

Figure 2: Multiple-choice items: Percentages correct and curriculum match, by content domain



Three restricted use multiple-choice items had a full match with the South African curriculum, but there was little correlation between an MCQ item being in the South African curriculum and learner performance.

The curriculum match between the TIMSS and the CAPS plays little role in what items are easy or difficult for South African learners.

A.7.2. South African vs international scores: Is there a common pattern?

We compared the South African Grade 9 scores with the international average to see if we could find any similar patterns. Focus on the height of the bars in Figures 1 and 2. There was no clear similarity between the performance of the South African learners and learners internationally.

However, it is noteworthy that South African learners performed better than their international counterparts on CRQ **ITEM 18** and were very close on CRQ **ITEM 22** and **ITEM 23** and MCQ **ITEM 5** and **ITEM 13**.

A.7.3. Performance by cognitive domain

We asked whether the cognitive domain of the items affected the performance of learners. In theory, 'knowing' items should be easier than 'applying' items, which should be easier than 'reasoning' items. Table 3 shows the results of our analysis.

Table 3: Average percentages of learners answering correctly by cognitive domain of restricted use items

Cognitive domain	Number of items	South Africa	International average
Knowing	11	30%	43%
Applying	14	25%	36%
Reasoning	6	24%	39%

Both the South African and the international group of learners performed better on average in the 'knowing' items. There was very little difference in performance between 'applying' questions and 'reasoning' questions.

A.7.4. Does the language of the TIMSS items contribute to difficulty?

We know from previous research (Dempster & Reddy 2007; Prinsloo et al., 2017; Van Staden, Graham & Harvey, 2020) that the readability of TIMSS items affected South African learners' performance. They performed worse in items that had many scientific terms and/or that had long sentences. We were therefore concerned about the readability of some of the TIMSS items we analysed.

Previously we found that learners avoid answers in MCQs that contain unfamiliar or scientific words (Dempster, 2007). This was confirmed in subsequent research where children told the researcher that they do this (Dempster & Zuma, 2010). Grade 9 learners also told researchers that they translate questions into their home language to try to make sense of them. Sometimes, they are unable to translate scientific terms, thereby losing important information. For CRQs, they try to construct an answer in their home language and then translate it into English (Dempster & Zuma, 2010). Thus, test language proficiency is a significant barrier to their performance in assessments such as TIMSS.

In Part B we will refer to sentence complexity and readability. Sentence complexity is calculated as the number of words in a single sentence or the average number of words per sentence in a section of text, such as a paragraph. We do not have reliable figures for children, but for English-speaking adults, 11 words per sentence are easy to read while 21 words per sentence are difficult (Vincent, 2014). Part B also refers to the specific language issues linked to the items.

Although language contributes to the difficulty South African learners experience in answering TIMSS items, it is not the only problem and must be viewed in relation to other issues that have an influence on the teaching and learning of science (see the South African TIMSS 2019 Grade 9 Results[10] for a comprehensive analysis of factors influencing science achievement).

A.7.5. Performance in Multiple-Choice and Constructed Response Items

Table 4 shows the percentage of South African learners and the international average for learners who answered the restricted use MCQ and CRQ items correctly.

Table 4: Average percentages of learners answering restricted use items correctly

Question type	South Africa	International average
MCQ (16 questions)	31%	45%
CRQ fully correct (15 questions)	15%	27%
CRQ partially correct (4 items)	23%	26%

As expected, South African learners scored lower than the international average in both MCQ and CRQ items. However, both groups performed better in answering MCQ items than in answering CRQ items.

How do we explain this? When learners answer an MCQ, they must read the question and/or look at a picture. They then must recognise the correct answer from the four responses provided. When they answer a CRQ, they must read the question and/or look at a picture and recall or reason out the answer. They then must write the answer in their own words.

Learners in the international average and South African samples found CRQs more difficult to answer than MCQs. Recalling an answer and writing it down is more difficult than recognising an answer that is provided.

A.7.6. Questions not answered or incorrectly answered

We noticed that South African learners, in comparison with their international counterparts, seemed more inclined to try to answer constructed response items, even if they got it wrong. Table 5 shows the responses for the MCQs and CRQs.

Table 5: Average percentages of learners giving incorrect answers or omitting items

	Incorrect		Omitted	
Question type	*South Africa*	*International average*	*South Africa*	*International average*
MCQ (16 questions)	64%	52%	5%	3%
CRQ (15 questions)	69%	50%	9%	15%

As expected, more South African learners gave an incorrect answer to MCQs and CRQs than the international average.

[10] https://www.timss-sa.org/publications/timss-national-reports

South African learners were slightly more likely to omit an MCQ than the international average. Both groups omitted more CRQs than MCQs, but South African learners were less likely to omit a CRQ than their international counterparts.

It seems that South African children were more likely to try to answer CRQs than to leave them out, even if they did not know the answer. This is consistent with the authors' experience, where learners are inclined to try, even if they do not know the answer.

A.7.7. Performance differences between boys and girls

Research has shown that boys perform better than girls on MCQs and the reverse is true for CRQs (Federer, Nehm & Pearl, 2016). At the same time, there is a concern worldwide that girls are outperforming boys at school and university levels (Stoet & Geary, 2018; Wellington & Ireson, 2012). In South Africa, for science, Grade 9 girls outperformed boys by a significant 12 points in the TIMSS assessment (Reddy et al., 2022).

We explored whether there was a performance difference between boys and girls in the TIMSS 2019 restricted use items. Table 6 shows the results.

Table 6: Average percentages of Grade 9 boys and girls answering MCQs and CRQs correctly for restricted use items

	Boys		Girls		Difference (girls-boys)	
Question type	*South Africa*	*International average*	*South Africa*	*International average*	*South Africa*	*International average*
MCQ (16 questions)	31%	45%	32%	45%	1%	0.7%
CRQ (15 questions)	14%	26%	16%	29%	2%	3%

On average, girls performed slightly better than boys in South Africa and internationally on the restricted use items. The difference was small for MCQs, but slightly higher for CRQs.

In **Part A** of this report, we introduced the TIMSS study and the background to South Africa's participation in TIMSS since 1995. We also presented some broad performance patterns for South African Grade 9 learners that support a better understanding of their science achievement.

Part B presents an item-by-item analysis of the restricted use items from the TIMSS 2019 Grade 9 science assessment.

PART B

TIMSS 2019 ITEM ANALYSIS FOR GRADE 9 SCIENCE

In this part of the report we present an analysis of each restricted use item (28 items) that appeared in the TIMSS 2019 science assessment. The key research questions that informed the analysis of the items and the reporting were:

1. How did the learners perform (i.e. the correct and incorrect percentages) in each item?
2. What was the TIMSS content and cognitive categorisation of the item?
3. Which part of the South African curriculum did the item fit into?
4. What cognitive processes were required to answer each question correctly?
5. What types of errors did learners make in answering science questions?
6. What is the explanation for the learners' responses?

The first section of Part B discusses each of the restricted use Multiple-Choice Questions (MCQs) and the second section discusses the Constructed Response Questions (CRQs).

The Constructed Response items required a learner to recall information and provide a reasoned response to the question. Correct answers were coded as 10 (one correct answer) or 20 (two correct answers).

Incorrect answers were generally coded as 79. If a systematic incorrect answer was observed this was coded as 70. The systematic incorrect responses were noted as well.

For each item, we report on the percentage of learner responses as well as the percentage of learners who did not respond to a question (i.e. omitted an answer). In addition, we provide information about the performance by gender (i.e. the percentage of boys and percentage of girls answering an item correctly) and by school fee status (i.e. the percentage of learners in fee-paying and no-fee schools answering an item correctly).

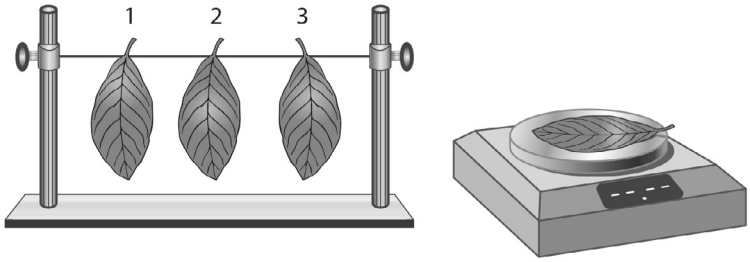
Each item was also analysed for the level of curriculum match and the coded match was reported. A match of 0 means no match, 1 = weak match, 2 = partial match and 3 = full match. The correct answer for MCQs is shaded darker in each table.

Please note the following:

1. In this analysis, we provide the South African responses as well as a comparison with the international average. The international average is derived from the responses of 17 countries (see the explanation in section 6 of Part A).
2. For ease of reading, the percentages of learner frequency responses were rounded to whole numbers.

ITEM 1

Adam investigates how the mass of leaves changes over time.
He removes three leaves from a tree and finds the mass of each leaf.



After one week Adam finds the mass of each leaf again.
He records his results in the table.

Leaf	Mass at start (grams)	Mass after one week (grams)
1	2.22	1.65
2	1.93	1.34
3	2.08	1.6

Which statement best explains this decrease in mass?

A. The leaves released oxygen.
B. The leaves used glucose.
C. The leaves lost water.
D. The leaves released carbon dioxide.

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match[11]
Biology: Ecosystems	Applying	Grade 8 – Respiration in plants. Grade 8 – Photosynthesis in plants. Transpiration is not mentioned in the Senior Phase curriculum. Experimental procedure, but not this experiment.	1 – weak match

[11] The match between the TIMSS item and the South African Senior Phase CAPS, as explained in Table 2.

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	22	10	45	22	1	44	46	44	45
International average (n=17)	19	9	56	14	2	55	56		

COGNITIVE PROCESSING

Scientific terms in this item are *mass, oxygen, glucose and carbon dioxide*. Sentences are short and aided by diagrams. The experiment demonstrates the loss of mass due to evaporation from the surface of a leaf. It is usually associated with the process of transpiration, or loss of water through the stomata of leaves. While learners should have studied the processes of photosynthesis and respiration in plants in Grade 8, they had not yet studied transpiration.

The results show that all three leaves lost mass after one week. Answer A is plausible because leaves release oxygen during photosynthesis. Answer B is plausible because leaves use glucose in the process of respiration. Answer C is plausible because leaves release water because of transpiration and respiration. Answer D is plausible because leaves release CO2 during respiration.

The question asked is: Which statement **best** explains this decrease in mass? Learners must eliminate answers A, B and D to arrive at the correct answer C OR they select the most obvious answer, which is C (loss of water).

TYPES OF ERRORS

South African learners performed well on this item, with 45 percent selecting the correct answer (C), which compares well with the international average of 56 percent correct. Answer B was the least favoured answer by both South African learners and learners internationally. There was little difference between the percentage of girls and boys answering correctly, as was the case internationally. There was also little difference between the percentage of learners from fee-paying schools and no-fee schools answering correctly.

EXPLANATION

South African learners should not have been able to answer the question because the context (loss of water through the stomata) is not included in the Senior Phase curriculum. However, the answer is evident without requiring knowledge of transpiration. The context was clearly described.

ITEM 2

In which structure of an animal cell does DNA replication take place?

A. chloroplast
B. nucleus
C. membrane
D. cytoplasm

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Biology: Cells and functions	Knowing	Grade 9 – Cell structure mentions DNA but not DNA replication. Chloroplast, nucleus, membrane and cytoplasm appear in the Grade 9 curriculum. DNA replication is studied in Grade 12.	2 – partial match

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	18	35	31	14	2	36	35	35	38
International average (n=17)	12	48	17	21	2	48	48		

COGNITIVE PROCESSING

Learners must know the scientific terms *DNA replication, chloroplast, nucleus, membrane* and *cytoplasm*. They must also be able to identify in which part of the cell DNA replication occurs.

TYPES OF ERRORS

South African learners preferred the correct answer B, with the distractor C attracting more learners than distractors A or D. South African girls were slightly more frequently correct than boys. Learners in fee-paying schools were slightly more likely to answer correctly than learners in no-fee schools, but still below the international average.

EXPLANATION

South African learners encounter the scientific term DNA and knowledge of basic cell structure in Grade 9, but not DNA replication. They could have answered the question correctly by associating DNA with the nucleus, which is the correct answer. This does not mean that learners know that DNA replication occurs in the nucleus.

The term "membrane" may be more familiar to learners than chloroplast and cytoplasm and therefore served as a plausible distractor to learners.

ITEM 3

Francois had a male rabbit and a female rabbit. He kept them in a pen painted white on the inside. Both rabbits had black hair. When these rabbits bred, some of their offspring had white hair.

Which of the following explains how this pair of black-haired rabbits could produce offspring with white hair?

A. When any black-haired male and female rabbits breed, they will eventually produce some white-haired offspring.
B. The male and female black-haired rabbits can pass some traits on to their offspring, even though they do not express the trait themselves.
C. If the male and female black-haired rabbits are old, they will only produce offspring with white hair.
D. Male and female rabbits will produce offspring that blend in with the colour of their surroundings.

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Biology: Life cycles, reproduction and heredity	Applying	Grade 7 – Variations exist within a species; variations can be inherited. Genetics is covered in Grade 12.	1 – weak match

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	25	25	23	23	4	25	25	26	36
International average (n=17)	17	47	8	25	3	51	43		

COGNITIVE PROCESSING

Two scientific terms are key to answering this question correctly: *offspring* and *traits*. The average sentence complexity of the stem was nine words per sentence, the question has a sentence complexity of 17 and the mean sentence complexity of the answers was 18. Both the question and the answers have high sentence complexity that adds difficulty to the item. Learners should have been exposed to the concept of variations and their inheritance in Grade 7, but they would not have encountered the concepts of dominant and recessive genes.

Learners should know that variation exists in a species, and that it can be transmitted from parents to offspring. Learners should know that genetic traits can be carried in a masked form (recessive alleles) and then expressed in some offspring. They should know that the term "traits" refers to physical characteristics.

TYPES OF ERRORS

The pattern of answering (25% correct) by South African learners was consistent with random guessing, whereas 47 percent of learners internationally selected the correct answer. South African boys and girls answered similarly, whereas internationally, girls were much more likely to select the correct answer than boys. Learners in fee-paying schools were more likely to select the correct answer, although less than the international average.

EXPLANATION

The South African curriculum does not include genetics and inheritance. South African learners would therefore not have known the answer to this question. High readability demand contributed to the difficulty of the item, together with lack of exposure to genetics and inheritance.

ITEM 4

Insects that feed on nectar pollinate flowering plants as they move from flower to flower.

What kind of relationship is this?

A. predation
B. parasitism
C. competition
D. symbiosis

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Biology: Ecosystems	Knowing	Grade 5 – Plants and animals depend on each other. Grade 7 – Pollination (context). Grade 8 – Feeding relationships mention predators only. Ecological relationships are studied in the Further Education and Training (FET) Phase.	1 – weak match

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	35	22	24	17	1	19	15	16	23
International average (n=17)	17	21	10	49	3	48	51		

COGNITIVE PROCESSING

Scientific terms used in this item are *nectar, pollinate, predation, parasitism, competition* and *symbiosis*. Learners must know the different types of relationships between species in an ecosystem. They must make the following links: Insect collects nectar and pollen from flowers → insect cross-pollinates flowers as it moves from flower to flower → both insects and flowers benefit from the relationship → this is symbiosis.

TYPES OF ERRORS

South African learners preferred answer A, with the correct answer D being their least favoured option. The percentage of South African learners selecting D (17%) was well below the international average of 49 percent. South African girls were more frequently correct than boys, unlike the international average. Learners in fee-paying schools were more likely to answer correctly than learners in no-fee schools, but still scored well below the international average.

EXPLANATION

Learners should have studied feeding relationships in Grade 8 and they should have studied pollination in Grade 7. However, the only named feeding relationship in the curriculum is *predation*. *Predation* is therefore a familiar term. *Parasitism*, *competition* and *symbiosis* are unfamiliar to South African learners. This could partially explain why answer A was more popular among South African learners than other answer options. Over one-third of learners avoided unfamiliar terms and selected the only familiar term. Learners would not have known the answer to this question.

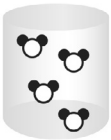
ITEM 5

Rowan wants to illustrate a chemical reaction. He uses models of Substance 1 and Substance 2 as shown below. Circles represent atoms of each substance.

Substance 1 Substance 2

How should he illustrate the results of a chemical reaction after Substance 1 reacted with Substance 2?

A 

B 

C 

D 

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Chemistry: Chemical change	Reasoning	Grade 9 – Chemical reactions (relates to representing and balancing chemical equations, although the concepts of conservation of matter and chemical vs physical changes are not explicitly dealt with at Senior Phase, but only in FET Phase).	2 – partial match

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	6	20	26	44	4	45	44	45	52
International average (n=17)	6	18	25	49	3	49	48		

COGNITIVE PROCESSING

The scientific terms used in this item are *chemical reaction* and *atoms*. Learners must know that the atoms before a chemical reaction must be the same as the atoms after the reaction (conserved). They also need to know that the atoms are rearranged during a chemical reaction, not just mixed in their original form. They need to apply this knowledge and use their reasoning to work out which of the diagrams represent the results of a chemical reaction.

