Content Map for Natural Sciences in the GET band

Layer 3

Reasons for allocation to Grades, detail on concepts, research on learning, examples of activities

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Introduction to Layer 3

In this Layer, the reader can "drill down" to the concepts in each topic and see what is involved in understanding them. For each topic, there is

- a justification for placing it in its particular Grade,
- a discussion of the level at which the learners should understand the concepts,
- a section on research on learning and teaching these concepts, including misconceptions and common problems of understanding difficult ideas and problems of language.
- a section with examples of activities that develop process skills and produce evidence of outcomes.

We begin with four statements about principles that have been used to allocate the content to Grades.

1 Inputs are not outcomes

Outcomes are what the **learners** produce with the inputs that the teacher makes. Inputs are all the actions that a teacher and a school organise to bring about learning; in our classroom setting, inputs are most often presentations of content. Good presentations of content are important; after a good presentation one can easily feel that the job of teaching has been mostly done. It's easy then to lose sight of the outcomes the **learners** should have produced. In fact the teaching is not done until the learners are producing outcomes using the inputs.

In selecting content, we need to remember that the outcomes children can produce usually depend on the topic. For example, if we choose a topic, a piece of content, for Grade 5, do we want the learners to **recall** this content, **interpret** information about it, **apply** it in a slightly unfamiliar situation, **suggest questions** about it to **investigate**, make **predictions** about it, discuss its **impacts** on people's lives? All these outputs by learners are parts of the Learning Outcomes. So in selecting content, the question is not "Do we enjoy presenting it?" but "Can they learn it meaningfully?" and "Can they produce outcomes with it?"

They won't produce worthwhile outcomes with a topic if the concepts in it demand a kind of thinking that they are not yet ready to do, so we don't have a completely free hand in what we choose for each Grade. We have to know quite a lot about the concepts in the topic but also we need to know about the learners and the kind of thinking they can do.

2 The "use it or lose it" principle in content

This is the principle that teachers introduce some content only if the learners are going to apply that content soon after it is introduced. If learners learn something but have no need to apply it soon after, they lose most of their learning.

This principle can be illustrated with a negative example: in the old 1975 and 1982 General Science syllabuses, Grade 7 learners spent the first term on the topic of *Measurement*. Learners were supposed to practice reading scales on measuring instruments to measure length, volume, mass, temperature, diameter, and so on. It needed expensive apparatus including fragile glass burettes and pipettes, and obtaining them became a big task, often unsuccessful and distressing. However, during the rest of Grade 7 they almost never needed to measure anything. In Grade 7 this was content for its own sake, because only in Grade 11 and 12 did the practical work require accurate measurements.

Grade 8 learners had to memorise a set of chemical reactions and their products, such as the reaction when sodium hydrogen carbonate $NaHCO_3$ was heated (it gives off CO_2). Later on, the syllabus required the properties of hydrogen, oxygen and carbon dioxide. Again, these properties were rote-learned because the learners did not need to use the knowledge for anything. Their rote knowledge did not lead them anywhere. But if the gas properties had been done first, then the learners could have **investigated** various chemical reactions, **applying** their knowledge of various gases to **identify** the gases produced.

Across the Grades, a similar principle applies. By selecting content with careful regard to its application, we make the curriculum meaningful because learners are soon going to use what they have learned in order to learn something more.

However, in order to leave learners enough time to think about new concepts and apply them, we should not have too many topics in a year. This applies particularly to the Planet Earth and Beyond strand with its three sub-strands. In some schools, the work schedule moves the learners from lessons with *Weather and atmosphere* to lessons with *The changing Earth* to lessons with *Our place in Space*, **all within a total of eight weeks**. This tourist-guide approach to teaching new ideas does not give learners time to do activities, think about the concepts and use the new vocabulary. A learner from a school in New Zealand says it best:

> *You just start to get to know what you're talking about and they* [the teachers] *change* [the topic] *. . . you forget everything that you know . . . in the end you do not know what you are doing.*

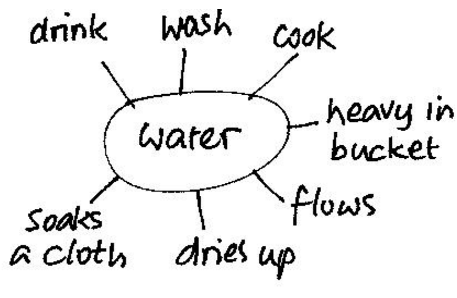
(In Bell and Freyberg, 1985)

3 The word for the concept is not the concept

Teachers often say that language is a major barrier to success in science when the language of instruction is not their learners' mother-tongue. This barrier is real, but this is not the whole problem: mother-tongue learners also face difficulties with science language, as the work of Cassels and Johnstone (1978) showed. They tested large numbers of Scottish and Australian children around Grade 8, all of whom were taking science. They found that alarming percentages of these learners did not understand the meaning of mother-tongue words like "average", "correspond" and "negative". So the problems in understanding science may lie deeper than the language of instruction, and it seems to lie in the ways that teachers use language. The message is that teaching learners the word for a concept is not the same as teaching them the concept.

A concept is an idea which organises and summarises a lot of facts and experiences; each concept has a word to **represent** it. To take a specific example, a child will have experiences of water: it is a substance she drinks, or washes in, or plays with. Water can be cold (and refreshing), or warm (and pleasant), or hot (and dangerous). She will also know some facts about water: it will flow and spread out on the floor if she spills it. A bucket full of water is heavy and tiring to carry. Water from the river might make her sick unless it is treated with bleach. Water can make a cloth wet but the cloth becomes dry again. By the time she starts school, all these facts and experiences are linked to the word "water" in her mind. If we sat and talked with her for a time, she would unpack these meanings, these facts and experiences for us. For her, the word "water" is like a label on a package full of meanings. The package is the facts she knows and the experiences she has had. And of course, her friend may have had different experiences of water, know different facts and have different meanings in his package, but it is also labelled “water”. This kind of concept we can call a primary concept because she can see, feel and taste water.

Figure 1 *“Water” is a like a label on this child’s package of personal meanings.(Her meanings may differ from those in another child’s package which also has the label “water”.)*

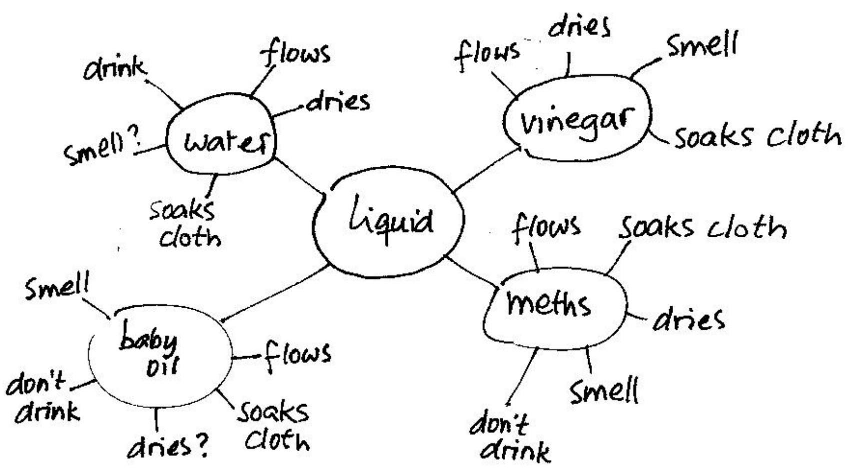


As she goes through school she will encounter another concept such as “liquid” which she can’t experience directly but which depends on primary concepts like “water”.

She learns that liquid is a name for a **class** of substances like water. The concept “liquid” is more powerful than the concept “water” because it links the meanings of many other concepts such as oil, paraffin, meths, vinegar and mercury. The meaning of “liquid” depends on her knowing the meanings of “paraffin”, “oil”, and so on. Her teacher must give her experiences of these substances, so that she can extract the understanding “**all** these things are liquids, because they all have some properties in common. They all flow, take the shape of their container, soak through cloths, dry up . . .”

This kind of concept, like “liquid”, which organises primary concepts, is called a **secondary** concept. (Other examples of secondary concepts are habitat, materials, energy, current, seasons, mixture, because they depend on a number of primary concepts.) We can represent the concept of “liquid” in another diagram, in **Figure 2**.

Figure 2 *The concept “liquid” links together a number of other concepts of specific substances in this way.*



All these substances that belong to the class called “liquids” can flow, will take up the shape of their containers, will soak through a cloth, and will dry up if we leave them long enough. If she has the concept “liquid”, and she hears about acetone, a liquid she has never seen before, she will be able to make some sensible guesses as to the properties of acetone. Acetone is not just another bit of new information, she can make sense of it because she already has an organiser, which is the concept “liquid”.

Let’s sum up what we have thus far:

- The word for a concept works like a label on a package of meanings. The meanings may be different for different people, and depend on the experiences they have had.

- A concept becomes a powerful thinking tool because it reduces the amount of memorisation that we have to do. Knowing the concept (e.g. “a liquid”), we can go to the appropriate mental package, open it and use the set of connections we have built up there (e.g. “Liquids all flow, ...).
- A concept provides a way of making sense of new information. Because a concept has connections and links, we can often take new information and fit it into what we already know.

What does this mean for conceptual development in lessons?

- We have to provide learners with experiences and examples of the important concepts we want them to use.
- We do not assume that learners already have the concepts we want them to use; instead we get ready to build those concepts.
- We must assume that the learners do have their own ideas and meanings already, based on their life experience and on partly-understood words
- We must build the language they need for talking about the concepts
- We remember that even if all the learners and the teacher seem to know the correct **word** for a concept, the **meanings** of that word may be different for each of them.

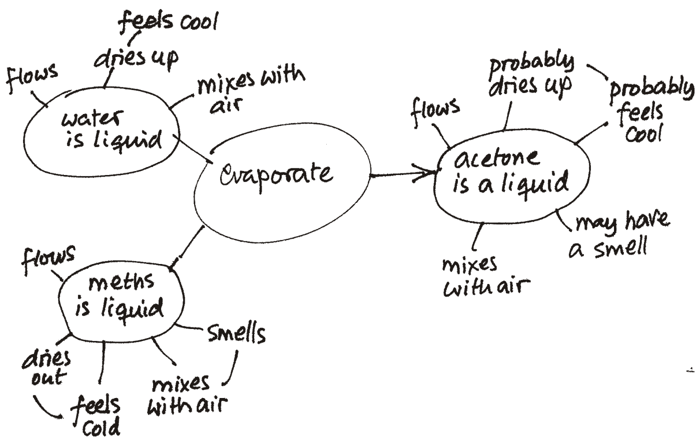
Let’s say that Annie’s teacher wants the class to use the concept “evaporation”. The teacher does not begin by giving them a definition of the word, because then Annie would be getting only the **label** for the concept, not the concept. Instead, her teacher lets the children look at wet cloths drying, and each day they look at the water level in a basin getting lower.

He asks them to think about the questions, “Does the water still exist somewhere?” and “if so, where has it gone?” and “What if we put a clear glass jar over the wet cloth? Could we perhaps see whether the water still exists?” He asks them to draw pictures of how they imagine the water leaving the wet cloth and then appearing on the glass jar.

When the children have discussed the question and drawn pictures, he also builds the language for talking about this. He introduces the word “vapour” and perhaps links it to their experiences of breathing the vapours of Vicks Vaporub™. Then he links this word “vapour” to the new word “evaporate”.

But this is still not enough to build the concept “evaporation” as a useful thinking tool – it becomes useful when they know that **all** liquids evaporate, not only water. So the children must use the concept of evaporation in new situations. The teacher also introduces other liquids such as methylated spirits. He ensures that the children see, smell, feel and talk about methylated spirits evaporating, to extend their concept of evaporation. He asks them whether other liquids they know could also evaporate. The teacher gives the children a range of experiences in which they see that this concept “evaporation” is a useful thinking tool, because it applies to other liquids and not only to water. Now he shows the class a bottle of a new and unfamiliar liquid called acetone and asks them what they think it is like. Annie knows several other specific liquids and she has the secondary concepts of “liquid” and “evaporation”. She can use these concepts to make some good guesses about this new and unfamiliar liquid. **Figure 3** shows this in a diagram.

Figure 3 *A new idea like "evaporate" fits into a set of concepts she already has.*



Her concepts of "liquid" and "evaporate" have become powerful thinking tools, because she can **predict the meaning of new words** like "acetone".

When a learner has a good grasp of some important basic concepts, she can **make more connections between ideas for herself** and extend her framework of concepts. This is meaningful learning.

The teacher began by working from **facts** which are based in the children's experiences (a wet cloth dries out, and the liquid that was in it seems to disappear), to **concepts** (evaporation) and is aiming for a **generalisation** (such as, "when liquids evaporate, they cool the surface they are on").

Some language concerns in concept development

Some English words that we use to label concepts change their meanings in different contexts, and we have to explain the changes to learners. For example, in lessons about living organisms the word "cell" labels a certain package of meanings, but it labels a completely different package of meanings in lessons about electric circuits. A learner will be quite lost if she has a good package of meanings for "cell" as a part of an organism but the teacher is using the word "cell" with electricity in mind. And of course the teacher needs to make clear that the word is not "sell", a concept in Economic & Management Sciences, because it will sound the same!

In the cartoon that follows we can see what might happen if a teacher is unaware that her learner hears a different meaning to the one she has in mind.

Figure 4 *The teacher gives a definition of a science concept.*

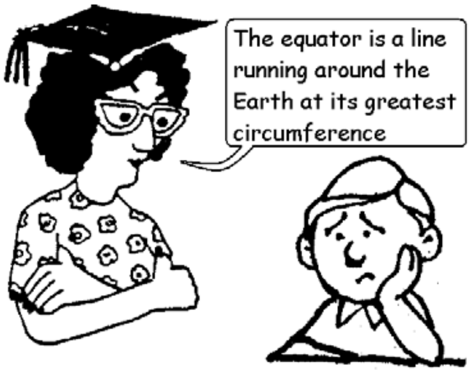
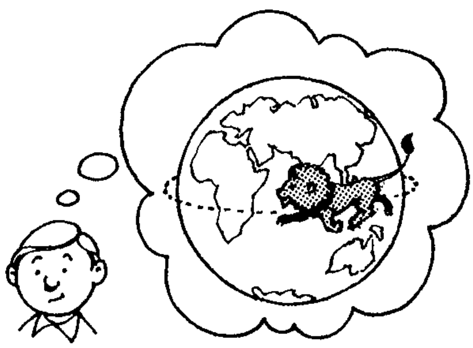


Figure 5*: But her words may call up a quite different picture in the mind of the learner. ..*



In a test, the learner write exactly what he **thinks** the teacher told the class: “The equator is a lion running around the Earth at its greatest circumference.” She reads this and takes off a mark for spelling.

He wonders what was wrong with his answer.

Notice what is happening here: **neither the teacher nor the learner** realise that the other person has a different picture in their mind. **Neither of them** will realise that there is a misconception here, and the learner might carry the misconception along in future lessons.

This is a simple and humorous example, but it is the kind of misunderstanding that happens daily in science lessons.

English has many words that sound the same, like “lion” and “line”, “sell” and “cell”. In speaking to the learners, teachers need to be aware that their learners might be hearing a completely different word to the one the teacher has in mind.