TYPES OF ERRORS

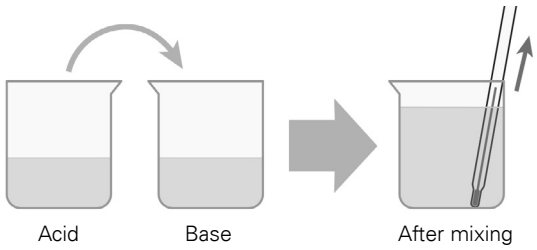
South African learners performed well in this question, with 44 percent selecting the correct answer, D. This was slightly below the international average of 49 percent. South African girls and boys performed similarly well on this question, as did international girls and boys. Learners in fee-paying schools were more likely to answer correctly than learners in no-fee schools, and performed better than the international average.

EXPLANATION

Learners should have learnt how to represent and balance chemical reactions in Grade 9, and the curriculum document specifically recommends building models to illustrate what happens with the atoms during a chemical reaction. This may be the reason for South African learners performing well in this question. The second-most popular response was the distractor which shows a physical change (mixture) rather than a chemical change. This concept is not covered in the curriculum until the FET Phase (Grades 10—12) in South Africa. These responses show that just under half of the South African learners were able to correctly identify the diagrams which conveyed conservation of matter before and after a reaction.

ITEM 6

An acid solution and a base solution are mixed. The temperature increased.



What happened when the two solutions were mixed to cause the temperature to increase?

(A) The solutions reacted to form an oxide.
(B) The solutions reacted to make a stronger acid.
(C) The solutions reacted to form a flammable gas.
(D) The solutions reacted to neutralise each other.

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Chemistry: Properties	Knowing	Grade 9 – Reactions of acids and bases (loose connection, as temperature change is not covered).	1 – weak match

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	12	42	17	27	3	31	24	28	33
International average (n=17)	16	29	20	32	3	34	30		

COGNITIVE PROCESSING

Scientific terms used in this item are *acid, base, solution, oxide, neutralise* and *flammable*. Learners must know that an acid solution mixed with a base solution is a neutralisation reaction, and that this kind of reaction is exothermic (gives off heat). They need to apply this knowledge to the scenario where the two kinds of solutions are mixed and the temperature rises.

Note that neutralisation reactions could include the formation of an oxide. Thus, response A could technically be a possibility for this reaction since the reaction of an acid solution with a metal carbonate is exothermic (forming an oxide and resulting in a temperature rise). However, response A is a subset of the reactions represented by response D, which is the more correct and inclusive response.

TYPES OF ERRORS

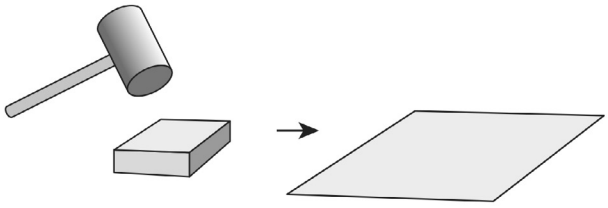
South African learners preferred answer B (42%), with the correct answer D being the second-most popular option (27%). The percentage of South African learners selecting D (27%) was below the international average of 32 percent (which was the most popular option for international learners, by a small margin). South African girls were more frequently correct than boys, like the international average. Learners in fee-paying schools were more likely to answer correctly than learners in no-fee schools, as well as learners internationally.

EXPLANATION

Learners would not have studied the energy of reactions at this point and it would not have been possible for them to make the link with an increase in temperature. What is interesting is their choice of option B as their preferred option, since this is the least scientifically correct answer. There is no possibility that a mixed acid and base solution could form a stronger acid, which shows that there is a strong misconception about the reactions between acids and bases, and very little understanding of neutralisation reaction.

ITEM 7

A block of metal is pounded into a flat sheet with a mallet.



Which statement about the atoms in the flat sheet is true?

(A) The atoms are flattened.
(B) The atoms remain the same.
(C) The atoms are changed into molecules.
(D) The atoms are broken into smaller atoms.

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Chemistry: Composition of matter	Knowing	Grade 7 – Properties of materials and properties of metals. Grade 8 – Atoms as the basic building blocks of matter. Physical vs chemical change is not covered at Senior Phase, but only in FET Phase.	2 – partial match

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	25	19	21	31	4	17	21	18	26
International average (n=17)	25	32	15	26	2	30	33		

COGNITIVE PROCESSING

Scientific terms used in this item are *atoms* and *molecules*. Learners must know that when the shape, size or thickness of an object is changed, the atoms themselves are unchanged, since they are the indivisible building blocks of matter. They need to apply this knowledge to the scenario where a piece of metal is flattened – knowledge of the malleability of metal and physical changes would assist learners to answer this question correctly.

TYPES OF ERRORS

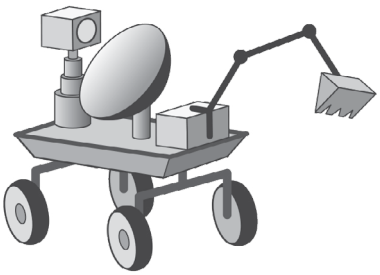
South African learners preferred answer D (31%), with the correct answer B being their least favoured option. The percentage of South African learners selecting B (19%) was well below the international average of 32 percent. South African boys were more frequently correct than girls, similar to the international average. Learners in fee-paying schools were more likely to answer correctly than learners in no-fee schools, but still well below the international average.

EXPLANATION

Learners should have studied atoms as the basic building blocks of matter, as well as the basic properties of metals, but they would not yet have learned to distinguish chemical from physical changes. Their most frequent response of option D shows a misconception that atoms can be broken into smaller atoms. Their second-most frequent response of option A shows a misconception that the shapes of atoms can be changed. Both responses show a misunderstanding about the nature of atoms.

ITEM 8

Scientists sent a special vehicle to Mars to make a map of the surface of the planet. A diagram of the vehicle is shown.



The vehicle has a different weight on Mars than it has on Earth.
Why does the vehicle have different weights on the two planets?

(A) The vehicle lost mass when it was transported from Earth to Mars.
(B) The vehicle gained mass when it began moving on Mars.
(C) The magnetic attraction on Earth is different from Mars.
(D) The gravitational attraction on Earth is different from Mars.

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Physics: Motion and forces	Knowing	Grade 9 – Forces – Field forces, in particular the gravitational force.	3 – full match

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	14	13	16	53	5	57	49	54	69
International average (n=17)	9	8	15	64	3	67	62		

COGNITIVE PROCESSING

Scientific terms used in this item are *weight, gravitational* and *magnetic*. Learners must know that the mass of an object does not change in different locations, but that the gravitational force can change on different planets. They must apply this knowledge to the scenario of the vehicle on Mars.

TYPES OF ERRORS

South African learners preferred answer D (53%), which was the correct answer. This was below the international average of 64 percent. South African girls were more frequently correct than boys, like the international average. Learners in fee-paying schools were more likely to answer correctly than learners in no-fee schools, and they achieved above the international average.

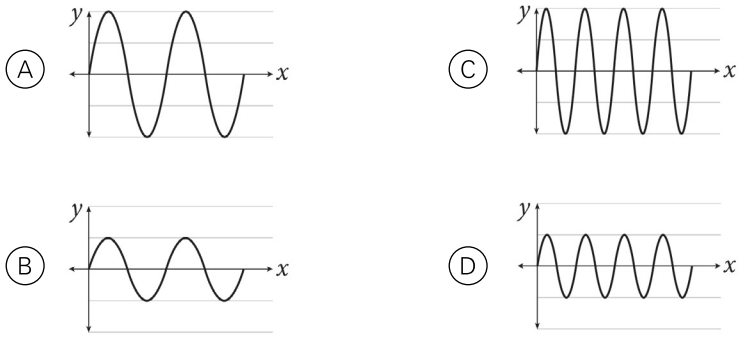
EXPLANATION

Learners performed well in this question. The reasons for this may include that they were familiar with the subject matter, having studied gravitational forces and learnt that these can vary on different planets. The question itself is also straightforward, with no conceptual difficulty if learners know the core concepts. There was no appreciable difference in the frequency of learner responses for the other three distractors – option C was marginally favoured by both South African and international learners.

ITEM 9

Each graph below represents a musical note. Time is represented on the x-axis and magnitude is represented on the y-axis. All of the graphs have the same scale.

Which graph represents the note that has both the softest volume and the lowest pitch?



TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Physics: Light and sound	Applying	Graphs of waves and properties of sound waves are not covered at Senior Phase, but only in FET Phase.	0 – no match

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	9	48	16	25	3	44	51	49	51
International average (n=17)	11	53	16	19	3	53	52		

COGNITIVE PROCESSING

The scientific terms used in this item are *magnitude*, *volume* (with respect to sound) and *pitch*. Learners must know the meaning of pitch and volume of a sound wave, and how these characteristics correlate with the shape of the graph of a sound wave. They need to deduce which graph represents the sound wave with the lowest pitch and volume.

TYPES OF ERRORS

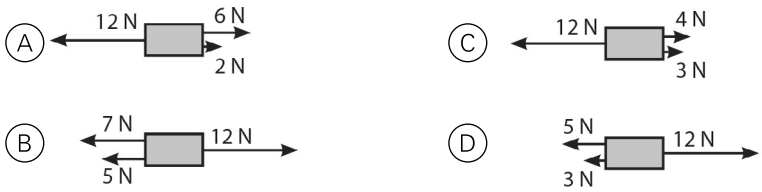
South African learners performed well in this question, with 48 percent selecting the correct option, B. This was slightly below the performance of learners internationally at 53 percent. South African girls were more frequently correct than boys, similar to the international average. Learners in fee-paying schools were slightly more likely to answer correctly than learners in no-fee schools, but still slightly below the international average.

EXPLANATION

Although South African learners would not have studied the characteristics of sound waves or the graphs of waves, they performed well in this question. They may have come across these concepts in previous years.

ITEM 10

A box is being pulled by three forces.
Which combination of forces produces a total force acting towards the right?



TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Physics: Motion and forces	Applying	Vector addition is not covered at Senior Phase, but only in FET Phase.	0 – no match

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	16	35	24	22	3	19	25	19	32
International average (n=17)	10	22	17	47	4	46	48		

COGNITIVE PROCESSING

Scientific terms used in this item are *forces* and *total force*. Learners must know the concept of vectors, and that the magnitude of a vector is represented by the length of an arrow. They need to know how to find the resultant of vectors in one dimension and apply this knowledge to the given force diagrams.

TYPES OF ERRORS

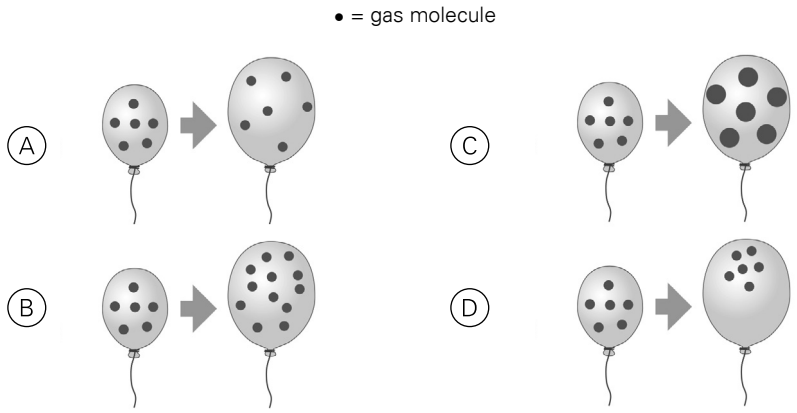
South African learners preferred answer B (35%), with the correct answer D being their second-least favoured option. The percentage of South African learners selecting D (22%) was well below the international average of 47 percent. South African boys were more frequently correct than girls, similar to the international average. Learners in fee-paying schools were more likely to answer correctly than learners in no-fee schools, but still well below the international average.

EXPLANATION

South African learners would not have encountered the concept of vectors at this stage of their schooling, so it is unsurprising that they performed below learners internationally at this question. South African learners who chose answer B did not seem to understand the concept itself and selected the option where the sum of the vectors to the left equalled the sum of the vectors to the right. The South African curriculum also does not include calculations of forces.

ITEM 11

Gas inside of a balloon expands when heated.
What happens to the gas molecules when the balloon expands?



TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Physics: Physical states and changes in matter	Applying	Grade 8 – Particle model of matter.	3 – full match

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	20	27	39	8	5	21	20	20	28
International average (n=17)	35	25	26	8	7	37	33		

COGNITIVE PROCESSING

The scientific term used in this item is *gas molecules*. Learners must know that when a gas is heated the movement of the particles increases and the particles move further apart, increasing the volume of the gas. They need to interpret the information represented in the diagrams and link these with the particle behaviour of gases.

TYPES OF ERRORS

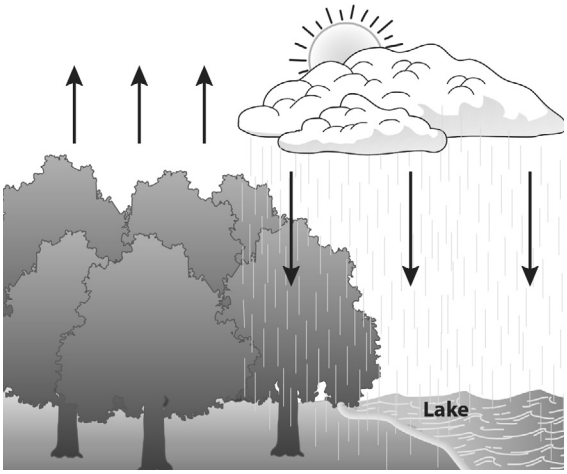
South African learners preferred answer C, followed by answer B, with the correct answer A being their third-favoured option. The percentage of South African learners selecting A (20%) was below the international average of 35 percent. South African girls were more frequently correct than boys, similar to the international average. Learners in fee-paying schools were more likely to answer correctly than learners in no-fee schools, but were still well below the international average.

EXPLANATION

Learners should have studied the particle nature of matter in Grade 8, and the expansion of gases on heating. However, this is an abstract concept, since particles are not visible to the naked eye, and so this relies on good teaching. Learners' preference for option C shows that they had the misconception that the actual sizes of particles increase with heat, rather than the space between them. This shows a fundamental misunderstanding of the particle model of matter. Their second-highest preference showed a lack of understanding of the conservation of matter. This concept should have been covered in Grade 8, Term 2.

ITEM 12

The figure below shows how water cycles through a forest ecosystem.



The arrows pointing down show rain falling on the forest. Some of this water is taken up by the trees from the soil.

What process in the water cycle is shown by the arrows pointing up?

(A) Absorption of water by tree roots.
(B) Production of carbon dioxide by the trees.
(C) Evaporation of water from tree leaves into the air.
(D) Release of carbon dioxide into the air by animals living in the trees.

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Earth science: Earth's processes, cycles and history	Knowing	Grade 4 – Materials around us – The water cycle (in Matter & Materials). Grade 4 – Plants and animals depend on resources in their habitat, including water (weak link). Grade 6 – Ecosystems – Relationships between living things and non-living things in an ecosystem.	3 – full match

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	25	15	46	13	2	48	45	46	55
International average (n=17)	22	13	57	7	1	58	56		

COGNITIVE PROCESSING

The scientific terms needed to answer this question are *ecosystem, water cycle, evaporation* and *carbon dioxide*. Learners should have encountered the concept of the water cycle in Grade 4, five years before they wrote the TIMSS assessment. The text helps learners to interpret the diagram. Learners must make the following interpretation of the image: water falls from the clouds to the ground → plants absorb water through their roots → water evaporates from the leaves → water vapour enters the atmosphere.

TYPES OF ERRORS

South African learners performed relatively well at this question, with 46 percent choosing the correct answer, compared with an international average of 57 percent. Answer A was the strongest distractor, attracting 25 percent of South African learners. Slightly more girls than boys answered the question correctly, similar to the international average. Learners in fee-paying schools were more likely to answer correctly, and were close to the international average.

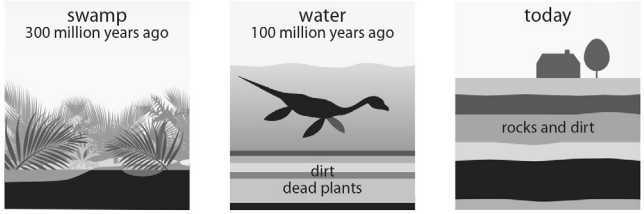
Learners avoided answers B and D which contained the scientific term *carbon dioxide*. Answer D is a true statement, except that the item specifically refers to the water cycle. Most learners rejected this answer, indicating that they engaged with the question and selected the correct answer.

EXPLANATION

The word *water* appears in the stem of the question and in two answers (A and C). We have shown previously that learners are strongly attracted to answers that contain key words that appear in the stem. However, almost half of South African learners eliminated A and chose the correct answer, C. They understood the water cycle and answered the question correctly.