Then there are English words that have the same sound and spelling but their meaning changes, depending on the context. Think of how the meaning of the word “charge” changes if the teacher is talking about electrostatics, or a police matter, or being charged too much for an item, or the war poem, *The Charge of the Light Brigade*, or a charge of dynamite. A learner might go from one teacher’s lesson to another, and hear the same word being used with two completely different meanings – and neither teacher might realise that the learner is confused.

When the teacher and learners speak several languages, the conceptual development work needs even more care by the teacher. Some multilingual teachers use their ability to give learners explanations in different languages, or insert words that learners commonly use into their explanations in the official language of instruction. This is usually called “code-switching”. For example, if learners use the colloquial word *igesi* to refer to electricity, the teacher may include *igesi* in an English or Afrikaans sentence about electricity.

But the teacher might forget that learners also use *igesi* to refer to energy, and that *igesi* sounds very similar to the English word “gas”. This careless use of *igesi* could create a difficulty for the learners later on.

As another example, in some classrooms teachers use the term *ukubila* to refer to a liquid bubbling. Bubbles form in liquids for different reasons: bubbles form in a liquid when it boils, or when fermentation is happening, or when a gas is being generated at an electrode. While boiling is a physical change to a liquid, the other two events are chemical changes. In Xhosa there are some precise ways to describe these different kinds of bubbling but they are not in common use and some teachers use the term *ukubila* to refer to all these phenomena (Xipu, pers. comm. 2009).

In general, code-switching requires expert knowledge of science vocabulary in different languages or it runs the risk of using terms that seem to be equivalent but in fact refer to different phenomena.

4 Learning is more than receiving information - learners need activities that allow them to work with the information to make sense of it

The section above made the point that learners cannot learn science by learning the words of science; they must experience the phenomena (like evaporation), and make links to other experiences or ideas they already have. They make their mental links by interacting with other learners and the teacher as they draw, write and talk about their ideas. Language is the means of bringing ideas into being, of creating the connections.

Forty years of educational research has shown us that what children learn in the classroom depends largely on the ideas they already hold before they come into the classroom. They come in with heads full of experiences, images, and perhaps fuzzy ideas from previous Grades. As the teacher speaks, their minds search for meaning in connections between what they already believe and what the teacher seems to be saying.

It is simply not possible to transfer an idea that is in the teacher's head, unchanged, into the heads of the learners. Learners always try to make sense of it in their own way and in the process the idea is changed. As Piaget stated in 1929,

> *Even that which seems copied* [by the learner] *is in reality deformed and recreated. The words the child uses, for example, are the same as we use, but they have a different meaning, either wider or narrower as the case may be. The associations are different* [even if] *the syntax and style* [are the same as the] *original.*

So now we must see learning as the **learner** making connections between previous ideas and new ideas. Learners must modify, or extend, or elaborate their existing sets of ideas. And each learner must do it for himself or herself. And the kind of talk that happens between learner and learner, and between teacher and learner, is crucial in this.

We must now see teaching as the task of creating opportunities and activities for learners to make connections between their own ideas and the new ideas in the curriculum. To help in creating suitable activities, the NCS for Natural Sciences has a section headed ***Process skills across the three Learning Outcomes*** (DoE, 2002, pages 13 and 14). These mental skills are the way we make meaning in science. They are listed as

Observing and comparing
Measuring
Recording information
Sorting and classifying
Interpreting information
Predicting
Hypothesizing
Raising questions about a situation
Planning science investigations
Conducting science investigations
Communicating science information

Activities that make use of process skills[1] create opportunities for learners to work with the science ideas in many ways that involve talking, writing and drawing, and in this way they create many opportunities for teachers to get diagnostic information about their learners' thinking and other assessment evidence of their progress.

In summary, then,

- Learning in science is a process in which learners must modify (i.e. correct), or extend, or elaborate their existing sets of ideas. Increasingly, learners' ideas must become linked and

[1] The process skills were deliberately built into the Assessment Standards. In most cases, it is impossible to assess learners against the Assessment Standards unless learners are using process skills. But it appears that teachers have not made much use of the process skills as a tool in designing activities in GET.

connected in a logical framework and not remain as isolated bits of information.

- Learners' ideas about the world that they bring to a science lesson can be non-scientific ones. But because these are their own ideas, and seem logical to them, the ideas will have a big influence on how the learners understand or misunderstand new information the teacher provides.
- If the teacher hopes to modify learners' ideas, he or she needs to know something about the typical misconceptions that learners form, and needs to do careful diagnostic assessment to find out what his/her class thinks.

An example - how learners' conceptions of photosynthesis are influenced by teaching

As they move up the Grades in Intermediate Phase, learners should repeatedly meet the idea that plants can make their own food and so plants do not eat other plants. The food they make is often also food for us. Plants use water, energy from the Sun and substances from the air and soil.

By the time learners are in Grade 9, they should have met this idea in all the strands - in *Energy and Change* (plants store energy and we eat plants for energy), in *Matter and Materials* (leaves are where chemical reactions change water and CO_2 to starch and then other materials such as cellulose), in *Life and Living* (animals depend on green plants) and in *Planet Earth and Beyond* (plants maintain the balance of gases in the atmosphere). We could feel that they will move on to FET with a solid basis for understanding the concept "photosynthesis".

But when faced with a diagnostic question, "Where did the wood in a big tree come from?" many FET learners will still say that it must have come from the soil. In their own minds, the science idea is unbelievable – it couldn't be true that the hard wood of a massive tree is made from water and a gas that is only 0.03% of the atmosphere. Therefore they will hang onto their own idea that trees "eat" soil through their roots in some way in order to grow.

Now we have different possible outcomes to teaching:

- some learners conclude that trees grow by eating soil ***and*** by photosynthesis (their conception combines the teacher's idea with their own idea). (Leach and Scott, 2000)
- other learners actually believe that trees grow big by ingesting soil but they know that in an exam they must say plants grow bigger by photosynthesis (and their teacher might give them full marks for their answer, not knowing what they really think).
- finally, there are some learners who really accept that the chemical reactions in photosynthesis do make enough starch to produce the material for a big tree.

To summarise this introduction,

- Inputs are not outcomes – this means that when we select content we want to input, we have to ask ourselves whether the children can produce outcomes with the input.
- Know the difference between a concept and the label for the concept. If children can give us the label it does not mean that they have the concept. Teachers build a concept in children's minds by multiple activities that allow learners to see how the concept is useful in different contexts.
- Therefore a work schedule must plan tasks so that learners use a new concept several times soon after it is introduced. Don't put in too many topics in a term or a year, because then children have

to deal with too many new concepts that are not related. Every topic we put in has its own set of concepts and concept-labels for learners to work through and new language to master.

- Children always re-create our inputs in terms of what they already know — so we have to provide opportunities and activities for them to re-create it in their own ways (talk, draw, write, act out, make models); in doing this they disclose to us what they think after we have taught them.

A framework of pedagogical content knowledge (PCK) for science teaching

In 1986, Lee Shulman proposed a model for understanding the **specialised knowledge of teaching**. In our terms, this is the specialised knowledge of teaching that science teachers have but that scientists do not have. Shulman and colleagues defined a term, "pedagogical content knowledge", or PCK, as the knowledge that teachers develop to teach particular topics so that learners understand those topics Shulman's model has generated a great deal of research in how teachers might become very good teachers. What follows is a selective extract from the literature, and draws on a chapter in the *2007 Yearbook of Science Education* (Abell, 2007).

To be an effective science teacher, a teacher needs both **content** knowledge and **pedagogical** content knowledge.

1 Content knowledge This means that if, for example, the teacher has to teach Natural Sciences, then he or she needs a solid basic education in the main concepts of life sciences, matter and materials, energy, electricity, the structure of the Earth and so on. This education must go far enough to enable the teacher to understand and explain the links between the concepts.

2 Pedagogical content knowledge (PCK) This refers not to general teaching skills but is specific knowledge about how to teach specific natural science topics. It is made up of

- **teachers' knowledge about learners**. This includes knowing about learners' life experiences that relate to Natural Sciences, the games they play and the words they use for things. The knowledge includes knowing how children's thinking develops as they grow, and knowing the ideas that learners will probably bring to the lessons, and the typical misconceptions[2] that they are likely to develop as they try to make sense of the lessons that will follow. It also means knowing which parts of a particular topic are difficult for learners in this particular Grade and knowing where to slow down and check understanding. (The ***Research on teaching and learning this topic***, below, deals with parts of this knowledge, and in many cases the section ***Reasons for placing this topic in Grade X*** draws on such knowledge.)
- **teachers' knowledge of science curriculum**. This includes knowledge about national standards (e.g. the South African NCS policy documents with their Assessment Standards) and knowledge of specific textbooks and other curriculum materials and curriculum programmes that teachers can use. This Content Map document will also become a part of teacher knowledge, as it sets out recommended content and level for each Grade in South African schools.

[2] The term "misconception" refers to the incorrect ideas which learners form about a topic. The term "alternative conception" is also used, but mostly by academics who study the ways people develop ideas. Teachers who face daily difficulties in helping children to understand science ideas tend to prefer the term "misconception".

- **teachers' knowledge of instructional strategies for a particular topic**. This type of teacher knowledge deals with teaching and formative assessment methods such as the use of models and analogies, knowledge of activities that generate good learner involvement, knowledge of investigations that learners usually do well and knowing how to manage specific demonstrations so that learners see the key ideas. (The sections called ***Examples of activities that can develop concepts and language*** point to the need for this kind of teacher expertise.)

The research on PCK (for example, Shulman, 1986) tells us that becoming a good science teacher takes years of professional development, and this is a challenge to the saying "a teacher teaches children, he does not teach a subject." School managements sometimes use this saying to justify moving teachers, almost yearly, from one Learning Area to another. But this lack of continuity ensures that a teacher does not become really competent in teaching any of those Learning Areas. A teacher who is not building his or her own PCK in a Learning Area cannot teach children very much.

Experience in science teaching really is valuable. When we have even the beginnings of it, we need to keep it and nurture it.

Grade 4 topics

> These notes focus on the **science knowledge** in the NCS. But the science knowledge is not the curriculum, and these notes are not a learning programme. The curriculum is about learners using the knowledge to produce outcomes. So these notes are just the basis for learning programmes that build the Assessment Standards for Learning Outcome NS1 ***Scientific Investigations*** and Learning Outcome NS3/Tech3 ***Science, Technology, Society and Environment***, as well as building the Assessment Standards of Learning Outcome NS2

4.1 Living things that share the world with us

Reason for placing this in Grade 4

This topic allows children to express their existing knowledge of animals and plants in simple ways, and the language demands are not high because the relationships between plants and animals are kept simple. This topic also takes advantage of young children's fascination with dinosaurs, and encourages process skills of inference and hypothesising (e.g. to describe how big some dinosaurs were).

The emphasis must not be on memorising facts or definitions but be on activities that use process skills like **observing differences**, **sorting and classifying**, **describing**, **drawing**. Activities should allow learners to work with these concepts:

Concepts	**Suggested elaboration**
1 There is a great variety of plants.	For example, learners must describe visible differences between several different plants, and compare their leaves, fruit, flowers. Plants are green living organisms, but some are very small like algae, some are very large, like trees, and there are many sizes and shapes in between the very small and the very large. Leaves and flowers and stems are very varied.
2 There is a great variety of animals.	Learners should discuss visible differences between animals, differences in behaviours of some familiar animals including very small animals like insects and other invertebrates
3 Fossils	Some rocks have traces, called fossils, left by other plants or animals that lived here in South Africa long ago.

Research on learning and teaching this topic

Activities must help to develop learners' vocabulary (in English or their other more fluent languages) to talk about the visible features and properties of a variety of living things, not limited to the examples that the teacher introduces.

Science uses common English words like "plant", "animal", "living" and "consumer" in particular ways:

‣ "plant" (in English) usually calls up a mental picture of a bean plant or small bush. In science, learners should also see a tree, grass, or algae as part of the group of living things called "plants".

‣ The teacher cannot assume that "animal" has the same meaning to all the learners. All learners will see a hairy four-legged animal like a cow as an animal, but many of them will not think of a spider (which has 8 legs) and an earthworm (which has no legs) as animals. Yet in science all these organisms are regarded as animals. So the teacher has to develop or find activities that allow children to extend their concepts of “plant” and “animal” to include these wider meanings. (The research on learning tells us that even if learners memorise a correct definition, they may still think as they did before, e.g. they will **still not** think of a spider as an animal.)

Examples of activities to build concepts and language

Learners should do activities based on questions such as

- How do you know that something is an animal?
- What differences between animals can we see? Describe all the differences you can find.
- What kinds of things are called animals? For example, which of these are animals: cow, cat, spider, worm, cricket, frog, mosquito, fish?
- Let's make a list of all the things that all animals do.
- How many different kinds of plants can you find in the school grounds / a small area?
- In what ways are the plants different from each other? Describe these differences. Do all plants have the same parts?
- What kinds of things are living? For example, which of these are living: mouse, fire, wind, river, bird, soil?

Other activities can be

- describe, name and identify birds by colours, behaviour, song, habitat (Process skills are **observing** and **comparing**)
- collect, sort and describe seeds and grasses (**observing** and **comparing**),
- sort cards representing herbivores, carnivores, omnivores. Learners must explain why they put certain cards together. (**Sorting** and **classifying**)
- work out the real size of *Tyrannosaurus rex* or other dinosaurs and draw their footprints to real size on the ground and mark their height on a wall, with chalk. (**Interpreting** and **inferring**, **estimating** and **measuring**)

4.2 How plants and animals live, and the places where they live

Reason for placing this in Grade 4

This topic extends the learning in 4.1 about kinds of plants and animals by asking the children to reason about the ways plants and animals depend on each other. The notion of a food chain, or the need for a habitat with places to hide, seems to be understood fairly easily, and this lays an essential basis for the concept of interdependence which becomes increasingly important as the learners move up the Grades.

The emphasis must not be on memorising facts or definitions but be on activities that use process skills like **observing differences**, **sorting and classifying**, **describing**, **drawing**.

Concepts	Suggested elaboration
1 Plants make their own food	Plants do not need to eat other living things; they can make their own food using sunlight, water and the air. (No understanding of photosynthesis is expected)
2 How animals feed	Some animals eat plants, some animals eat plant-eating animals, and some animals eat both plants and other animals. (Include small invertebrates for study)
3 Habitats for plants	Each kind of plant needs a place (a habitat) where these plants have soil, water, light, shelter from things that could kill it.
4 Habitats for animals	Each kind of animal needs a place where they can survive (i.e. they need a habitat). They need to feed, to get water, have a place to shelter or escape predators and to reproduce (include habitats in wetlands, grasslands and areas close to the classroom).
5 Humans and animals cannot live without plants	Dependence of animals and humans on plants: explore simple food chains. (Include small invertebrates for study.)
6 Humans, animals and plants cannot live without water	Dependence of plants, animals and humans on water: The bodies of animals, humans and plants continually give out water in different ways, and they must replace this water.