ITEM 13

The process of forming a natural resource in an area of Country A is shown in the diagrams.



What natural resource is being formed in the diagrams?

(A) geothermal energy
(B) groundwater
(C) fossil fuels
(D) fertiliser

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Earth science: Earth's processes, cycles, and history	Applying	Grade 6 – Fossil fuel formation millions of years ago from dead plants and animals *(under Mains electricity).* Grade 5 – Fossil formation and types of fossils (weak link).	2 – partial match

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	9	29	39	17	7	42	35	38	51
International average (n=17)	17	21	41	17	4	42	41		

COGNITIVE PROCESSING

The scientific terms needed to answer this question are *natural resource, geothermal energy, groundwater* and *fossil fuels*. Learners should have encountered the concept of fossil fuels in Physics in Grade 6, three years before they wrote the TIMSS assessment. The visual literacy demand is high in this question. Learners must interpret the images as follows: 300 million years ago plants grew alongside swamps → dead plants fell into the swamps → soil and water covered the dead plants → the dead plants turned into fossil fuels over time → at the present time, the fossil fuels are underground.

TYPES OF ERRORS

South African learners performed relatively well at this question, with 39 percent choosing the correct answer compared with an international average of 41 percent. Answer B was the strongest distractor, attracting 29 percent of South African learners. More girls than boys answered the question correctly, contrasting with the international average in which boys and girls answered equally well. Learners in fee-paying schools were more likely to answer correctly, achieving above the international average.

Learners avoided answer A which contained the unfamiliar scientific term *geothermal energy*. Answer D *(fertiliser)* was also avoided. Answer B was favoured by 29 percent of learners and is a plausible answer since groundwater is a natural resource, but it does not form over very long periods of time. The pattern of answers indicates that learners engaged with the question and selected the correct answer.

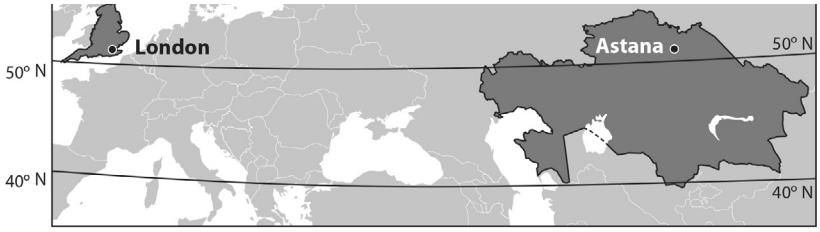
EXPLANATION

Fossil fuels is the most familiar scientific term of the four possible answers. The diagrams are misleading. For example, the black layer (presumably coal) appears in the first diagram, is shown as a thin layer in the second image, and reappears in the third image.[12]

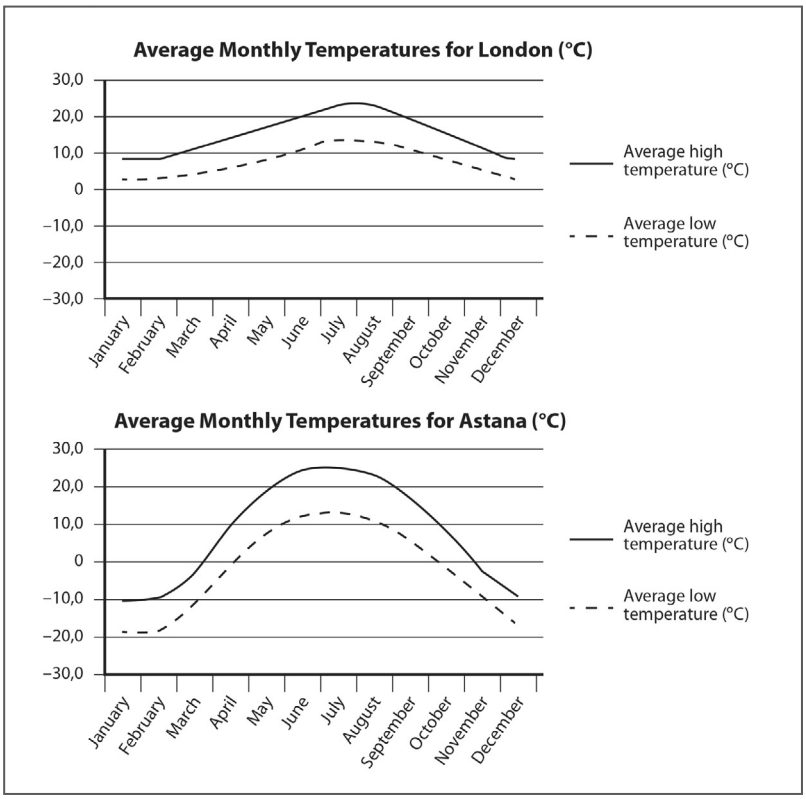
[12] A more accurate diagram can be found at
http://1.bp.blogspot.com/-7OeqPVzj4V4/VbjAbdDlTMI/AAAAAAAABPk/-1VoYOdfFgE/s1600/clip_image002_0011.jpeg

ITEM 14

Look at the map below. The cities of London and Astana are marked.



The two graphs show the average monthly temperatures (°C) for London and Astana.



B. What about the geographies of the cities explains the differences in their climates throughout the year?

(A) London's climate is less variable because it is near the ocean.
(B) London's climate is less variable because it is further west than Astana.
(C) Astana's climate is warmer in the summer because it receives warm ocean breezes.
(D) Astana's climate is colder in the winter because it is further north than London.

This TIMSS item contained two parts. This is Part B. Part A is **ITEM 28**, *on page 62, discussed under Constructed Response Questions.*

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Earth science: Earth's processes, cycles, and history	B: Reasoning	Weather and climate are not part of the Natural Sciences curriculum but are included in the Social Sciences curriculum.	0 – no match

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	25	19	25	21	9	25	26	26	32
International average (n=17)	29	21	24	22	6	27	31		

COGNITIVE PROCESSING

This item requires several skills: reading text, reading a map and interpreting graphs. The term *climate* is key to answering this question correctly. Weather and climate are not included in the Natural Sciences curriculum in South Africa, but are included in the geography curriculum.

Learners must read from the map that London and Astana are at similar latitudes in the northern hemisphere. They must also notice that London is on an island and is close to the ocean, whereas Astana is on a large landmass. When reading the graphs, they must note that the scales on the y-axis differ and that the lines show the average maximum and minimum temperatures for each month (shown on the graph as *Average high* and *Average low*).

Part B of the item requires learners to make inferences using the information given on the map and their existing knowledge. They need to know about the moderating influence of the ocean on climate and the directions of the compass. Terms that may present problems are *variable*, as used in relation to climate, and *ocean breezes*. Variable is a word with at least two meanings in science, making it a difficult term to comprehend. Sentence complexity was 16 for the question and an average of 12.3 words for the answers. Thus, language difficulties may have affected learners' ability to answer this question.

TYPES OF ERRORS

The spread of choices across the four options indicates that most learners randomly guessed the answer, with 25 percent choosing the correct answer, A. The international average was 29 percent correct, indicating that this question was difficult for most children. Boys were slightly more frequently correct than girls in South Africa and internationally. Learners in fee-paying schools were more likely to choose the correct answer and scored higher than the international average.

EXPLANATION

The topic on which this question is based was not known to most learners in South Africa and other parts of the world. Language factors and the ability to interpret diagrams could have contributed to the difficulty of the item.

ITEM 15

Scientists have evidence of changes in Earth's climate over the last 650 000 years.

Which of the following statements would be evidence that the Earth is becoming warmer?

(A) a decrease in the size of Earth's polar ice caps.
(B) a decrease in the average depth of Earth's oceans.
(C) an increase in the number of volcanoes erupting.
(D) an increase in the number of sunspots.

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Earth science: Earth's processes, cycles and history	Reasoning	Grade 9 – Atmosphere (global warming, leading to increased temperature of the atmosphere and sea levels rising).	2 – partial match

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	24	26	19	25	7	24	24	23	29
International average (n=17)	48	15	15	18	5	47	48		

COGNITIVE PROCESSING

The scientific terms needed to answer this question are *climate, polar ice caps, sunspots, volcanoes, erupting*. The stem has an average sentence complexity of 13.5 words per sentence, which is high. The average sentence complexity of the answers was 8.5. To answer the question, learners must make the following cognitive links: warmer Earth → ice melting → decrease in size of polar ice caps.

TYPES OF ERRORS

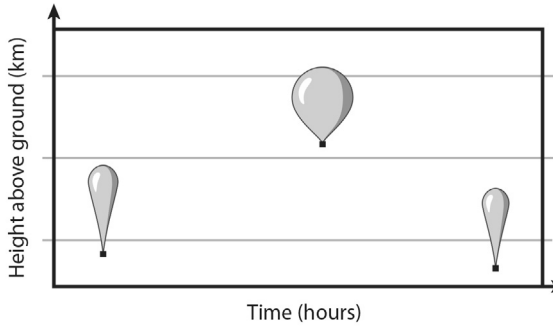
South African learners performed poorly at this question, with an almost equal spread of selected answers, consistent with random guessing. Twenty-four percent of learners chose the correct answer, compared with an international average of 48 percent. Answer C attracted only 19 percent of the learners, being the least favoured answer. There was little difference between the proportion of girls and boys answering the question correctly, as was the case with the international average. Learners in fee-paying schools were slightly more likely to answer correctly, but far below the international average.

EXPLANATION

This item addresses a topic that is included in the South African Natural Sciences curriculum for Grade 9 but would not have been covered at the time that learners wrote the TIMSS assessment. South African learners did not know the answer to the question. Language difficulties could also have contributed to their low performance.

ITEM 16

The diagram shows the height above the ground of a helium-filled weather balloon during a period of several hours.



What causes the balloon to become bigger as its height above the ground increases?

(A) Gravity decreases.
(B) Atmospheric pressure decreases.
(C) The balloon is heated by the sun.
(D) The balloon absorbs air.

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Earth science: Earth's structure and physical features	Knowing	Not in the CAPS curriculum.	0 – no match

PERCENTAGES OF LEARNER RESPONSES

	A	B	C	D	Omitted	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	15	12	21	46	6	13	12	10	18
International average (n=17)	19	36	21	21	3	36	37		

COGNITIVE PROCESSING

The scientific terms needed to answer this question are *helium-filled weather balloon, gravity* and *atmospheric pressure.* The average sentence complexity of the stem is 16.5 words per sentence, which is high. The average sentence complexity of the answers is low at 4. Learners should have encountered the concept of gravity in Physics, but not the other two terms. Learners must interpret a pictogram, which is partially explained in the question. They must then make the following cognitive links: increasing height above the ground → air pressure decreases → gas expands in the balloon → the balloon gets bigger.

TYPES OF ERRORS

South African learners performed poorly at this question, with only 12 percent choosing the correct answer, compared with an international average of 36 percent. Answer D proved to be a strong distractor, attracting 46 percent of South African learners. Slightly more girls than boys answered the question correctly, contrasting with the international average in which boys were slightly better than girls at answering this item. Learners in fee-paying schools were more likely to answer correctly, but scored far below the international average.

EXPLANATION

Learners avoided answers that contained scientific terms such as *gravity* and *atmospheric pressure*. The notion of a balloon absorbing air was selected in preference to the balloon being heated by the sun, both of which contained familiar terms and were plausible answers. This indicates that learners engaged with the answers and considered D to be the most likely to be correct.

This item addresses a topic that is not included in the South African Natural Sciences curriculum. The complexity of the stem, an unfamiliar pictogram and the use of unfamiliar key words added to the difficulty of this item. The preference for the incorrect answer D indicates a lack of knowledge, language difficulties and/or a possible misconception.

B.2. Constructed Response Questions

A scoring guide was provided to each country to ensure that all markers correctly and consistently scored the TIMSS Constructed Response Items. Scores were given to learners using the four codes explained below.

Correct Responses:
Code 20: the learner provided two correct responses
Code 10: the learner provided one correct response

Incorrect Responses
Code 70: the learner provided an incorrect answer, showing a particular predefined misconception for that question
Code 79: the learner provided any other incorrect answer

ITEM 17

List two substances plants obtain from their environment and use as raw materials for photosynthesis.

1. _____

2. _____

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Biology: Cells and their function	Knowing	Grade 5 – Plants use carbon dioxide from the air and release oxygen into the air. Grade 6 – During photosynthesis the plant uses sunlight energy, carbon dioxide (from the air) and water to make glucose sugar. Grade 8 – Photosynthesis – Plants use carbon dioxide (from the air), water (from the soil) and energy from the sun to produce glucose.	3 – full match

PERCENTAGES OF LEARNER RESPONSES

	20	10	79	Omitted / Not reached	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	9	41	40	10	9	9	9	11
International average (n=17)	9	48	27	16	8	9		

COGNITIVE PROCESSING

Scientific terms needed to understand this question are *environment, raw materials* and *photosynthesis*. Learners should have encountered the process of photosynthesis in Grades 5, 6 and 8. Learners must understand that plants use raw materials from the environment for photosynthesis. The TIMSS scoring guide requires that learners identify water and carbon dioxide as the raw materials.

TYPES OF ERRORS

Only nine percent of South African learners and nine percent internationally could name two raw materials, while a further 41 percent and 48 percent respectively could name one correct raw material. Forty percent of South African learners got the answers incorrect, compared with 27 percent internationally. Similar percentages of boys and girls answered the question correctly, as was the case internationally. Learners in fee-paying schools were slightly more likely to give two correct answers, higher than the international average.

EXPLANATION

Research on 6 to 7-year-old children shows that they commonly focus on one feature of a process rather than several features (Harlen & Qualter, 2018). This also applies to older children in the eighth or ninth year of schooling. Universally, more than 48 percent of learners in the eighth or ninth year of schooling could name one but not two factors, despite the process of photosynthesis being very well known. South African learners showed the same pattern. Given that they should have studied photosynthesis in Grades 5, 6 and 8, learners should have been able to answer correctly. This indicates a lack of knowledge about raw materials for photosynthesis or a carelessness in not providing two responses.

ITEM 18

Plant cells and animal cells have some similarities and some differences.

A. List two ways that plant cells and animal cells are **similar**.

1. _____

2. _____

B. List two ways that plant cells and animal cells are **different**.

1. _____

2. _____

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Biology: Cells and their functions	Applying	Grade 9 – Cell structure and differences between plant and animal cells.	3 – full match

PERCENTAGES OF LEARNER RESPONSES

Question Part A	20	10	79	Omitted / Not reached	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	18	24	48	11	22	14	18	27
International average (n=17)	26	23	28	23	29	23		

Question Part B	20	10	70	79	Omitted / Not reached	Girls % Correct	Boys % Correct	No-fee % Correct	Fee paying % Correct
South Africa	6	19	5	60	11	7	6	7	8
International average (n=17)	9	13	12	42	25	10	8		

COGNITIVE PROCESSING

One scientific term is included in this item: *cell*. Cell structure and differences between plant and animal cells are included in the Grade 9 curriculum, but were not studied earlier.

Learners must know the concepts of *similarities* and *differences*. They must be able to list two similarities and two differences between plant and animal cells. This is a standard exercise when learners study cells.

TYPES OF ERRORS

This item was poorly answered by both South African learners and learners internationally. Almost half of the South African learners gave an incorrect answer to part A of the item, and only a quarter of learners gave a correct answer to part B. Interestingly, the international average shows that a far greater proportion of learners omitted the item than did South African learners.

Girls were considerably more likely to name two similarities than boys in both the South African sample and internationally. The difference was less marked for part B of the item. Learners in fee-paying schools were more likely to answer both parts of the item correctly – with the pattern similar to the international average.

EXPLANATION

Similarities and differences between plant and animal cells were not clearly understood by the average learner internationally or in South Africa. South African Grade 9 learners should have studied this topic at the beginning of Grade 9, so they should have been able to answer this question fully. Teaching and testing of this topic and understanding similarities and differences must be improved.

ITEM 19

In some large cities, owners of large buildings and houses have planted gardens on the roofs. Having more gardens helps reduce the amount of carbon dioxide in the air.

How does increasing the number of gardens help reduce the amount of carbon dioxide in the air?

_____

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Biology: Ecosystems	Reasoning	Grade 5 – Plants use carbon dioxide from the air and release oxygen into the air. Grade 6 – During photosynthesis, the plant uses sunlight energy, carbon dioxide (from the air) and water to make glucose sugar. Grade 8 – Photosynthesis – Plants use carbon dioxide (from the air), water (from the soil) and energy from the sun to produce glucose. Grade 8 – Balance in an ecosystem.	3 – full match

PERCENTAGES OF LEARNER RESPONSES

	10	79	Omitted / Not reached	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	20	67	13	20	20	21	33
International average (n=17)	44	38	19	47	41		

COGNITIVE PROCESSING

One scientific term appears in the stem: *carbon dioxide*. The average sentence complexity of the stem and the question is 15, which is high. Learners must know the concept of a garden and that plants remove carbon dioxide (CO_2) from the air during the process of photosynthesis. They must then make the following associations: gardens → plants → photosynthesis → removes carbon dioxide from the air. The scoring guide also gives credit to answers that link roof-gardens to cooling and, therefore, less use of electricity and lower CO_2 emissions.

TYPES OF ERRORS

Only 20 percent of South African learners gave a fully acceptable answer, compared with 44 percent internationally. Two-thirds of South African learners gave an incorrect answer (coded 79) and a further 13 percent did not attempt to answer. There was no difference between the percentage of girls and boys answering correctly, unlike the international average where girls were more likely to answer correctly than boys. A greater percentage of learners in fee-paying schools answered correctly than in no-fee schools.

EXPLANATION

South African learners should have been able to answer the question because they should have learnt about plants taking in carbon dioxide for photosynthesis in Grades 5, 6 and 8. There was only one scientific term, but the stem had high sentence complexity. Language and cognitive level complexity may have contributed to the low scores attained.

The context (rooftop gardens) would be unfamiliar to most South African learners. Contextual information was unnecessary to answer the question. If learners had focused on the question alone, they might have performed better on the item. However, poor knowledge likely contributed to the poor performance of learners on this item.

ITEM 20

Here is a list of animals.

ant cat dolphin earthworm fish frog jellyfish

A. Classify the animals into two groups based on whether or not the animal is a mammal.
List the animals in each group in the table.

Mammal	Not a mammal

B. The same animals have been classified into these two groups.

Group 1	Group 2
cat dolphin fish frog	ant earthworm jellyfish

What characteristic was used to classify the animals into these two groups?

_____

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Biology: Characteristics and life processes of organisms	Applying	Grade 5 – Different kinds of animals (vertebrates and invertebrates). Grade 7 – Classification of living things; specifically, diversity of animals (five classes of vertebrates, arthropods and molluscs).	3 – full match

PERCENTAGES OF LEARNER RESPONSES

Question Part A	10	70	79	Omitted / Not reached	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	5	9	84	2	6	5	4	10
International average (n=17)	25	18	54	3	25	25		

Code 70: One animal in an incorrect column.

PERCENTAGES OF LEARNER RESPONSES

Question Part B	10	79	Omitted / Not reached	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	8	83	10	8	7	8	13
International average (n=17)	16	60	25	17	15		

COGNITIVE PROCESSING

Learners must understand the principle of classification, which involves grouping organisms according to shared characteristics that contrast with those of another group. They must know the scientific terms *classify, characteristic* and *mammal*. Part A requires that learners are familiar with types of mammals and can identify the mammals from the list of animals given. The list includes non-mammal vertebrates (fish, frog) as well as invertebrates (ant, earthworm, jellyfish). A cat is an obvious mammal, but a dolphin has fish-like characteristics (it lives in water and lacks fur) and is more difficult to identify as a mammal.

Part B requires learners to do the reverse process: to identify the characteristic that separates the animals into two given groups. They need to know what characteristic separates vertebrates from invertebrates. They need to recognise *cat, dolphin, fish* and *frog* as vertebrates and *ant, earthworm* and *jellyfish* as invertebrates. They do not have the benefit of images to help them. Part B is not the answer to Part A, but may have been interpreted as such by some learners.

TYPES OF ERRORS

South African learners performed poorly in part A of the question, with only five percent answering correctly and a further nine percent writing one animal in the wrong list. Eighty-four percent answered totally incorrectly. The international average answering correctly was only 25 percent, indicating that this item was experienced as a difficult question by many learners. Slightly more girls than boys answered the question correctly. Learners in fee-paying schools were more likely to answer correctly, but scored far below the international average.

Part B of the item was even more poorly answered by South African learners and learners internationally. South African and international figures show that girls were slightly better at answering this item than boys. Learners in fee-paying schools were more likely to answer correctly than learners in no-fee schools, and were closer to the international average.

EXPLANATION

South African learners should have been able to answer the question because classification, and specifically the diversity of animals, is introduced in Grade 5 and covered in more detail in Grade 7. The Grade 7 curriculum prescribes the classes of vertebrates and uses arthropods and molluscs as examples of invertebrates.

The poor answers given indicate that learners generally find it difficult to apply specific examples to a general principle. Images were not provided, so learners had to recognise the names of animals, some of which may have been unfamiliar, e.g. earthworm, jellyfish, dolphin.

ITEM 21

Atoms can contain **protons, electrons** and **neutrons.**

Which of these subatomic particles are located **outside** the nucleus of an atom?

_____

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Chemistry: Composition	Knowing	Grade 8 – Atoms – Subatomic particles.	3 – full match

PERCENTAGES OF LEARNER RESPONSES

	10	79	Omitted / Not reached	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	28	61	12	32	23	30	39
International average (n=17)	49	37	14	53	45		

COGNITIVE PROCESSING

Scientific terms used in this item are *protons, electrons, neutrons, nucleus, subatomic particles* and *atoms*. Learners must know the different types of subatomic particles and their relative positions in the atom. They must identify electrons as the subatomic particles that exist outside the nucleus, which involves correct mental visualisation of the atom.

TYPES OF ERRORS

Twenty-eight percent of South African learners correctly identified electrons as the subatomic particles that exist outside the nucleus, which is well below the international average of 49 percent. South African girls were more frequently correct than boys, similar to the international average. Learners in fee-paying schools were more likely to answer correctly than learners in no-fee schools, but still well below the international average.

EXPLANATION

Learners should have studied atoms and subatomic particles in Grade 8, and so they should know that electrons "move around the nucleus" (direct quote from CAPS). However, these terms are technical, and learners may have only encountered them once in their Natural Sciences learning, which may explain their inability to correctly identify electrons and to visualise the structure of the atom.

ITEM 22

This is a portion of the periodic table of elements.

^{1}H							He
Li	Be	B	C	N	O	F	Ne
Na	Mg	Al	Si	P	S	Cl	Ar

Hydrogen (H) is the first element of the periodic table. The nucleus of a hydrogen atom contains one proton. The atomic number of hydrogen is 1.

Four elements from the periodic table are shown below. The elements are not ordered by their atomic numbers.

Write each element in the boxes to order them from smallest atomic number to largest atomic number.

Sodium (Na) Fluorine (F) Helium (He) Carbon (C)

Smallest Largest

☐ ☐ ☐ ☐

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Chemistry: Composition	Applying	Grade 7 – Introduction to the periodic table of the elements. Grade 9 – Compounds – The periodic table.	3 – full match

PERCENTAGES OF LEARNER RESPONSES

	10	79	Omitted / Not reached	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	21	68	11	25	17	22	31
International average (n=17)	24	64	12	26	22		

COGNITIVE PROCESSING

The scientific terms used in this item are *periodic table, elements, atomic number* and the names of the elements *hydrogen, helium, carbon, fluorine* and *sodium*. Learners must be able to identify the shape of the periodic table, and link this with the meaning of the positions of the elements in the periodic table with respect to their atomic numbers, i.e. that elements are arranged from left to right across successive periods (rows) in order of increasing atomic number. They then must interpret the positions of the elements shown with bold borders in terms of their atomic numbers, and then order these from the smallest to highest atomic number.

TYPES OF ERRORS

Twenty-one percent of South African learners correctly identified the order of the elements, which is just slightly below the international average of 24 percent. South African girls were more frequently correct than boys, like learners internationally. Learners in fee-paying schools were more likely to answer correctly than learners in no-fee schools, and performed better than learners internationally.

EXPLANATION

Learners should have been introduced to the periodic table in both Grade 8 and Grade 9. This question is fairly complex as learners not only needed to know the meaning of the term *atomic number* and understand the arrangement of the elements in the periodic table in terms of the atomic number, they also had to interpret the positions of the elements shown with bold borders in terms of their atomic number, and then order these from smallest to highest atomic number. The complexity of the question explains the poor performance of both South African learners and learners internationally.

ITEM 23

The table below shows the results of dipping universal pH indicator paper into three different solutions.

	pH	Colour of indicator paper
Solution 1	7	Green
Solution 2	6	Yellow
Solution 3	8	blue

Is each solution acidic, basic, or neutral?
Shade one circle for each solution.

	Acidic	Basic	Neutral
Solution 1	A	B	C
Solution 2	A	B	C
Solution 3	A	B	C

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Chemistry: Properties	Knowing	Grade 7 – Acids, bases and neutrals (loose connection with acid-base indicators, but only red and blue litmus paper is covered in Grade 7; knowledge of the pH or universal indicator is needed to answer this question). Grade 9 – Acids & bases, and pH value.	3 – full match

PERCENTAGES OF LEARNER RESPONSES

	10	79	Omitted / Not reached	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	20	74	6	22	18	20	25
International average (n=17)	26	67	7	29	24		

COGNITIVE PROCESSING

The scientific terms used in this item are *pH, universal indicator, acidic, basic neutral*. Learners must know that acidic solutions have a pH lower than 7, neutral solutions have a pH equal to 7, and basic solutions have a pH greater than 7. They should then interpret the information in the table to identify each of the solutions as acidic, basic or neutral. If they are familiar with universal indicator paper they could use the colour scheme, but it is not essential to answering the question.

TYPES OF ERRORS

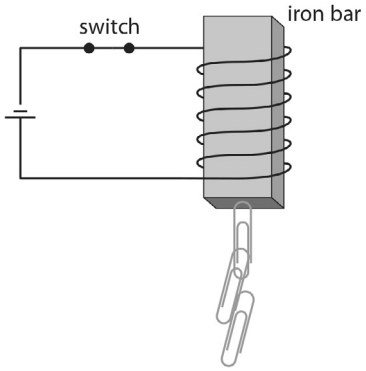
Twenty percent of South African learners correctly identified the pH of the solutions, which is slightly below the performance of learners internationally (26%). South African girls were more frequently correct than boys, similar to the trend with the international average. Learners in fee-paying schools were more likely to answer correctly than learners in no-fee schools, and were just below the international average.

EXPLANATION

Learners should have studied the pH scale and its link with whether a solution is acidic, basic or neutral. However, linking a numerical scale with a scientific meaning is a cognitively challenging task. In addition, the inclusion of the colour scheme for universal indicator paper may have added to the complexity of the question, although it is not essential to answering the question. The presence of two factors that learners must interpret is known to increase the cognitive challenge of a question. Learners who have not had access to practical equipment or posters that present the pH scale may have experienced this question as more challenging than those who have had access.

ITEM 24

The diagram shows an electromagnet. When the switch is closed, the electromagnet can pick up a few metal paper clips.



Write one change that can be made to the electromagnet so that it can pick up more metal paper clips.

_____

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Physics: Electricity and magnetism	Knowing	Factors influencing the strength of the electromagnet are not covered at Senior Phase, but only at FET Phase.	1 – weak match

PERCENTAGES OF LEARNER RESPONSES

	10	79	Omitted / Not reached	Girls % Correct	Boys % Correct
South Africa	22	72	6	19	24
International average (n=17)	21	60	19	20	21

COGNITIVE PROCESSING

The only scientific term used in this item is *electromagnet*. Learners must know the concept of an electromagnet and the factors that influence the magnetic strength of an electromagnet. They must then apply these concepts to the scenario described in the text and image. The image is a straightforward depiction of an electromagnet.

TYPES OF ERRORS

Twenty-two percent of South African learners were able to answer this question correctly, which was higher than the international average (21%). South African boys were more frequently correct than girls, similar to the international average. Only six percent of South African learners omitted this question, in contrast with 19 percent of learners internationally.

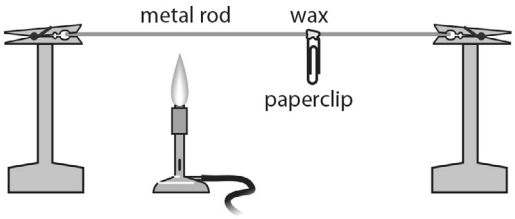
EXPLANATION

Although South African learners should have encountered the concept of electromagnets, they would not yet have learned the factors that affect the strength of electromagnets. Nevertheless, South African learners slightly outperformed learners internationally on this question, with boys outperforming girls. This may be because the answer can be deduced using common sense reasoning, especially if learners have previously encountered any form of electrical motor.

ITEM 25

Tom investigates whether iron conducts heat better than copper. He uses wax to attach one paperclip to an iron rod and another paperclip to a copper rod.

He heats each rod until the wax melts and the paperclip falls off. Tom measures how much time it takes for each paperclip to fall off its rod.



How should Tom design his experiment?

Shade one circle in each row to show the things Tom should do to make sure he will be able to tell which metal is a better conductor of heat.

	Yes	No
Use the same type of wax on both rods	A	B
Use a higher flame for the copper rod than for the iron rod	A	B
Use paperclips made from different materials for each rod	A	B
Attach the paperclip the same distance from the flame for both rods	A	B
Use a thick iron rod and a thin copper rod	A	B
Use more wax on the iron rod than the copper rod	A	B

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Physics: Energy transformation and transfer	Reasoning	General – Process skills – Planning investigations.	3 – full match

PERCENTAGES OF LEARNER RESPONSES

	10	79	Omitted / Not reached	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	18	78	4	20	17	15	30
International average (n=17)	36	60	4	38	35		

COGNITIVE PROCESSING

Although there are no complex scientific terms in this item, learners must comprehend a lot of text, together with a diagram that they have to interpret. There are 12 sentences with a total of 156 words that learners have to read and comprehend to answer the question completely, at an average sentence complexity of 13 words per sentence. Learners must know the concept of a fair test and apply this concept to the given scenario. They are required to select "Yes" or "No" for a range of experimental conditions.

TYPES OF ERRORS

Only 18 percent of South African learners were able to answer correctly, well below the international average of 36 percent. South African girls were more frequently correct than boys, similar to the international average. Learners in fee-paying schools were more likely to answer correctly than learners in no-fee schools, but still scored well below the international average.

EXPLANATION

Learners should have studied investigations and the need for fair tests. The amount of reading and conceptualisation involved in the setting of this question is likely to have presented a challenge, particularly to learners who do not speak the Language of Learning and Teaching (LoLT) as their home language. In addition, learners have to give the correct response for six out of six statements, since there are no part-marks awarded. This reduces the chances of learners performing well in this question.

ITEM 26

Naledi hangs her cell phone under a glass bowl as shown. The sound on the phone is turned on. She removes the air from under the bowl so that her phone is in a vacuum.

Naledi asks her friend to call her phone. Will they hear it ring?
(Tick one box.)

☐ Yes

☐ No

Explain your answer.

_____

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Physics: Light and sound	Applying	Not in the SA curriculum (sound as mechanical waves is only dealt with in the FET Phase).	0 – no match

PERCENTAGES OF LEARNER RESPONSES

	10	79	Omitted / Not reached	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	11	84	5	13	10	11	18
International average (n=17)	32	64	3	34	31		

COGNITIVE PROCESSING

The only scientific term used in this item is *vacuum*. Learners must know the concept of a vacuum, and the concept of sound waves as mechanical waves, i.e. they need a medium through which to propagate and cannot move through a vacuum. They then need to apply this to the description and the diagram portraying the scenario.

TYPES OF ERRORS

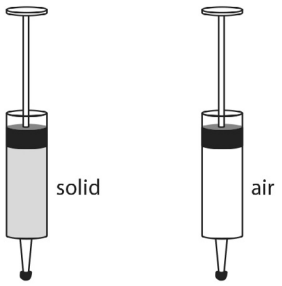
South African learners performed poorly at this question, with only 11 percent answering correctly. This was well below the international average (32%). South African girls were more frequently correct than boys, similar to the international average. Learners in fee-paying schools were more likely to answer correctly than learners in no-fee schools, but were still well below the international average. Interestingly, although learners would not have encountered these concepts, only five percent omitted this question.

EXPLANATION

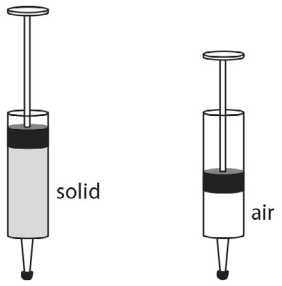
Learners would not have encountered the concepts of a vacuum or sound waves. It is therefore not surprising that they were unable to answer this question, since it is not possible to answer this without knowing these concepts.

ITEM 27

Tumelo filled two syringes with equal volumes of a solid and air and sealed the ends so that none of the materials could escape.



He pressed the plungers of the syringes and observed the following:



Explain his observations in terms of particle spacing in solids and in gases.

_____

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Physics: Physical states and changes in matter	Applying	Grade 8 – Particle model of matter.	3 – full match

PERCENTAGES OF LEARNER RESPONSES

	10	79	Omitted / Not reached	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	11	80	9	12	10	10	21
International average (n=17)	29	54	18	32	25		

COGNITIVE PROCESSING

The scientific terms used in this item are *solids, gases, particles* and *volume*. Learners must know that gas particles have large spaces between them and are thus able to be compressed more easily than solid particles. They need to interpret the given diagrams and apply their knowledge to these diagrams, explaining the reasoning for the observations.