Research on learning and teaching this topic

The development of language and concept remain closely linked here. For example, the concept of "consumer" is a useful way to distinguish between animals (that must **consume** plants or other animals for food) and plants (that can produce their own food in their green parts). So, if the teacher says that "consumer" is another name for "animal" the learner can link the concept of "animal" and the new concept "consumer" – but the link does not work if the learners don't see earthworms, spiders, etc. as part of the group we call "animals" (Bell and Freyberg, 1985, pp 38 – 40).

Learners should begin using the language of relationships between things. Words like “depend” or “giving and taking” should come into learners’ language as they talk about the relationships between living things and their habitats.

From *Atlas of science literacy* (2006):

> *Lower elementary-school students can understand simple food links involving two organisms. Yet they often think of organisms as independent of each other but dependent on people to supply them with food and shelter. Upper elementary- school students may not believe food is a scarce resource in ecosystems, thinking that organisms can change their food at will according to the availability of particular sources (Leach et al., 1992). Students of all ages think that some populations of organisms are numerous in order to fulfill a demand for food by another population (Leach et al., 1992).*

Examples of activities to build concepts and language

Learners should do activities based on questions such as

- How do people use plants?
- How do plants spread?
- What do plants need, to survive and grow well?
- In what kinds of place does each sort of plant grow well and make more plants?
- What do animals need, to survive and grow well?
- In what kinds of place does each sort of animal grow well and have babies?
- What do animals need from us, if we keep animals?
- How should people behave towards animals (i.e. how should humans treat animals?)
- Do some animals guard their territory? What do they do to keep other animals away? Why do they do this?

4.3 The rocks of Earth

Reason for placing this in Grade 4

This sub-strand of *Planet Earth & Beyond* can be treated in a concrete manner, and in practical terms, young learners can do some enjoyable activities with stones, sand, water and mud, and they usually enjoy collecting pretty or interesting stones. The teacher does not need a course in geology to teach this topic, provided that he or she has an adequate textbook and teacher's guide.

The reason for treating the whole of the sub-strand *Changing Earth* (*The rocks of Earth)* in a single Grade

Readers may query why all three sub-strands in the Planet Earth strand (*Earth in Space, Atmosphere and weather,* and *The changing Earth*) are not represented in Grade 4, with teachers doing a part of each sub-strand in Grade 4, 5 and 6. The main reason is to avoid an overload of concepts and new language and to allow learners to expand their existing ideas and language about a single familiar context (rocks, in this case).

To elaborate, each of the three sub-strands in the *Planet Earth* strand has a number of new concepts (which must be built through repeated experiences), and their new vocabulary.

These concepts are easier for learners to understand and apply when they are **inter-related around a single familiar context**, i.e. rocks, sand, water and mud. The learners can relate new vocabulary to a single set of activities and observations. The words like "rock", "sand", "erosion" are used **in the same context** and are thus easier to associate and remember (Language teachers are familiar with this strategy – they teach new words in a single context e.g. the teacher shows the learners a house being built, and introduces new words like "brick", "brick-layer", "trowel", "cement" and so on. The learners can remember them by association with building a house..)

If Grade 4 learners had to develop the concepts and learn the vocabulary from *Our place in Space*, *Atmosphere and weather*, and *The changing Earth* all in the eight weeks available for them, the context would keep shifting, the concept-building experiences would be too brief and the load of new language would be overwhelming.

For similar reasons, only one of the remaining sub-strands from *Planet Earth* is tackled in each of Grade 5 and Grade 6.

Concepts	Suggested elaboration
1 The Earth beneath our feet	The Earth goes far down below our feet. (To see the concept, imagine that we dig a very, very deep hole and we try to think what we will find as the hole goes deeper and deeper. However, the aim is not to build the concept of the Earth as a ball – learners will see the Earth as a ball in Space briefly in Grade 5, and then work with it in Grade 6 astronomy)
2 The Earth is hot, deep down.	The Earth deep down is so hot that the rocks may melt. Sometimes the molten rock comes up and breaks through the surface in a big explosion, and in other places it just flows out. These places where molten rock comes out are called volcanoes. Sometimes the molten rock fails to break through the surface and so it cools off under the ground.

3	Igneous rock	Igneous rock is rock that cooled from hot molten rock. Granite is an example of igneous rock.
4	Weathering	The action of the weather breaks the outsides of rocks into smaller pieces. The breaking up happens through the rock becoming hot and cold during the day and the night, through water that gets into cracks, ice that widens cracks, wind that blows sand against rocks.
5	Erosion	Erosion is the process that moves the pieces of rock away. Wind, moving water and other rocks that fall down mountainsides move pieces of rock away. As rocks roll down a river, they knock pieces off each other, and in the processes of weathering and erosion the pieces of rock become smaller and smaller. Very small pieces are called grains of sand and extremely small pieces are called grains of clay.
6	Deposition	Wind and moving water carry the sand and clay (= pieces of rock) and put them down (deposit them) in new places. Deposition is the process of depositing the pieces in another place.
7	Sediment	The grains of sand and clay collect in layers. A layer of sand and clay grains is called a sediment.
8	Sedimentary rock	Sediments become hard and they form sedimentary rock. Shale is an example of sedimentary rock; shale forms from layers of clay.
9	Fossil	A fossil is the shape of a living organism (i.e. plant or animal) that has been preserved in rock. Some kinds of fossils form when fine grains of rock replace parts that were once parts of the plant or animal. Other fossils are only an indentation that the plant or animal left in mud, such as a footprint or a leaf-shape, for example. Many fossils show us that animals and plants that lived long ago were different to the plants and animals we see nowadays.
10	Metamorphic rock	Rocks which are heated while they are under the ground may change into another kind of rock. The heating is caused by molten rock coming up from deeper down in the Earth. Metamorphic rock and the processes which form it do **not** require much attention in the curriculum. The only example the learners need in Grade 4 is shale which may be changed to slate. Shale is clay that has formed sedimentary rock (learners may know it as the red or yellow stones that they can write with; a piece of shale can be like a crayon.) Slate is hard and dark grey and we find it in flat sheets in the ground. (Learners may know slate because some schools use pieces of slate for writing on.)

Research on learning and teaching this topic

There does not seem to be much research on children's ideas about this topic yet, but the learning challenge is obvious: they need to understand that a stone they hold in their hand was not always like it is now. It has been changed by processes that happen over very long periods of time.

One of these processes that change rocks is erosion. Learners can relate this concept to steps that are worn away by many feet, or paint that has been rubbed off a pole by many hands touching it. They may find that the hard cement beneath a tap has been worn away (i.e. eroded) by the dripping water from the tap.

Another long-term process is the formation of sedimentary rock. Over long periods of time, grains of rock that lie in layers are cemented together by moisture and by substances that were dissolved in the water. Learners can relate this concept to sugar in a jar becoming a hard lump, or cement powder in a bag that gets damp and becomes hard as a rock.

The language is the language of sequencing: "In the beginning . . . then what happened was . . ., and after that, . . . and in the end after a long, long time . . ."

We do not have to deal with geological time lines in Grade 4. Both adults and children find it hard to grasp the idea of any process that continues for thousands of millions of years, but children are satisfied with the idea of "very, very long ago".

We also do not have to deal with the concept of the Earth as a rocky ball in Space; the learners will encounter that in Grade 5 and again in Grade 6. At Grade 4 it is enough for the learners to think of the ground beneath their feet, and wonder what they would find if they dug deep holes.

We have some information about learners' ideas in New Zealand, and these may be relevant here:

Some learners see stones as something different to rocks; "rocks" are heavy and large, while "stones" are small and lighter. They do not see stones as pieces which have come from rock. (Learning in Science Project, Working Paper 17, 1982)

Some learners see stones which have been polished (e.g. gravestones, kitchen counters) as man-made and not a natural substance. (We may find that this confusion is increased now that artificial granite surfaces as well as artificial boulders have become popular in gardens and public buildings.)