TYPES OF ERRORS

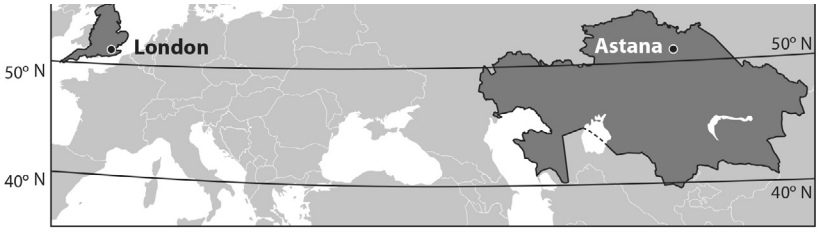
South African learners performed poorly on this question, with only 11 percent answering correctly. This is well below the international average of 29 percent. South African girls were more frequently correct than boys, like learners internationally. Learners in fee-paying schools were twice as likely to answer correctly than learners in no-fee schools, but still performed below the international average.

EXPLANATION

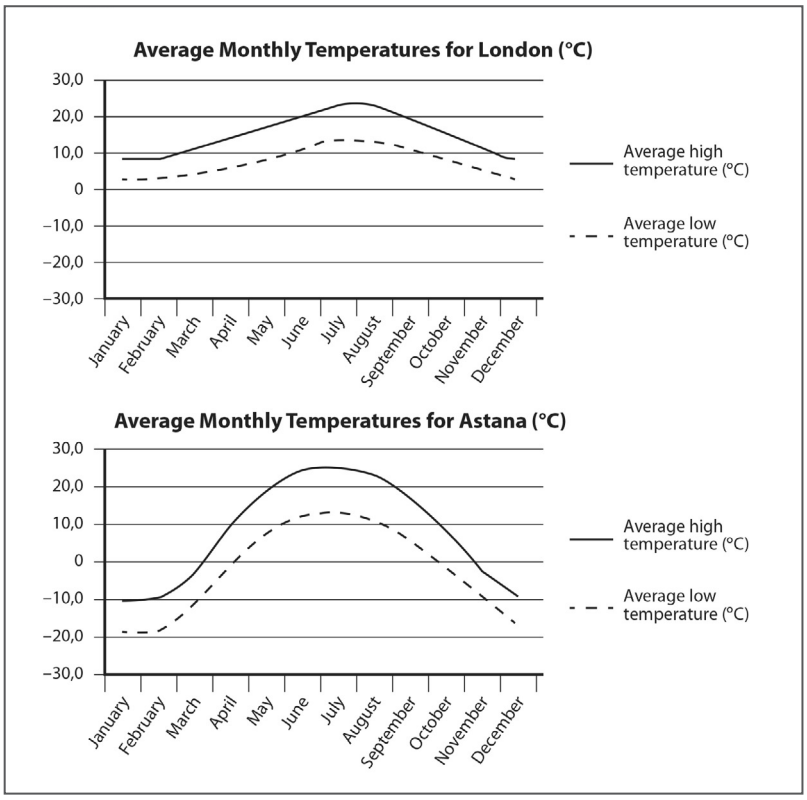
Learners should have studied the particle nature of matter in Grade 8, and the relative spacing of particles in solids and gases. However, this is an abstract concept, since particles are not visible to the naked eye, and this relies on good teaching and the ability to form concepts through visualisation. Learners' poor performance is likely due to a combination of having a poor understanding of the spacing between particles in solids and gases and having to explain their reasoning, which is especially challenging for learners who do not speak the LoLT as their home language.

ITEM 28

Look at the map below. The cities of London and Astana are marked.



The two graphs show the average monthly temperatures (°C) for London and Astana.



A. Shade one circle to answer each of the following questions.
(Shade one circle in each row.)

	London	Astana
Which city is warmer in March?	A	B
Which city is cooler in October?	A	B
Which city is warmer from December to February?	A	B
Which city has a larger range in average temperature?	A	B

This TIMSS item contained two parts. This is Part A. Part B is **ITEM 14**, *on page 35, discussed under Multiple-Choice Questions.*

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Earth science: Earth's processes, cycles, and history	Applying	Weather and climate are not part of the Natural Sciences curriculum but are part of the Social Science/Geography curriculum.	0 – no match

PERCENTAGES OF LEARNER RESPONSES

	10	79	Omitted / Not reached	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	22	70	9	20	24	22	31
International average (n=17)	34	61	6	34	33		

COGNITIVE PROCESSING

This item requires several skills: reading text, reading a map and interpreting graphs. The term *climate* is key to answering this question correctly. Weather and climate are not included in the Natural Sciences curriculum in South Africa, but are part of the Geography curriculum.

Learners must read from the map that London and Astana are at similar latitudes in the northern hemisphere. They must also notice that London is on an island and is close to the ocean, whereas Astana is on a large landmass. When reading the graphs, they must note that the scales on the y-axis differ and that the lines show the average maximum and minimum temperatures for each month (shown on the graph as *Average high* and *Average low*). Answering part A of the item requires learners to interpret information from the graphs.

TYPES OF ERRORS

Learners had to answer all four statements correctly to score a point. Twenty-two percent of South African learners gave an acceptable answer, compared with 34 percent internationally. Seventy percent of South African learners gave an incorrect answer, compared with 61 percent internationally. More boys than girls gave a correct answer, unlike the international average in which boys and girls were almost equal. Learners in fee-paying schools were more likely to answer correctly (near the international average) than learners in no-fee schools.

EXPLANATION

South African learners would not have studied climate topics in their Natural Sciences curriculum, but just over one-fifth were able to answer part A of the question correctly by interpreting the graphs. It is concerning that almost 80 percent of learners were unable to interpret the graphs correctly.

ITEM 29

Describe one important geographic factor that a country must consider when selecting the safest location for a new nuclear power plant.

_____

TIMSS DOMAINS AND LINK TO CAPS

Content Domain	Cognitive Domain	Link to CAPS	Coded match
Earth science: Earth's resources, their use and conservation	Reasoning	Grade 5 – Mains electricity – the source of energy in a power station can be a fuel such as coal. Grade 9 – Energy and the national electricity grid (nuclear power is mentioned but safety aspects are not covered at Senior Phase, but only at FET Phase).	1 – weak match

PERCENTAGES OF LEARNER RESPONSES

	10	79	Omitted / Not reached	Girls % Correct	Boys % Correct	No-fee % Correct	Fee-paying % Correct
South Africa	10	70	20	9	10	10	23
International average (n=17)	29	41	30	30	28		

COGNITIVE PROCESSING

Two terms are key to answering this question correctly: *geographic factor* and *nuclear power plant*. Nuclear energy is mentioned in the Grade 9 curriculum in relation to the national electricity grid. Learners must know that safety is important for a nuclear power plant. The location of such a plant is determined by geographic factors. They must be able to recall and express the geographic factors in their own words.

TYPES OF ERRORS

Ten percent of South African learners gave an acceptable answer, compared to 29 percent internationally. Almost 70 percent of South African learners gave an incorrect answer, compared with 41 percent internationally. There was a very small difference between the percentage of boys and girls giving a correct answer. Learners in fee-paying schools were more likely to answer correctly than learners in no-fee schools, but still scored below the international average.

EXPLANATION

South African learners did not understand this question and/or did not have the knowledge, but about 80 percent were willing to try to answer.

Part B of the report analysed each of the restricted use Grade 9 science items in relation to learners' performance, the errors made and possible explanations for the ways learners answered the questions.

In Part C, we present a set of recommendations about how educators can attempt to improve science teaching and learning in their classrooms.

PART C

IDEAS FOR REMEDIATION

The TIMSS 2019 results have shown that Grade 9 learner performance, while improving, is still low. We therefore need to identify ways to enhance science teaching and learning. The analysis of the learner responses to the TIMSS restricted use items suggests that the following areas need to be strengthened to assist teaching and learning.

1. Use of scientific terms
2. Talking about science
3. Reading about science
4. Writing science
5. Interpreting images and graphs in science
6. Using the scientific method
7. Encouraging higher order thinking skills
8. Content areas that need strengthening

C.1. USE OF SCIENTIFIC TERMS

The language of science is different from the language of everyday speech. It is more precise and uses words that have specific scientific meanings.

Learning a language usually follows the sequence of first talking, then reading and finally writing. Below, we look at how you can use these three language activities to promote the language of science in your teaching.

C.2. TALKING ABOUT SCIENCE

Talking is the foundation of learning. At the Senior Phase, you should encourage children to talk about the science they are learning. It is best that they talk about actual objects or processes that they can observe. Science provides interesting contexts and opportunities to observe and to discuss observations.

Children should talk in their own language if that encourages free expression, but if the language of learning and teaching (LoLT) at the school is English or Afrikaans, you need to speak English or Afrikaans. If your home language is the same as most of your learners, you are probably code-switching from your home language to English in your science classes (Maluleke, 2019). You probably use the home language to ensure learners understand the science concepts and to encourage your learners to participate actively in class. Your 'teacher-talk' may consist of scientific terms in English with other parts of the sentence in their home language.

C.2.1. Introducing scientific terms

When should you introduce scientific terms? Learning scientific terms starts with experiencing the thing they are learning about (Harlen & Qualter, 2018). Personal experience is the best way, but it is not always possible to organise. Use videos, pictures or any other source you can get to create opportunities for learners to experience and talk about scientific processes. They can use their home language to describe what happens. Then introduce the scientific terms, linking them to learners' own words until the new words become familiar. Thereafter, encourage them to use the scientific terms to reinforce the learning.

1. Let's look at the teaching and learning of a real object, such as the electric circuit.

You have brought the components of a simple electric circuit to class, including a light bulb, wires and a torch cell (battery). Ask learners to talk about the components and name them.

When they have talked about the components and experimented with them you can introduce the terms.

This part here (point to the torch cell) is the 'energy source' for electricity. It is called a 'cell'. This part (point to the wires) carries the electricity. It is called a 'conductor'. This part (point to the light bulb) is the 'device'.

Then ask learners to connect the wires to the torch cell and then to the light bulb. When they connect the wires correctly, the light glows.

Did you notice that you must connect the wires to specific places on the cell to make the light glow? The points where you have to connect the conductors are called 'terminals'.

Next, draw the circuit on the chalkboard and point to the different parts.

Learners say the name of each part. From now on, use the scientific terms for those parts of the circuit.

2. Some scientific terms describe a concept rather than a physical object. For example, suppose you are teaching the concept of feeding relationships in the Senior Phase.

Learners have been discussing how different living organisms get food. Using pictures, they group organisms that make their own food, those that eat plants, those that eat animals, those that eat both plants and animals, and those that feed on dead organisms or dung. They talk about why they have created their groups. They may use words that mean 'eats grass' or 'eats meat' or 'feeds on dung'.
Now is a good time to introduce the scientific term 'feeding relationships'.

Science has a name for the different ways of feeding. It is called 'feeding relationships'. Learners, name the different types of feeding relationships you have identified.

C.2.2. Linking words

Linking words are very important in science because they connect sentences or parts of a sentence (Wellington & Osborne, 2001).

Some examples are:

as, if, therefore, because, so that, in terms of, to, based on, whether or not, evidence that.

Techniques that we could use to introduce the linking words are: (i) Fill in the blanks; (ii) Spot the mistake; and, (iii) Sentence completion.

1. Fill in the blank so that the sentence makes sense.

Talk about a few linking words at a time. Write the following linking words on the chalkboard and read them together with the learners.

in terms of, because, in case of, as, evidence that, if, so that, based on.

Explain what each word means, using equivalent words in the home language if you are code-switching. Read out some sentences and ask learners to say which words, from the list above, fits in the blank spaces:

1. Durban's climate is warm in the summer ……..……. it receives warm ocean breezes.
   (Answer: *because/as*)
2. A decrease in the size of Earth's polar ice caps is ….…….. the Earth is becoming warmer.
   (Answer: *evidence that*)
3. A balloon becomes bigger …..…… its height above the ground increases.
   (Answer: *as*)

2. Spot the mistake, i.e. which word is incorrect in the sentence.
Say sentences with the wrong linking word. Ask learners to spot the mistake and correct it.

1. Explain your observations because of particle spacing in solids and gases.
   (Answer: Replace *because of* with *in terms of*)
2. A nuclear power plant should be far from towns based on a radiation leak.
   (Answer: Replace *based on* with *in case of*)
3. Classify these animals into two groups in case of whether the animal is a mammal.
   (Answer: Replace *in case of* with *based on*)

3. Sentence completion.
Ask your learners to complete the sentences:

1. Plant and animal cells are similar because ……
2. We know a cell is a plant cell if ……
3. A decrease in the size of Earth's polar ice caps is evidence that ……
4. A pencil placed in a glass of clean water looks bent as a result of ……

C.2.3. Teaching prepositions

Prepositions are small words that link two parts of a sentence.

Examples are:

'in, on, over, under, before, behind, in front of, around, to, at, by, into, beside'.

Look at the prepositions in the four sentences in the box below. In each case, the preposition tells the learner about the position and direction of the light rays.

Sentences 1 and 2 look similar, but the prepositions *at* and *off* tell the listener different things about light rays.

Sentences 3 and 4 are both about a triangular prism, but the prism serves different functions in each sentence.

1. Draw a ray diagram to show the change ***in*** direction ***of*** light rays ***at*** a smooth reflector.
2. Draw a ray diagram to show the changes ***in*** direction ***of*** light rays reflected ***off*** a rough surface.
3. Draw a ray diagram to show how light is dispersed and focused ***by*** a triangular prism and a magnifying glass.
4. Observe the sequence ***of*** colours ***in*** the visible spectrum when you shine light ***through*** a triangular prism.

Teaching tips for prepositions:

- Introduce and explain prepositions when you need them for your teaching.
- Say full sentences in English, using prepositions, when you are talking about science.

C.3. READING SCIENCE

Learners must be able to read with meaning to answer TIMSS questions. We know from previous research that reading affects how learners perform on TIMSS items (Dempster & Reddy, 2007). The Natural Sciences curriculum includes reading as a suggested activity for some topics, e.g. 'read about how animals are adapted to live in extreme environments'. Learners must be able to read scientific text to understand science and answer questions in science.

Unfamiliar words and long sentences make reading difficult. For example, **ITEM 11** (page 29) is easy to read, as it uses short sentences and has diagrams in the answer options. In contrast, **ITEM 3** (page 14) is difficult to read because it contains two unfamiliar words *(offspring, traits)* and it has long sentences in the question and the answers.

C.3.1. How can we help learners read science?

Below, we discuss three ways to help learners read science: (i) Learning to navigate your way through a book; (ii) Improving scientific vocabulary; and, (iii) Active reading and interpreting questions.

Learning to navigate your way through a book

Create a habit of looking at the overall structure of a whole book, a section within the book and a chapter.

1. Look at the table of contents and sections the book is divided into. This gives learners a sense of what they are going to study over the whole year.
2. As you begin a section (e.g. Life & Living), look at the chapter headings. This gives learners a sense of what they are going to study in each section.
3. As you begin a chapter or unit, look at the title and the subheadings. Ask learners to create a mind map using the headings and subheadings. This gives them a sense of the whole chapter and how it fits together.

Improving scientific vocabulary

One of your aims in teaching science should be to increase learners' vocabulary of science terms. You should do this by talking about science, but you need to reinforce scientific terms through reading. For example, you can make name-cards for physical objects, such as body parts. Ask learners to place the name-cards in the correct places on physical objects or diagrams of the objects. Practice reading the correct terms until the words become familiar to the learners.

Reading whole sentences is different from learning the terminology of science. Choose a text that is at or a little above your learners' reading level. Choose material with short sentences and use labelled diagrams to help learners visualise the material. In the Senior Phase, learners should be able to read sentences but be careful about having too many qualifiers in succession.

The stem of **ITEM 16** (page 39) illustrates a sequence of qualifiers that are underlined and separated by a '|' in the sentence below.

'The diagram below shows the height above the ground | of a helium-filled weather balloon | during a period | of several hours.'

We can simplify the item like this:
'Scientists filled a weather balloon with helium gas. They released the balloon and measured its size for several hours.'

Active reading and interpreting questions

Encourage active reading instead of passive reading. Active reading means that learners are reading for a specific purpose. You, as the educator, are the coach, helping learners to achieve that purpose. Active reading is usually done in groups of two or three learners who work together to achieve the purpose (Wellington & Osborne 2001).

Your purpose is to encourage learners to interact with the text so that they understand what they are reading. They are also learning the structure of scientific writing. Which are the content words? Which are the linking words? Which are the prepositions? Most importantly, what do I learn from reading this text?

We illustrate active reading and interpreting questions with examples in **Appendix 1** and **Appendix 2**.

Here are techniques you can use to encourage active reading.

Underlining – underline specific words in the text such as scientific terms, linking words or prepositions.
Table completion – Complete a table that has missing information. Learners must identify the pattern in the information you have provided and fill in relevant missing information.
Labelling parts of text – Ask learners to identify and label sections of text. For example, you could ask them to identify the parts of a scientific report.
Sequence information – put information into a sequence such as largest to smallest or start to finish of a process.
Set a question – learners must ask a question based on the text they have read.
Diagram labelling – provide a descriptive text with a blank diagram. Learners must use the text to label the diagram.
Text completion – fill in missing words, phrases or sentences related to the text.
Unscrambling text – to form a logical sequence, e.g. putting a set of instructions into a logical order.
Construct diagrams showing the flow of text – diagrams can be flow charts or networks or branching trees. Concept maps are useful for a large section of text such as a chapter.

C.4. WRITING SCIENCE

The average percent correct for the TIMSS science assessment was 33 percent for Multiple-choice Questions (MCQs) and 20 percent for Constructed Response Questions (CRQs) (Reddy, et al., 2022). Learners have more difficulty giving written answers to questions. Table 4 showed that 15 percent of South African learners and 27 percent of the international sample answered CRQs fully correctly. These are low scores for both South African learners and learners internationally. Let's look at **ITEM 17** (page 41) where nine percent of South African learners answered fully correctly, while another 41 percent got the answer partially correct, and **ITEM 27** (page 60), where 11 percent of South African learners answered the question correctly.

ITEM 17 (page 41) is easy to read and learners must provide one-word answers. The scoring guide shows that a fully correct response would name carbon dioxide (CO_2) and water, while 'air' is not acceptable as an answer. A partially correct answer would provide only one correct substance.

The writing demand of this question is low, and the topic (photosynthesis) should have been studied in Grades 5, 6 and 8. Learners should have been able to answer this question with ease. Most South African learners did not have the basic knowledge of photosynthesis.

ITEM 27 (page 60) required learners to give a written explanation or draw a diagram. They had to refer to the particle arrangement of solids and gases, referring to spaces between the particles. Examples of correct written answers are:

- *Solid particles are closely packed, so cannot compress very much, but gas particles are further apart, so can compress.*
- *In a solid, the particles are close together, so there is no room for them to get compressed. In air, the particles are farther apart so there is room to compress them.*

C.4.1. How can we help learners write science?

Learners must know the vocabulary of science, such as scientific terms, linking words and prepositions. Before learners write their own sentences, they must be able to talk and read about scientific topics. Writing science reinforces the language of science. You can use any of the language activities for talking about science as writing exercises.

Here are some ideas for active writing in science:

Fill in the blanks

1. Give learners sentences, written in the LoLT, with key words missing. The words can be scientific names, linking words or prepositions.
2. Supply the words as a separate list.
3. Learners must fit the missing words into the correct places in the sentences.

Use words from the list below to fill in the blanks in the sentences for the section Life and Living in Grade 8. You can use each word more than once or not at all.

air, carbon dioxide, chlorophyll, glucose, light energy, oxygen, photosynthesis, starch, water

The Sun is an important source of ……. for the process of ……..
Green plants contain a green pigment called ……. which absorbs ……
Plants combine ……. from the soil, ……. from the ……..
and energy trapped by ……. to produce ……
Plants then convert ……. to ……. for storage. ……..
is a by-product of the process of ……. It is released into the ……

Rearranging sentences to make paragraphs

Learners must learn how to write whole sentences for science. The South African Curriculum and Assessment Policy Statement (CAPS) has a suggested activity for the Life & Living section of Grade 8 that demonstrates that plant leaves contain starch. Learners must write a report on the investigation.

We soaked a leaf in boiling water to soften it. We put it in a test tube containing ethanol. We stood the tube in a beaker containing boiling water. After 5 minutes, we took the leaf out of the test tube with a pair of tweezers. We rinsed it in boiling water. We spread it out on a white tile. We put a few drops of iodine on the leaf. It turned dark blue-black. We concluded that the leaf contained starch.

Cut the text into separate sentences and jumble the sentences

We soaked a leaf in boiling water to soften it.
We concluded that the leaf contained starch.
We put it in a test tube containing ethanol.
We spread it out on a white tile.
We stood the tube in a beaker containing boiling water.
After 5 minutes, we took the leaf out of the test tube with a pair of tweezers.

We put a few drops of iodine on the leaf.
We rinsed it in boiling water.
It turned dark blue-black.

Give learners the following instructions

1. Rearrange the sentences into the correct order of your investigation.
   The first sentence is in the correct place.
2. Write an aim for this experiment.
3. Insert the headings: method, result and conclusion.

Learners should write the sentences into their notebooks and read them aloud. They should be able to identify errors in the sequence of their sentences.

Tell the story of the picture

Images are helpful in illustrating processes. **ITEM 12** (page 31) contains an image depicting the water cycle. We can use it to illustrate how you can use an image to develop writing skills.

Ask learners to:

1. Write a title for the diagram.
2. Describe in words what is happening in the diagram.

Provide learners with a writing frame to help them structure their answers. A writing frame provides the beginnings of sentences to help learners structure their descriptions:

The arrows pointing up show .....
The clouds form because .....
The arrows pointing down show .....
When water soaks into the ground, the trees .....

Writing frames for explanations

Explanations can take different forms. 'Explain how' requires the learner to link a cause with an effect. The Grade 7 Energy & Change curriculum has the following suggested activity:

'Explain how a solar water heating system works in terms of radiation, conduction and convection'.

A writing frame that can help learners carry out this task:

Title .....
I want to explain how .....
[a solar water heating system works]
The parts involved are .....
[solar panel, collector, pipes, water storage tank, etc.
The function of the solar panel is .....
[to absorb radiation energy from the sun]
Water flows .....
[through coiled copper pipes in the collector]
The collector / solar panel heats water by .....
[conduction and convection]
The function of the water storage tank is .....
[to store hot water]

Writing frames for investigations

The Natural Sciences curriculum has many suggested activities that involve investigating, practical work or demonstrations. Doing these activities enriches learners' experience of science and helps them enjoy science. Investigations also provide an opportunity to develop writing skills in science.

Here is a writing frame for an experiment:

Title .....
Aim .....
[What is the purpose? What are we hoping to show?
Methods .....
[How did we carry out the experiment? Write every step in the correct sequence. Draw a diagram if it helps show what we did. What special precautions did we take to make sure the experiment achieved its aim?]
Results .....
Describe the results briefly using words like these:
You can see that .....
The results show that .....
This means .....
[Show the results as descriptions, diagrams, tables or graphs depending on the investigation]
Conclusion .....
[What do my results show? Refer to the aim of the experiment. What could I do to improve my experiment?]

The most important message is that learning the language of science needs practice, practice and more practice. Learners will not improve their performance in science until they can talk about science confidently, read with meaning, and express their ideas in scientific language.

C.5. INTERPRETING IMAGES AND GRAPHS IN SCIENCE

Science makes use of images because they are helpful in communicating information, illustrating relationships and showing patterns and trends. Images are a very helpful way of communicating information that helps the reader to take in a lot of information in a short space of time and to better remember the information (Levie & Lentz, 1982). Images are processed 60 000 times faster than text (Parkinson, 2010) and presentations that use visual aids are likely to be 43 percent more effective than those without (Hanke, 2004). We need to support learners to be able to understand the information given in different images and for them to be able to answer questions such as those in the TIMSS tests.

Some images are straightforward, e.g. the image used in **ITEM 24** (page 54) to illustrate an electromagnet. However, some images are more complex or abstract and therefore difficult for learners to understand, such as the image used in **ITEM 26** (page 58) to illustrate a cell phone in a vacuum.

The poor performance of South African learners is mainly due to the unfamiliar concepts in this question that are not covered in the CAPS Senior Phase, namely the concepts of a vacuum and sound waves as mechanical waves. This would have made the meaning of the diagram difficult to interpret.

Some images are abstract because they show information that we never see with our naked eye, e.g. **ITEM 5** (page 18) that illustrates the atoms in different substances. Although this is an abstract image, South African learners performed relatively well on this item, with 44 percent choosing the correct answer, D, which was just below the international average (49%). This shows that learners correctly interpreted the diagram. The reason for this may be that South African learners are encouraged to balance chemical equations using beads (in Grade 9, Term 2), so they have become familiar with this kind of representation of atoms. This shows the importance of learners becoming familiar with scientific images and representations, allowing them to gain confidence in interpreting these images.

It is important that learners in Natural Sciences can interpret the meaning of graphs. **ITEM 28** (page 62) involves the interpretation of both a map and a graph. As discussed in Part B, to be able to answer this question, learners must read from the map that London and Astana are at similar latitudes in the northern hemisphere. They must also notice that London is on an island and is close to the ocean, whereas Astana is on a large landmass.

When reading the graphs, they must note that the lines show the average maximum and minimum temperatures for each month (shown on the graph as *Average high* and *Average low*). Answering part A of the item requires learners to interpret information from the graphs.

C.5.1. How can we help learners to understand images and graphs?

a. Understanding the information given in an image

When we work with an image in science, it is important that we understand what the image is telling us. The following are some suggested approaches for helping your learners to understand scientific images.

Discuss the meaning of images together

Give learners practice in understanding images by showing them various scientific pictures that relate to the theme they are studying at the time. Ask them what information the pictures are showing them and encourage them to discuss their ideas so that they help each other to see more elements in the pictures and see them from a wider perspective. When they discuss the images in groups, they can use questions to guide them, such as:

Use the following link to access an example of a science item for discussion:
PICTURE 1: https://www.flickr.com/photos/boellstiftung/35805740223

- What is this a picture of? Name the different objects that you can see, and try to describe for yourself what is happening with the objects in the picture.
- What type of image is it, e.g. a photo, a sketch, a labelled diagram, a graph?
- Does it show a process? If so, how?
- If it is a graph, what kind of graph is it, e.g. line graph, bar graph.

Creating scientific images

After you have completed a section of work, encourage your learners to create a labelled poster, collage or even a comic strip that illustrates some of the key concepts that they have learned. Here is an example of a poster.[13]

Acids	Bases
	

Knowing the difference between symbolic and realistic images

Sometimes in science we use symbolic (or schematic) images instead of realistic images to:

- help the reader to understand the **relationships** between different things;
- help the reader to understand things that **can't be seen** with the naked eye;
- communicate **essential information** without unnecessary detail;
- illustrate **steps or processes** in a procedure or experiment.

Ask your learners to discuss the images in groups and explain in words what they think is being illustrated in each diagram.

Examples of **realistic images** used in the TIMSS test are:
ITEM 4 (page 16), which illustrates a bee on a flower.
ITEM 24 (page 54), which represents an electromagnet.

Examples of **symbolic/ schematic diagrams** used in the TIMSS test are:
ITEM 5 (page 18), represents the atoms in Substances 1 and 2. We cannot see the atoms using our naked eye, so we use symbols (small circles) to represent the atoms.
ITEM 6 (page 20), which represents the processes involved in an experiment.
ITEM 7 (page 22), which represents the processes involved in a procedure.
ITEM 10 (page 28), which represents the forces on an object. These forces cannot be seen, so we use vectors (arrows) to represent them.
ITEM 11 (page 29), which represents the gas particles in balloons.

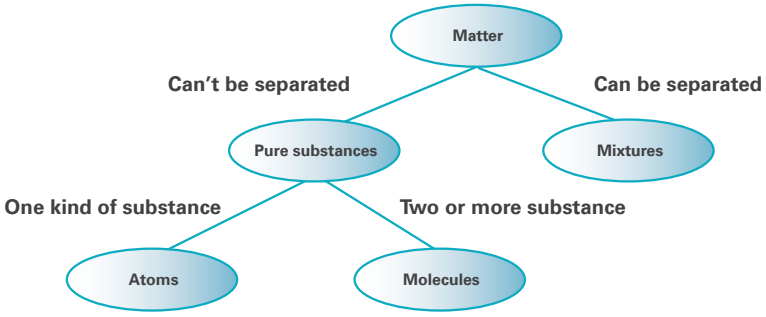
[13] You can find an example of a hand-drawn poster here: https://www.flickr.com/photos/vblibrary/4419780785.

Concept mapping

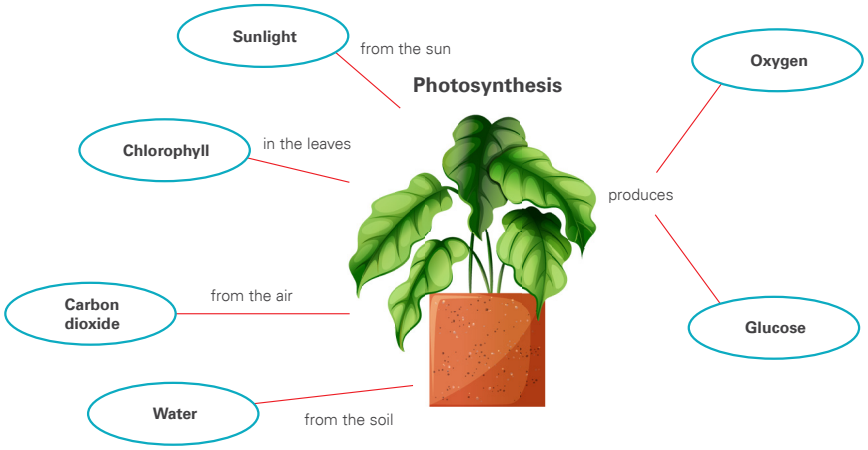
Concept maps are diagrams that we construct to show the key concepts in a topic and to show the links between the concepts. Concept maps allow learners to think deeply about science by helping them to better understand and organise what they learn, and to store and recall information more efficiently. Learners also express and challenge their thoughts about science when they discuss their maps with each other.

Here are three examples of different kinds of concept maps:

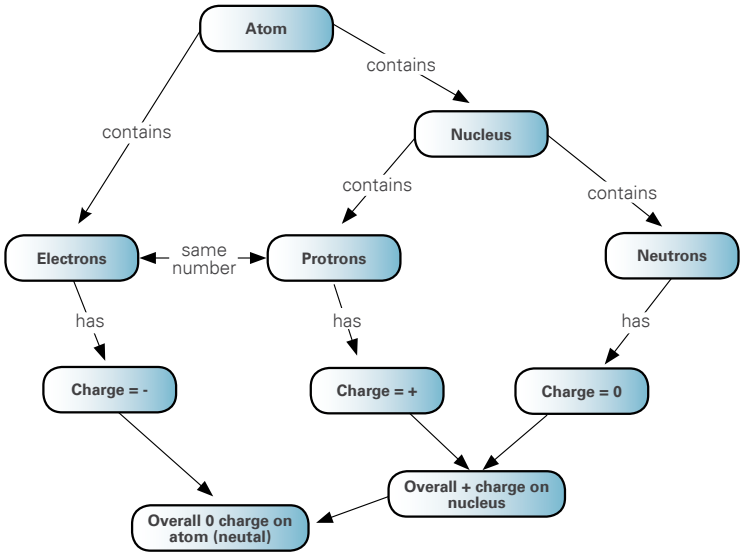
EXAMPLE 1



EXAMPLE 2



EXAMPLE 3



b. Understanding line graphs

Being able to draw and interpret graphs is an important scientific skill, and so it is important to help your learners to understand scientific graphs. In this section, we will look at line graphs.

In the TIMSS example, the line graph is used to show information that changes over time. We plot line graphs using points connected by straight lines, or with a trend line running through the points. The line graph has two axes, known as the 'x-axis' (horizontal) and the 'y-axis' (vertical). The axis labels are important to tell us about the meaning of the graph.

It is important that learners spend some time trying to understand what a graph is telling them before they answer any questions about the graph. Go to **Appendix 3** for practice exercises on interpreting graphs. Some possible questions you could ask learners to help them to make sense of graphs are:

- Look at the label of the vertical axis (on the left of the graph) – what does this axis tell you?
- Look at the label of the horizontal axis (usually at the bottom of the graph) – what does this axis tell you?
- If the graph has a key explaining what the different lines mean, what does this key tell you?
- Look at the shape of the line in the graph and use this to explain the meaning of the graph in your own words. We call this, "telling the story of the graph".

C.6. USING THE SCIENTIFIC METHOD

Science is investigated through the scientific method. Part of the scientific method involves formulating a hypothesis and then designing an experiment where we ensure that we are using a fair test by keeping some variables the same while changing other variables. Learners must be able to understand and apply the concept of a fair test to answer TIMSS questions.

An example in the TIMSS test where the concept of a fair test is applied is **ITEM 25** (page 56). To answer this question correctly, learners must understand and apply the concept of a fair test.

C.6.1. How can we help learners to apply the scientific method?

a. Understanding the scientific method

Science is about our experience of the world around us. Sometimes our experiences raise more **questions**. If we do not know the answer to the question, or if we cannot find an answer in books, then we perform an experiment to try to find an answer to the question. Once we have a question that we want to investigate, the next step in the process is to formulate a **hypothesis** that might answer the question. A hypothesis is our best guess at the answer to the question. We must be able to test this guess using an experiment.

Once we have drawn up a hypothesis, the next step in the process is to design an **experiment** to test our hypothesis. An important part of designing an experiment is to ensure that we are using a **fair test** by keeping some elements (the 'variables') the same while changing other variables. We then perform the experiment and we keep a note of our **results**.