Learners may view a volcano as a conical mountain that has something happening in its top, that causes lava to burst out. This misconception is probably reinforced by the ever-popular but incorrect model volcanoes that learners make for school projects using *papier maché*. These model mountains pour out red soapy foam. (See topic ***7.4 The changing Earth*** for a description of a more accurate model volcano)

Appropriate activities that build concepts and process skills

The emphasis should fall on process skills and on opportunities for learners to use of the new words. Activities can be based on questions such as these:

- Do stones all look the same, or what are the differences between them? (Process skills are **collecting**, **observing**, **sorting & classifying**)
- How did round, smooth stones get to be so round and smooth? Were they always like that? (**Hypothesising** and **predicting** can lead on to **modelling** or **testing ideas** about stones in rivers by, for example, shaking rough stones together in a tin for a long time.)
- Stone steps in an old building are sometimes curved downwards in the middle. Were the stone steps made like that, or what happened to make them hollowed out in the middle? (**Hypothesising**. With guidance this can lead on to **designing a test of an idea**.)
- Has the world **always** had big rocks and smaller stones? Do stones grow bigger until they become rocks? Or do rocks grow smaller until they become stones? What actually happens? (**Hypothesising**, lead on to **designing a test of an idea**)
- What will we find if we dig down under the classroom? What will we find if we dig REALLY deep? (**Hypothesising**. **Interpreting** pictures and diagrams.)
- Why do some rocks have layers like sandwiches? How did they get like that? (**Hypothesising**, **predicting**; goes on to **modelling**)

Other activities might be

- melting coloured candle-wax, letting it flow and then harden to simulate magma and lava hardening to igneous rock. They compare the hardened wax with pictures of pillow lava (lava that emerges from under-sea volcanoes and cools under water).

- rubbing these pieces of wax together to simulate the surface of rocks breaking up as they roll down a river bed.
- soaking these pieces of wax in water and placing them in a deep-freeze. They observe the effect when water freezes in cracks in the wax. Or they place a glass bottle of water in the freezer and observe how the ice cracks the glass.
- eroding an area with water, observing the area the soil was moved to, and describing the layers that have been deposited (**Observing**, **interpreting**, **communicating** science information. Concepts are erosion and deposition.)
- eroding a pile of sand mixed with cement powder, using a gentle “rain” from a water-sprinkler. They allow the sediment to settle and harden for a day, and feel the resulting “rock” that forms. They compare this to sandstone, a sedimentary rock.
- making model fossils in layers of simulated “rock” and predicting their appearance when the “rock” is opened. (**Modelling, predicting**)
- baking biscuits made with a mixture of dough and chocolate chips – and observing how the baked mixture has been changed by heating (**modelling** metamorphic rock).
- using the concepts to tell or illustrate a story about how a piece of granite (igneous rock) formed when it came up hot and molten from deep in the Earth, and then how it weathered and was eroded to fine grains and deposited where it formed shale (sedimentary rock), and then how the shale was buried under more sediment by a river, then pressed and heated until it became slate (metamorphic rock).

4.4 Choosing and changing materials

Reasons for placing this in Grade 4

This topic provides another opportunity for young learners to experience materials, modify them and compare results. The activities are not conceptually difficult but the teacher has many opportunities to develop the language that will be needed in Grades to come.

The topic can follow on from Topic 4.3 as it also deals with rocks and soil. **Earth materials** such as clay and water have traditionally been used for pots, statues and buildings. Cement, sand, and crushed stone are essential in building houses, stadiums, roads and schools. Also, the concept of **fossils** in Topic 4.3 provides a purpose for choosing materials: real fossils include small hollows in rocks that have retained the shape of a leaf, a footprint, or a sea-shell that landed on that mud millions of years ago. Learners can make such model fossils if they choose suitable materials.

The emphasis must not be on memorising facts or definitions but be on activities that use process skills like **observing differences**, **sorting and classifying**, **describing** or **drawing**. Activities should allow learners to work with these concepts:

Concepts	Suggested elaboration
1 Materials	Materials are the substances (i.e. the matter) we choose and use to make things. Examples are wood, plastic, salt, mealie-meal, steel, aluminium cooking-foil, glass, syrup, paint, Prestik™, water and even air.
2 Properties of materials	The properties of materials are described by adjective words such as hard, soft, springy, sticky, brittle, wet, dry, runny, stiff, shiny, dull for example. Learners might invent some words like “bendy” or “stretchy”. They can also use words like “Glass makes a ringing sound when I tap it with a spoon but it will crack easily” The materials learners examine and test should include metals and non-metals including ceramics (glass , porcelain, pottery) and polymers (plastics, rubber, fabrics). We choose materials with properties that will work best for the purpose we have (the things we want to make).
3 Combining materials to get materials with new properties	We can mix materials to get a new material**.** Sometimes we need to heat the materials in order to make them mix, and then let the mixture cool. The new material can have properties that are different to the properties of the starting materials. Examples are in the Activities below. Link these concepts with the Processing strand in Technology.
4 Solids, liquids and gases (their characteristic properties, and less emphasis on change of state)	Materials are called solids if their shape does not change. All the materials that flow but stay in a cup are called liquids. All the materials that will not stay in a cup but spread upwards and sideways by themselves are called gases (examples of gases are air, perfume, the gas that comes from vinegar, the gas that comes from bleach (“Jik”), gas from a gas stove, petrol vapour). By heating solid substances we can change them into the liquid state/form, and those hot liquids will cool down to become solids again. (This idea does not need much emphasis because learners will do more on change of state in Grade 5 – see topic ***5.6 Heating and cooling causes changes in materials***)

Research on learning and teaching this topic

The cognitive framework of this topic's lessons is (a) that we have words for properties of materials (b) that we can change materials to make new materials with new properties and (c) we use special words that refer to **classes** of things (for example, the word "liquid" refers to **very many** different materials that flow).

In the lessons, the learners should **first** have experiences of different materials (including solids, liquids and gases) and should use the words for the properties of these materials. **Near the end** of the topic or unit, the teacher explicitly teaches the names of classes of materials – solids, liquids, gases. This is done near the end, so that the learners have had sufficient hands-on experience of many different materials and can connect those experiences to the new words.

The cognitive challenge for learners is to realise that the concept of **classes** of materials. For example, word "**liquid**" refers to a **class** of materials, not just one example like water. So "liquid" is a second-level concept that includes many primary concepts like "water", "meths", "milk", "syrup", etc. Teachers must generalise from specific examples to the whole **class** of substances, so that learners realise that there are many kinds of substances called liquids, many kinds of substances called gases, many kinds of substances called solids.

Language concerns

In English, some of the words of this topic have more than one meaning and learners will hear them in the context of language or technology lessons. For example, "material" can mean simply "cloth" but in science we use material to include cloth and a million other substances. The word "solid" can be an adjective, as in "this is a good, solid house" meaning it is strong house. So the science teacher must tell learners that in science we use these words with special meanings.

However, within the science lessons, the words "solid", "liquid" and "gas" appear as adjectives too. For example, we may talk about solid wax and liquid wax. The term "gaseous water" (water-vapour) could also appear in textbooks.

Some conceptual difficulties the teacher should watch for

✗ Learners in Grade 4 will often say that an empty container has nothing in it, when the context of the lesson is that air spreads everywhere. This might have to do with the common meaning of the word "empty" but more likely the learners do not have a conception of air and other gases as real substances. (Russell, Longden and McGuigan, 1991, p.33).

✗ When learners are asked to talk about a gas such as the fumes from vinegar, they refer to the smell (Russell, Longden and McGuigan, 1991, p.33), and for a Grade 4 learner, the smell is the same thing as the gas. This raises the question of how they view air which they cannot smell.

✗ The Primary Science Programme, a nation-wide South African NGO, found that learners in science lessons did not think of air as a substance that spreads to occupy all available spaces; they saw air existing around people's noses and mouths (Mkhwanazi and Kekena, pers comm 1995). The PSP teachers had to ask questions such as "Is there air in the cupboard? Under the table? In this cup?"

✗ The *Science for All project* found that learners saw air as something different to the atmosphere: "air is what we breathe, and the atmosphere is up there" (Moodie, project observations, 1996).

Examples of activities to build concepts and language

- Learners place a teaspoonful of methylated spirit in a large clear container and watch it evaporate. They do language work to describe their observations of its change of state from liquid to gas. Language work must deal with terms like “liquid meths”, “changing from liquid to gas”, “smell” and “evaporate”.

- Learners press an apparently empty glass mouth-down into water and try to explain why the water rises only a short way inside the glass.
- Learners feel some substance or objects made of the substance inside a bag and they describe some properties of the substance, without looking inside the bag. Materials should include metals, ceramics and polymers.
- Learners discuss how to describe substances like powders (a heap of sugar or salt), rubber (rubber bands, balloons) or jelly. They should ask classifying questions such as “Does it keep its shape? Or does it flow? Or does it spread upwards by itself?” They can then decide on the best description of the substance – is it more like a solid, more like a liquid or more like a gas?
- Learners do a task in which the teacher creates a purpose for making a new material. The reader will notice the deliberate links with Intermediate Phase Technology in LO Tech2-Processing. Examples of purposes could be:
  - making a fossil model (a permanent imprint of a leaf, small footprint, sea-shell, dead beetle in clay or plaster of Paris)
  - making a pot to hold water, or making a pot to hold sugar
  - inventing a liquid with a smell that will keep mosquitos away.
- Learners must mix materials to make a new material, and compare the properties of the starting materials with the end material. An important part of the learning is the before-and-after comparisons, oral descriptions and language development (including written language). Learners should experience making at least two of these materials below – they must make them or shape them for a purpose. Some materials must dry in a warm place, others will react and set without such help.
  - mixing clay and water (varying quantities of water give varying stiffness of clays; also try the effect of mixing string or grass in the clay – do they make the object stronger?)
  - mixing sand, cement-powder and water to make concrete
  - mixing flour and water to make play-dough or to make glue (also try the effect of adding a little oil - does it prevent cracking?)
  - mixing Plaster of Paris and water (or Polyfilla,, or Rhinolite) to make a hard plaster
  - mixing epoxy resin and hardener (e.g. Pratley’s quick setting epoxy glue)
  - mixing liquids that give off smelly gases (e.g. vinegar and bleach) to get a new smell. (Warning: use small quantities of these liquids.)
  - mixing jelly-powder and water and food colouring to make a new kind of jelly
  - mixing sugar and bicarbonate of soda in a little water, heated together to make a kind of sweet.
  - mixing flour and bicarbonate of soda to make self-raising flour.
- Learners warm and melt candle-wax and let it harden. Language work must deal with terms like “solid wax”, “melting”, “liquid wax”, “changing back” from liquid to solid, “temporary change”.
- Learners look at a variety of solids, liquids and gases (including semi-liquids like golden syrup, and soft solids like rubber or cotton-wool, and powdered solids like sugar). They are asked to put them in three groups and describe the properties that are common across the groups.

4.5 Air, wind, sound and musical instruments

Reasons for placing this in Grade 4

This topic further develops the concept in ***4.4 Choosing and changing materials*** that air is a real substance. The topic lends itself to simple and enjoyable activities that provide opportunities to develop some important language. It draws on the young learners' experiences of music, singing and musical instruments which are common in most schools. It also offers an opportunity to investigate simple direct relationships, for example, the relationship between the tension in a string and the pitch of a note from that string (refer to Assessment Standards for Learning Outcomes NS1 and Tech1). This again allows the teacher to introduce some of the language the learners need for science investigations.

The energy concept is introduced quite simply via the idea that the wind can turn windmills, for example. Learners' usual starting-point in understanding energy is that their bodies have energy, and so the teacher can build on this idea as follows: the sound we hear from a musical instrument comes from the energy in the hands, fingers or chest (lungs) of the person who plays it.

The emphasis must not be on memorising facts or definitions but emphasis must be on activities that use process skills like **observing differences**, **sorting and classifying**, **describing**, **drawing**. Activities should allow learners to work with the following concepts.

Concepts	Suggested elaboration
1 Air is a real substance	Air is invisible but it is a real substance; it occupies space but it is compressible.
2 Wind	Wind is air moving in the same direction, and it can make other objects move.
3 Energy from the wind	Wind can do useful work if it moves a system like a windmill or a boat's sail. We say that wind has energy, because it can make things move.
4 Sound travels	Sound can travel through gases like air but also through solid materials like wood, and through liquids like water.
5 Vibrations	When our ears hear sound, it means that something is vibrating. Vibrations travel through solids, liquids and gases. Most of the sounds we hear have travelled through the air to our ears. (Learners need not learn the mechanism of hearing nor the structure of the ear.)
6 Vibrations pass energy on to other things	To make a thing vibrate, we must give it energy that makes it move backwards and forwards. The vibrating thing passes on the energy to the air, or wood that it is touching, and the energy reaches our ears. (Learners need to give their energy – from fingers or lungs – to a musical instrument, in order to get a sound from it. Learners can extend this activity to feeling the vibrating part of a radio loudspeaker and work out where the vibrating part gets its energy from.)
7 Quick and slow vibrations	The sounds from a musical instrument are called notes. Most instruments can give high notes and low notes. A quick vibration gives a high note and a slow vibration gives a low note.

8	Musical notes	Musical instruments make a mixture of quick and slow vibrations and people like to hear this mixture of vibrations. People choose the materials (= substances) for musical instruments that will give a pleasant sound. Wood is often used because it vibrates with a pleasant mixture of vibrations.
9	Resonators	Musical instruments often use a resonator to make the sound of the instrument louder. A resonator is a box or tube that vibrates with the strings or the beat of the player's hands. Examples are a flute, guitar, drum, marimba, kalimba, violin.

Research on learning and teaching this topic

Some African languages use the same word for breath, wind, and spirit (e.g. *moya*). If the teacher uses the word *moya*, then she must make sure that the learners know whether she means the English words "air", "wind" or "breath". Of course it's the concepts, not just the words, that matter here – science treats breath simply as a mixture of gases but for some learners the word "breath" is linked to a person's spirit or soul, and the learner may therefore add extra meanings to "breath" which the teacher is unaware of. (Msimang, 1995, pers.comm.)

Some young learners believe that air exists only in certain places such as around people's noses (PSP, project observations 1995). The SPACE project in Britain reported a similar finding. One interaction went as follows:

> "Where do we find air?" Response: "Over there, in the room" (points).

(Russell, Longden and McGuigan 1991, p.37)

Some children in the SPACE research also thought of a gas as a smell. In other words, the smell of vinegar is just the smell – they do not think of a substance that comes from the liquid vinegar into the air. The fact that air has no smell made it harder for them to think of it as a gas (Russell, Longden and McGuigan 1991, p.33-38)

Learners usual starting-point in thinking about energy is the energy that they themselves have, that is, their ability to move themselves and move other things (CLIS Project, 1985). The activities in this topic should extend that correct but limited concept of energy, so that they realise that they in fact pass on, or transfer, their energy to objects and materials. They do this by blowing on a toy windmill, or plucking the strings of a musical instrument to make them vibrate.

Language concerns Teachers will have to develop the learners' language as in the following recommendations:

"We can press air into a smaller space – air can be compressed – it is compressible."