Next, we need to compare our results with our hypothesis. If we have proved that the hypothesis is correct, we write a **conclusion**. If the hypothesis has been proved to be incorrect, we need to go back and try out another hypothesis.

b. How to formulate a hypothesis

A hypothesis is our **best guess** at the answer to the question that we are investigating. It does not have to be correct but must be a statement that can be tested using an experiment. Formulating a testable hypothesis is one of the most important steps in an investigation.

You can tell if a hypothesis is a good hypothesis if you can think of a way of testing it using an experiment, and if the results of your experiment will clearly be able to prove the hypothesis true or false.

Examples of good hypotheses

- Salt dissolves more quickly in hot water than in cold water.
- A grass roof will keep a house cooler on a hot day than a metal roof.
- Small grains of sugar will dissolve more quickly than large grains.
- In cold water, washing powder X can clean mud from a cloth better than washing powder Y.
- Black cloth is a better absorber of radiation energy than white cloth.

c. How to design a good experiment

When designing an experiment, it is important that you use a **fair test**. What this means is that if you are testing the effect of one factor, all the other variables should be kept the same. These are called **controlled variables**. See **Appendix 4** for Practice Exercises.

For example, you want to design an experiment to test the hypothesis "Black cloth is a better absorber of radiation energy than yellow and white cloth".

To test this hypothesis, you could do the following experiment:

1. Take three bottles of the same size, made of the same material.
2. Fill them with the same amount of tap water.
3. Measure the starting temperature.
4. Wrap one of the bottles in a black cloth, one in a yellow cloth and one in a white cloth.
5. Place all three of the bottles an equal distance from a lamp, or in the sunlight.
6. After a fixed amount of time, measure the temperature in each bottle.

The **controlled variables** in this experiment are the type of bottle, the amount of water, the starting temperature, the amount of radiation energy, the type of material and the amount of time.

The **measured variable**, i.e. the variable that is being changed in the experiment, is the colour of the material on the outside of the bottle.

C.7. ENCOURAGING HIGHER-ORDER THINKING SKILLS

One of the skills learners need when answering science questions is the ability to solve problems. In our analysis of the TIMSS results, Table 3 showed that South African learners performed better in the 'knowing' items, but less well in the 'applying' and 'reasoning' questions. This tells us that we need to strengthen developing learners' higher-order reasoning and their ability to solve problems.

C.7.1. Useful steps in problem-solving

When solving a problem in science, the solution will not always be obvious straight away. It is therefore useful to have a strategy that you follow that will help you tackle a difficult problem. The list of steps below describes some possible strategies:

1. Draw a diagram of the scenario if one hasn't been provided or spend time understanding the diagram that has been given.
2. Write a list of the information that has been given in the question.
3. Read the question carefully to decide exactly what is being asked.
4. Reflect on which aspect of science this question links to and remember the main concepts.
5. Apply the concepts to the problem and try to find a solution.
6. Reflect on your answer, making sure that your solution is sensible and that you have answered the question identified in Step 3.

Let's look at some examples of how these strategies could be applied in answering some of the 'applying' and 'reasoning' TIMSS questions. Practice exercises can be found in **Appendix 5.**

Metacognition: Reflecting on your thinking

Many learners might be able to answer a question correctly, but when you ask them how they got there, they might not know, and probably think that they just "knew" the answer (Adey & Serret, 2010). The ability to understand how we get to a correct answer is an important higher-order thinking skill, since it allows us to reflect on our knowledge and approach so that we can apply the same strategy to another problem or adapt our strategy if needed. Metacognition also allows us to reflect on our misconceptions. During informal assessments, it is helpful to not only assess whether learners get the right answer, but to ask them to explain the reasoning that they used to get to the answer. This will allow you to see if their reasoning is conceptually correct and will help them to develop their higher-order thinking capacity.

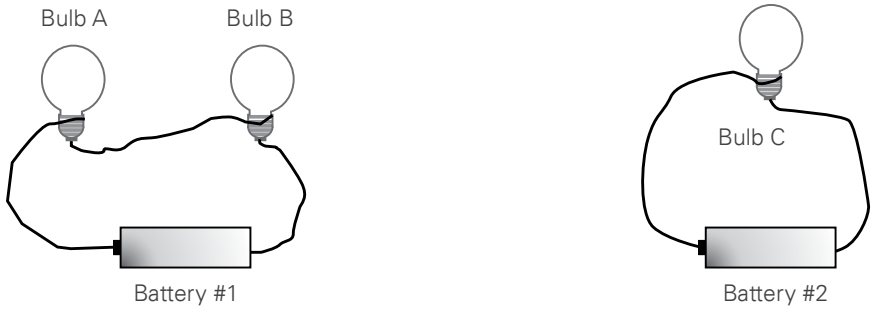
Reflection Activity 1

Encourage your learners to reflect on the thinking that they did to answer the practice examples in **Appendix 4** and **5**. Ask them to explain their reasoning to other learners in their group.

Reflection Activity 2

Sometimes learners may give a correct answer, but when asked to explain their reasoning it becomes clear that they have misconceptions. Here is an example of a typical problem with electricity.

Study the two series circuits shown in the diagram below (the circuits are made with identical light bulbs and batteries).



a. How does the brightness of bulb C compare to the brightness of bulbs A and B?
Answer: bulb C will be brighter than bulbs A and B.

b. If the brightness tells us about the current in each bulb, place bulbs A, B and C in order from greatest to least current.
Answer: current in bulb C > current in bulb A = current in bulb B.

c. Explain how you got to your answer.
Learners may say that the current from the battery is split between bulbs A and B, so they get half the current that bulb C gets. This is a misconception that you can only pick up when they explain their reasoning.

The correct explanation is: in a series circuit current does not split or divide, meaning that the same current flows everywhere in the circuit. The reason that bulbs A and B are dimmer than bulb C is that the resistance in the first circuit is greater than the resistance in the second circuit, so less current can flow in the first circuit. The greater the resistance in a series circuit, the lower the amount of current in that circuit.

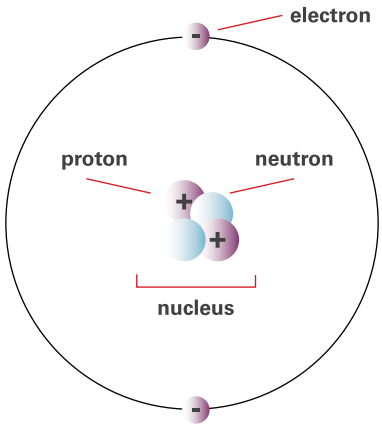
C.8. CONTENT AREAS THAT NEED STRENGTHENING

The results show that most South African learners had limited knowledge about the topics tested in the TIMSS restricted use items. **Figure 1** and **Figure 2** showed that the main areas of weakness, in both Physics and Chemistry questions, were (i) Atoms and subatomic particles, and (ii) The structure and arrangement of particles.

C.8.1. Atoms and subatomic particles

ITEM 21 (page 49) relates to the structure of atoms. Although the question is straightforward, without long sentences or difficult images, only 28 percent of South African learners answered correctly, which was lower than the international average of 49 percent. This shows that South African learners do not have a good understanding of the structure of the atom or the names of the subatomic particles.

How can we help learners understand the structure of the atom?
In Grade 8, learners are introduced to the concept of the atom, which is the basic building block of matter. Refer to your textbooks to revise the following terms: element, subatomic particles (protons, neutrons and electrons), nucleus. The diagram on the right illustrates the structure of a helium atom, showing the positions of the two protons, two neutrons and two electrons. You will find practice activities in **Appendix 6**.



Structure of a helium atom

C.8.2. The particle model of matter

The following TIMSS test items relate to the particle model of matter.

ITEM 27 (page 60): South African learners performed poorly on this question, with only 11 percent answering correctly. Learners should have studied the particle nature of matter in Grade 8, and the spacing between particles

in solids, liquids and gases. This shows that most South African learners are unable to explain the spacing between particles in different substances.

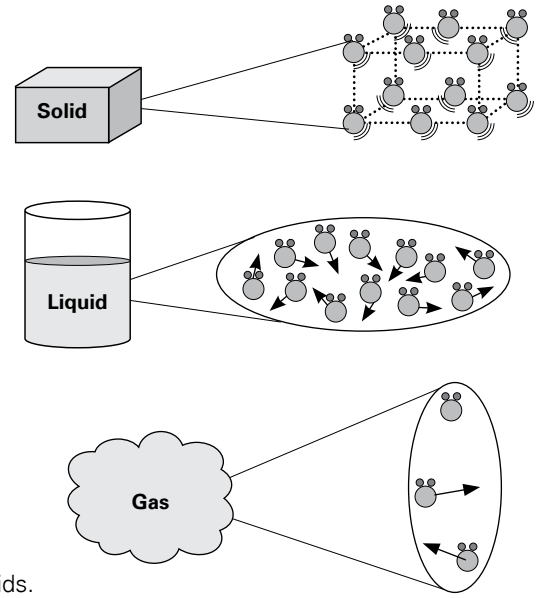
ITEM 11 (page 29): Learners' preference for Option C shows that they had the misconception that the actual sizes of the gas molecules increase with heat, rather than the space between them. This shows that the majority of South African learners do not understand the behaviour of particles in gases.

The particle model of matter is an abstract topic, since particles are not visible to the naked eye, and learners need strong support to understand this topic.

How can we help learners understand the particle model of matter?

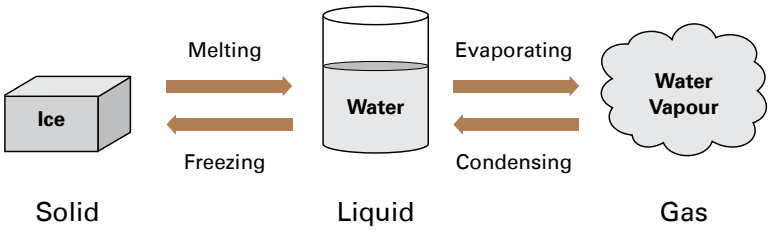
In the particle model of matter, all atoms and molecules are referred to as particles. The particle model of matter is a scientific theory that states the following:

- All matter (solids, liquids and gases) is made up of particles.
- These particles are too small to see.
- The spaces between the particles are completely empty (they don't even contain air!).
- The particles are arranged differently in a solid, a liquid and a gas.
- In a solid, the particles:
  - are closely packed in a regular arrangement;
  - do not move around but vibrate against each other;
  - have strong forces holding them together;
  - have small spaces between them.
- In a liquid, the particles:
  - are loosely arranged but still quite close together;
  - can move quite fast and slide past each other;
  - have weaker forces between them;
  - have small spaces between them.
- In a gas, the particles:
  - have no particular arrangement;
  - move very fast;
  - have extremely weak forces between them;
  - have very big spaces between them compared to solids and liquids.



The effect of heat on particles

- When a solid material is heated, the movement of the particles increases.
- When the particles have gained enough heat to move quickly enough, they begin to move past each other and form a liquid (melting).
- When the liquid is heated further, the temperature of the liquid particles increases, and they move more quickly.
- With further heating, the material changes from a liquid to a gas state (evaporation) and the particles move much further apart from each other.
- When a gas is cooled, the reverse process happens: the gas first changes to a liquid (condensing) and then changes to a solid (freezing or solidifying) when it is cooled further.
- These processes are illustrated in the following concept diagram:



Expansion and contraction of materials

When solids, liquids and gases are heated, they tend to expand. This is because, as the material is heated, the movement of the particles increases and they move further apart. When the material is cooled, the movement of the particles decreases and they move closer together, causing the material to contract. When a material expands or contracts, the **size and number of particles do not change**. Rather, the **spaces between the particles get bigger or smaller**.

Activities to enhance the concepts

To give your learners a chance to become familiar with these terms and concepts, you should give them activities to do where they are actively engaged with these ideas. Here are some examples. Further practice exercises can be found in **Appendix 7.**

1. Draw a table like the one below and fill in the characteristics of particles for solids, liquids and gases.

	Solids	Liquids	Gases
Arrangement of the particles			
Movement of the particles			
Space between the particles			
Forces between the particles			

2. Shade one circle in each row to show which state of matter satisfies the description

	Solids	Liquids	Gases
a. This state has the most closely packed particles	Ⓐ	Ⓑ	Ⓒ
b. This state has the most empty space between its particles	Ⓐ	Ⓑ	Ⓒ
c. The particles cannot move past each other in this state	Ⓐ	Ⓑ	Ⓒ
d. This state is formed when the particles of a solid start to move past each other	Ⓐ	Ⓑ	Ⓒ
e. This state condenses to form a liquid	Ⓐ	Ⓑ	Ⓒ
f. This state can be compressed the most	Ⓐ	Ⓑ	Ⓒ

Correct answers: *A; C; A; B; C; C*

Practical activities to enhance understanding of the particle model of matter

One of the most powerful ways of helping your learners to understand and remember what they learn in science is to allow them to do practical, hands-on activities. Two further activities can be found in **Appendix 8.**

Activity 1 – Observing the movement of water particles

You will need

Hot water, cold water, two glass beakers, food colouring

1. Pour hot water into one of your glass containers.
2. Pour cold water into the second glass container.
3. Add a few drops of food colouring to each container.
4. The movement of the food colouring tells you about the movement of the particles of liquid. What can you conclude about the movement of particles in hot water compared to cold water?

Activity 2 – Compressing solids, liquids and gases

You will need

Two plastic bottles, a solid object, some water

1. Fill one of your bottles with water, so that the water level is at the top of the bottle, and seal it tightly.
2. Seal your other bottle while it is "empty". Can we really say that it is empty? Discuss your ideas in your group.
3. Try squeezing your solid object. How much can you compress it?
4. Now try squeezing the bottle filled with liquid. How much can you compress it?
5. Lastly, try squeezing the bottle filled with air. How much can you compress it?
6. From your observations, what is the difference between solids, liquids and gases?
7. Explain your observations using the particle model of matter.

CONCLUDING REMARKS

You are probably thinking "This is all too much. I have to get through the curriculum and I can't add more activities." Try to incorporate the activities suggested here as part of your regular teaching. For example:

- When you introduce a new topic, use the ideas for talking about science.
- When you read the textbook or some notes, include an activity requiring directed reading.
- When you do an experiment, incorporate activities related to writing a good hypothesis, conducting a fair test and writing a report using a writing frame.
- Include problem-solving activities wherever the opportunity arises.
- Construct diagrams to capture the main points of a complex idea.
- Encourage higher-order thinking when it is appropriate to do so.

We encourage you to especially focus on developing your learners' language skills by talking, reading and writing about science. Science is a language-intensive subject, so a strong grasp of the language of instruction is essential to understanding scientific terms and concepts.

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APPENDIX 1:
Illustrating active reading

We use **ITEM 22** (page 50) to illustrate active reading.

1. Underline the scientific words in the question. Look up the meaning if you don't know what a word means.
2. Complete the table below using information from the text and the diagram. Refer to your textbook if you need more information.

Element	Number of protons	Atomic number
Hydrogen (H)	1	1
		2
		3
Phosphorus (P)		
Oxygen (O)		

APPENDIX 2:
Examples of how to read and interpret test questions

ITEM 25 (page 56) has a lot of reading and a diagram to comprehend. We can use directed questions to help learners navigate through the text.

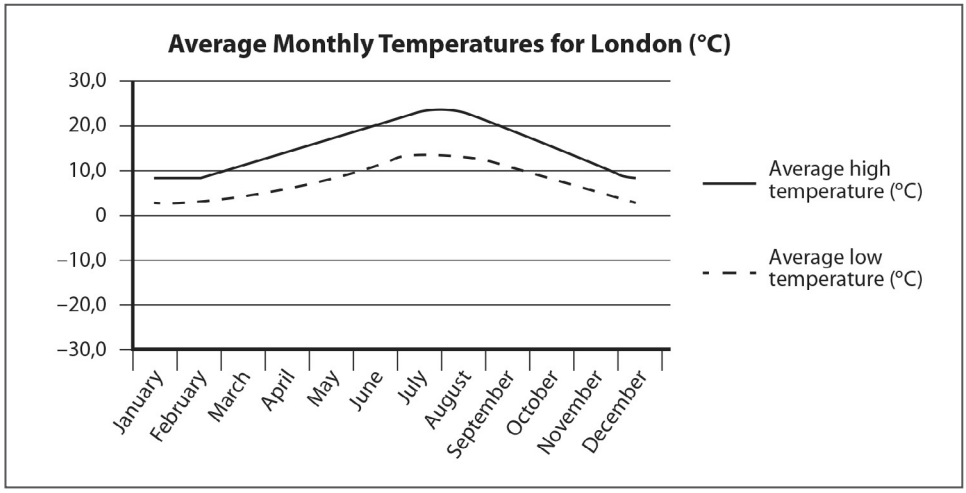
1. What is this question about?
   (A: *It describes an experiment*)
   1.1. What is the aim of Tom's investigation?
   (A: *Tom wants to find out whether iron conducts heat better than copper*)
   1.2. How did he set up the experiment?
   (A: *He used wax to attach one paperclip to an iron rod and another paperclip to a copper rod*)
   1.3. What did he do next?
   (A: *He heated each rod until the wax melted and the paperclip fell off*)
   1.4. What did he measure?
   (A: *How much time it takes for each paperclip to fall off its rod*)
   1.5 What does the image show?
   (A: *It shows the metal rod with the paperclip attached with wax. It shows a flame heating one end of the metal rod*)
2. What is the question I must answer?
   (A: *How should Tom design his experiment?*)
3. What must I do to answer the question?
   (A: *Shade one circle in each row to show the things Tom should do to make sure*)

ITEM 20 (page 47) is another example.

1. What is this question about?
   (A: *It is about the classification of animals*)
2. What is/are the questions I must answer?
   (A: *For part A, I must classify the animals into mammals and non-mammals. For part B, I must work out what distinguishing characteristic was used to classify the animals into Group 1 and Group 2*)
3. What must I do to answer the question?
   (A: *For part A, I must write the names of the mammals in the left column and the names of the non-mammals in the right column. For part B, I must name a characteristic*)

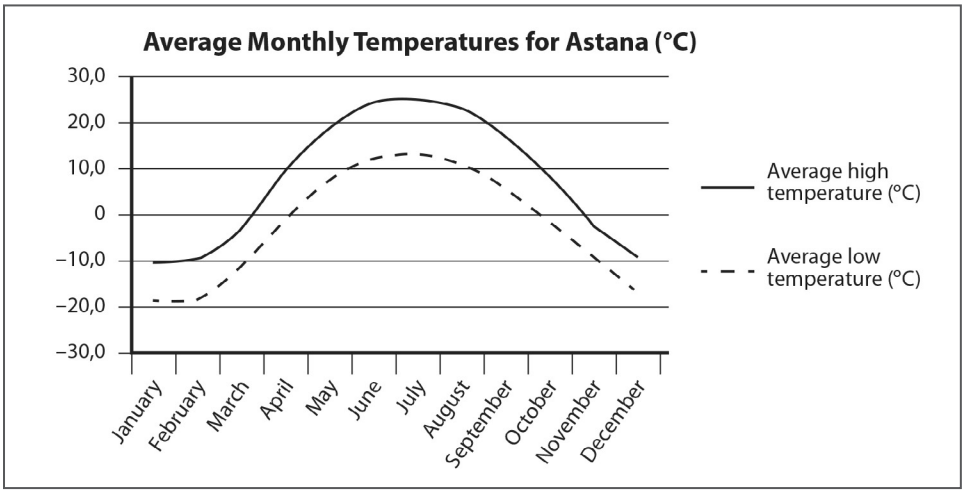
APPENDIX 3:
Practice exercise on understanding line graphs

Ask your learners to study the graph of average monthly temperatures for London and answer the questions that follow **ITEM 28** (page 62).



1. For the London graph, look at the number labels of the y-axis (the vertical axis) – what does this axis tell you?
   Answer: *This axis tells us the range in temperatures, from -30°C to +30°C.*
2. Look at the label of the horizontal axis (at the bottom of the graph) – what does this axis tell you?
   Answer: *This axis tells us the months of the year, starting with January.*
3. If the graph has a key explaining what the different lines mean, what does this key tell you?
   Answer: *The solid line tells us the average high temperature, and the dotted line tells us the average low temperature.*
4. Explain the meaning of the graph in your own words.
   Answers:
   - *This graph tells us that the London temperatures are lowest during January and December, and highest during June, July and August.*
   - *London has a maximum average high temperature of about 24°C and a maximum average low temperature of about 14°C.*
   - *London has a minimum average high temperature of about 9°C and a minimum average low temperature of about 2°C.*
   - *London has its summer around June–August, and its winter around December–January.*
   - *The average temperatures in London range from 2°C to 24°C.*

5. Now study the graph of average monthly temperatures for Astana and answer the questions that follow.



Explain the meaning of this graph in your own words.

Answers:

- *This graph tells us that the Astana temperatures are lowest during January and December, and highest during June, July and August.*
- *Astana has a maximum average high temperature of about 25°C and a maximum average low temperature of about 12°C.*
- *Astana has a minimum average high temperature of about -10°C and a minimum average low temperature of about -19°C.*
- *Astana has its summer around June–August, and its winter around December–January.*
- *The average temperatures in Astana range from -19°C to 25°C.*

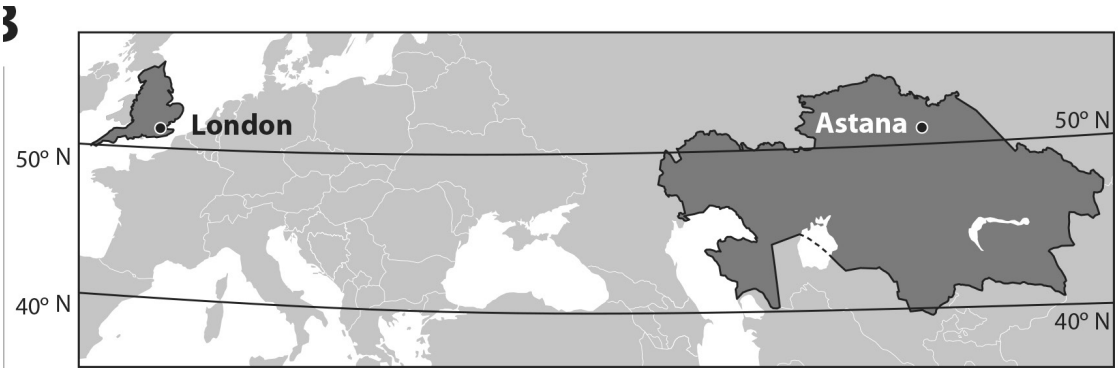
6. Now discuss the answer to the question for these graphs from the TIMSS test:

A. Shade one circle to answer each of the following questions.
(Shade one circle in each row.)

	London	Astana
Which city is warmer in March?	A	B
Which city is cooler in October?	A	B
Which city is warmer from December to February?	A	B
Which city has a larger range in average temperature?	A	B

Answer: *The correct answers are A, B, A and B.*

Now study the map below and answer the questions that follow.



7. What does this map tell you about the geography of London and Astana? Discuss your ideas in a group.

   Answer:

   - *This map tells us that Astana and London have the same latitude (neither one is further North than the other).*
   - *Astana is surrounded by land, whereas London is near the ocean.*

8. Now discuss the answer to the question for this map, and the above two graphs, from the TIMSS test:

> B. What about the geographies of the cities explains the differences in their climates throughout the year?
>
> A. London's climate is less variable because it is near the ocean.
> B. London's climate is less variable because it is further west than Astana.
> C. Astana's climate is warmer in the summer because it receives warm ocean breezes.
> D. Astana's climate is colder in the winter because it is further north than London.

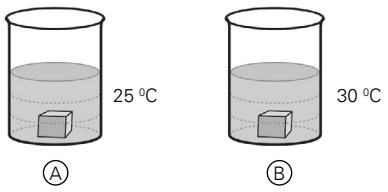
Answer: *The correct answer is A.*

APPENDIX 4:
Practice exercises on designing good experiments

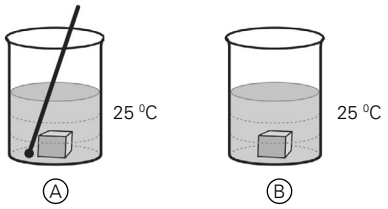
As an activity, you could ask your learners to answer the following questions in groups. Possible answers are shown in italics.

Look at the following three experiments with dissolving sugar. These diagrams are taken from the Grade 5 TIMSS test ITEM 9B (Dempster et al., 2022):

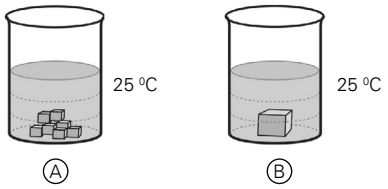
1. Test 1
Different temperatures



2. Test 2
One stirred



3. Test 2
Different cube sizes



In addition to keeping the amount of water the same for all the experiments, name one other variable that must be controlled to make each test a fair test?

Test 1: _____

(Answer: *size / mass / surface area of the sugar cube; amount of stirring — none of them are stirred OR all of them are stirred)*

Test 2: _____

(Answer: *size / mass / surface area of the sugar cube; temperature of the water)*

Test 3: _____

(Answer: *temperature of the water; amount of stirring — none of them are stirred OR all of them are stirred)*

APPENDIX 5:
Practice exercises using problem-solving

There is not just one way of applying the problem-solving steps to these problems, so allow your learners to explore this in an open-ended way.

ITEM 5 (page 18): The following is an example of the kind of reasoning they could do.

1. Spend time understanding the diagrams that have been given. Notice that the two diagrams given in the question show the arrangement of the atoms/ molecules of Substance 1 and Substance 2.
   For Substance 1, the atoms are represented by four black circles.
   The diagram for Substance 2 shows four molecules, each consisting of two atoms (represented by white circles) that are joined together.

2. Information that has been given in the question: The diagram of Rowan's model tells us that, for every four atoms in Substance 1 there are four molecules in Substance 2, each of which consists of two atoms. We are also told that there is a chemical reaction between Substance 1 and Substance 2.

3. The question is asking us to identify the correct illustration for the results of the chemical reaction.

4. This question links to representing chemical change, and the balancing of chemical equations. So we need to count the number of atoms in the reactants (Substance 1 and Substance 2) and ensure that there is the same number of each kind of atom in the diagram of the results of the reaction.

5. Applying this idea, the correct answer should be D.

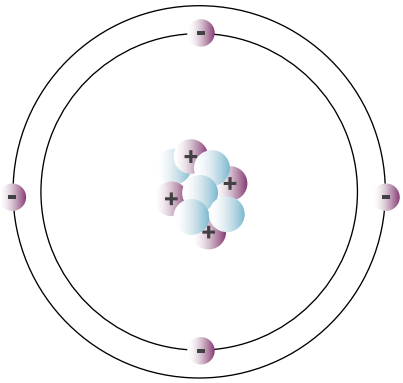
6. Answer D makes sense because there are four atoms represented by black circles and eight represented by white circles, so the chemical reaction is balanced.
   This is also true for answer C, but no chemical reaction has taken place in the case of answer C, since the atoms have not been rearranged. Answer C represents a mixture, not a chemical reaction.

APPENDIX 6:
Practice activities on atoms and subatomic particles

The concepts of the atom and subatomic particles are difficult for learners to understand because they are too small for us to see. The most helpful way for them to become familiar with these concepts is through practicing their knowledge of the terms and concepts. Here are some activities you could use:

Activity – The structure of the atom

Test your understanding of the structure of the atom by answering the following questions:

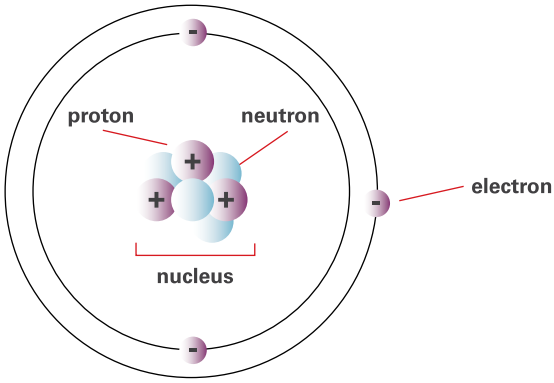


Structure of a beryllium atom

1. Hydrogen has 1 proton in its nucleus and no neutrons.
   How many electrons does a hydrogen atom have?
   Answer: *1*

2. The diagram on the right shows the structure of a beryllium atom.
   How many protons, electrons and neutrons does a beryllium atom have?
   Answer: *protons = 4, electrons = 4, and neutrons = 5*

3. Lithium has 3 protons and 4 neutrons. Draw the structure of a lithium atom. Use labels to show the following: protons, neutrons, electrons and the nucleus.
   The answer is shown in the diagram



Structure of a lithium atom

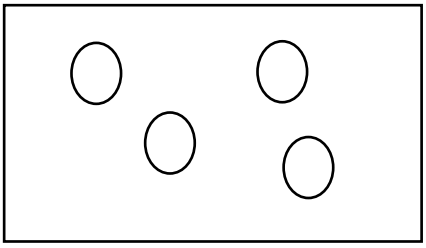
ITEM 27 (page 60):

Learners can explain the differences in compressibility in the solid and air-filled syringes by describing the particle arrangement of the solid and gas states correctly or representing their explanation with a drawing, referring to spaces between the particles.

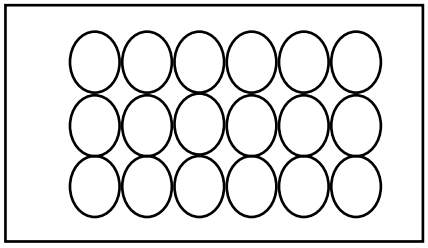
For example:

- Solid particles are closely packed, so they cannot compress very much, but gas particles are further apart and can compress easier.
- In a solid, the particles are close together, so there is no room for them to compress. In air, the particles are farther apart so there is room to compress them.

Example of correct drawings:



Gas

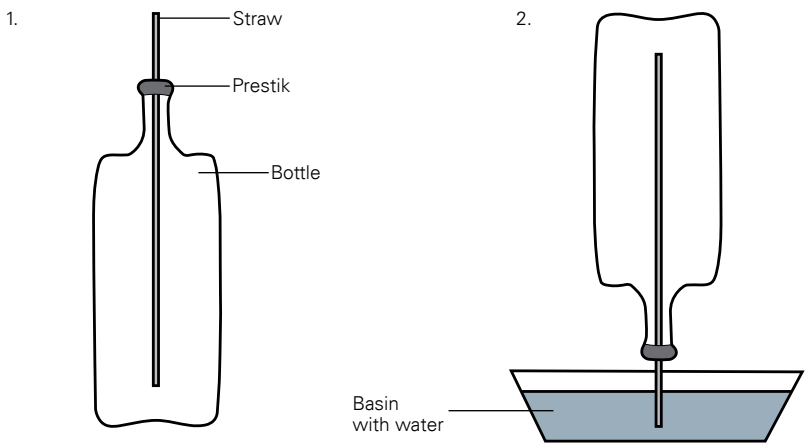


Solid

APPENDIX 8:
Activities on the particle model of matter

Activity 3 – The effect of heat on gases

You will need:
A bottle, a straw, some Prestik, two cloths, a glass jar, or basin filled with coloured water, a container with warm water, and a container with cold water.



Experimental steps:

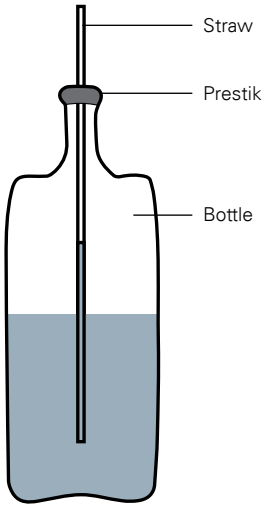
1. Using the Prestik, insert your straw into your bottle so that the straw sticks out of the bottle a little way. Use the Prestik to make sure the straw is firmly sealed in place.
2. Fill a glass jar or basin with some tap water, and add food colouring to this water. Turn the bottle upside-down so that the straw is in the water in the bowl, as the picture shows.
3. Dip a cloth into warm water and wrap this around your bottle. Carefully observe what happens.
4. Now dip your cloth into cold water and wrap it around your bottle (be sure to keep the bottle upside-down so that the straw stays in the water in the bowl). Carefully observe what happens.
5. What differences did you notice between the warm cloth and the cold cloth wrapped around your bottle?
6. What do you think caused this difference? Discuss your ideas in your group.

Discussion on the activity:

In this activity, learners should have seen bubbles forming in the liquid when they placed the warm cloth over the bottle. This shows that the gas in the bottle expanded and formed bubbles as it escaped through the water. When they placed the cool cloth over the bottle, they would have seen the coloured water rising in the straw, showing that the gas in the bottle had contracted and therefore sucked in some water. From this, we can conclude that when a gas is heated it expands, and when it is cooled it contracts.

Activity 4 – The effects of heat on liquids

You will need:
A glass jar, a straw, a marking pen, Prestik, coloured tap water, warm water and cold water.



Experimental steps:

1. Fill your bottle with coloured water and then, using the Prestik, insert your straw into your bottle so that the straw sticks out of the bottle. Make sure that some of the water is about halfway up the straw, and mark this water position using a marking pen. Use the Prestik to make sure the straw is firmly sealed in place.
2. Fill a bowl with some warm water, and stand your bottle in this warm water. What do you notice about the level of the water in your straw?
3. Now fill a bowl with some cold water, and stand your bottle in this cold water. What do you notice about the level of the water in your straw?
4. What do you think is happening? Discuss your ideas in your group.

Discussion on the activity:

In this activity, learners would have noticed the following:

- When water is heated, it expands. We can make this conclusion because we saw the water level in the straw rising when the bottle was placed in a basin with hot water.
- When water is cooled, it contracts (note that this is only true when it is cooled down to about 4°C, below which it expands again). We can make this conclusion because we saw the water level in the straw dropping when the bottle was placed in a basin with cold water.

NOTES

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