"Air is a substance that we cannot see – we say that air is invisible."

"We breathe air – the air we breathe in and out is called our breath".

Useful English words in this topic will be "resonate", "pitch" (as in singing), "loudness" and "tone" (of an instrument).

English words to **avoid** at this level are "frequency", "wavelength", "amplitude", "air as the medium" and "vibration as energy transfer"

Examples of activities to build concepts and language

The activities should build a resource of experiences for the children which the teacher draws on to develop concepts and explain the new words.

- Catch some air in a plastic bag, and feel how tight the bag is and how the air resists being compressed.
- Close the opening of a syringe, and attempt to compress the air in the syringe until the plunger reaches the bottom (they find that this is impossible)
- Make objects vibrate by giving them energy e.g. pulling a taut string to one side and releasing it, or make a hacksaw blade vibrate by pulling it down and releasing it.
- Listen to quiet sounds such as a clock ticking on a table, first in air and then with an ear pressed to the table. Fill a bag with water and hold a clock on one side – a learner puts his ear to the other side and hears the ticking clock more clearly.
- Learners make and play a musical instrument such as a *kalimba* (= thumb piano), in which they can adjust the length of the vibrating tines (teeth), or box guitar, in which they can adjust the length or the tension in the strings. (The concept is, for example, that there is a relationship between the length of the string and the pitch of the notes. The language that develops is, for example, "The shorter the string, the higher the note")

Grade 5 Topics

> These notes focus on the **science knowledge** in the NCS. But the science knowledge is not the curriculum, and these notes are not a learning programme. The curriculum is about learners using the knowledge to produce outcomes. So these notes are just the basis for learning programmes that build the Assessment Standards for Learning Outcome NS1 ***Scientific Investigations*** and Learning Outcome NS3/Tech3 ***Science, Technology, Society and Environment***, as well as building the Assessment Standards of Learning Outcome NS2

5.1 How living things depend on their environment

Reasons for including this topic in Grade 5

In Grade 4 learners worked with simple relationships between plants, animals, humans and water, and the concept of habitats. In Grade 5 they expand their concept of habitat to broader environments which provide different habitats for different organisms.

Children at about this age need the challenge of thinking about **relationships** between organisms, and this of course means they must develop more language to talk about relationships. They must become able to use words like "depends on . . ." and "needs something from" and "gives to . . ."

They should also be challenged to describe **a chain of events**, like "A grasshopper eats a plant, and then a lizard eats the grasshopper, and then a cat eats the lizard" and then describe the whole story again but they begin from the cat, "The cat ate the lizard that ate the . . . ."

The emphasis must not be on memorising facts or definitions but be on activities that build language and use process skills like **observing differences**, **sorting and classifying**, **describing**, **drawing, making predictions**. Activities should allow learners to work with these concepts:

Concepts	Suggested elaboration
1 What animals need to live	Animals depend on the soil, plants and other animals in their environment, for food, shelter and places to breed.
2 All animals depend on plants	Animals cannot make their own food, and so some animals eat plants for food while some animals eat other animals. All animals ultimately depend on green plants for their food.
3 Plants depend on the soil	Plants make their own food, but plants depend on the soil for water, air and anchorage for their roots.
4 Soil	Soil forms from broken-down (= weathered) rock and the remains of living organisms. Good soil has air, water, the remains of dead organisms and very small living organisms in it. Soil types are clay soil, sandy soil and loam. (Qualitative comparisons of water retention, stickiness, etc. are adequate. In Grade 8 learners can calculate % water retention of the soils and graph grain sizes.)
5 Habitats for plants and animals	A habitat for each kind of living thing is the kind of place where it can find or make food, find shelter and reproduce. Examples are the bark of trees, river-banks, ponds, the sea-shore above the high tide line, burrows in soil, wetlands, damp dark places.

Research on learning and teaching this topic on learning difficulties

Learners will use the word “living” without hesitation to tell about animals because they move around, and (after lessons), they will also use “living” to tell about plants. But then they will probably include rivers, fires, clouds, the Sun and even moving cars among their list of living things (Bell and Freyberg, 1985). So lessons must include activities in which learners grapple with the concept “living” versus “non-living”.

From *Atlas of Science Literacy* (2006) we have the findings:

> *Lower elementary-school students can understand simple food links involving two organisms. Yet they often think of organisms as independent of each other but dependent on people to supply them with food and shelter.* (Grade 4-6 learners in South Africa may have this misconception, because they know about animals that live with us, like chickens, dogs, cats or hamsters or garden birds. Many children do not think immediately about organisms in general e.g. insects, spiders.)
>
> *Upper elementary-school students may not believe food is a scarce resource in ecosystems, thinking that organisms can change their food at will according to the availability of particular sources (Leach et al., 1992).* (In other words, learners may incorrectly think that if insect-eating birds cannot find enough insects then they will begin to eat fruit instead.)
>
> *Students of all ages think that some populations of organisms are numerous in order to fulfill a demand for food by another population (Leach et al., 1992)*. (In other words learners may incorrectly think that frogs around a pool have large numbers of eggs <u>in order to provide</u> food for fish and crabs in the pool.)

Examples of activities to build concepts and language

Learners can develop these concepts by activities starting from questions such as

- How do we know that something is living? What do ALL living things do?
- How do people use plants?
- How do plants spread?
- In what kinds of place does each sort of plant grow well and make more plants?
- What do animals need, to survive and grow well?
- What prey does this animal eat? And what did the prey eat?
- In what kinds of place does each sort of animal grow well and have babies?
- How should people behave towards the places where animals live?

Activities can include

- investigating habitats for small living things such as trunks and roots of trees, river-banks, ponds, burrows in soil, wetlands, damp dark places.

5.2 Plant and animal reproduction

Reasons for including this topic in Grade 5

In Grade 4, learners find that living things grow and reproduce. In Grade 5 they look more closely at this growth, modes of reproduction and life cycles of plants and animals. The co-operation and social structure in some animal communities (bees, sociable weavers, prides of lions, etc.) appeals to young children. With creative teaching, they can appreciate how each way of living depends on the animals' environment.

However, another reason for placing this topic in Grade 5 is that is can develop important kinds of thinking called "operational thought." As children develop operational thought, they progress from having the real, actual thing in front of them to a new level in which they can call up a **memory** of the real thing and **imagine** how it could change or respond. This makes their thinking much more powerful than when they were younger and needed to try something physically to see what would happen.

They will need operational thinking in Grade 6 as they imagine how their muscles connect to their bones, or as they watch salt disappear in water and decide whether the salt is still there.

So, at about Grade 5 age, learners need the cognitive challenges of dealing with the stages in a multi-step process (such as understanding the correct sequence in the development of a flowering plant or a fruit-fly). Learners tend to see stages in a cycle as separate events and not as a sequence of linked stages; they may be able to remember the first and the last stages but have difficulty with the stages in between. So the life cycle activities (which have similarities to the water cycle challenges) come at the right stage of the children's mental development. That is not to say the lessons will be easy – it is to say that the learners' effort in grappling with the concepts is worth it.

Another cognitive challenge these Grade 5 learners need is questions about how things grow big. To an adult, it is obvious that growth needs some explanation – how does a tree that began as a tiny seedling grow to 10 tons of wood and leaves? But many children about this age don't see it as something that needs explaining – growth just happens. So we need to challenge them to think about growth and change.

The emphasis must not be on memorising facts or definitions but be on activities that build language and use process skills like **observing differences**, **describing**, **putting steps in the correct sequences, making hypothese**s, **drawing**. Activities should allow learners to work with these concepts:

Concepts	Suggested elaboration
1 Plant reproduction from seeds	Plant reproduction from seeds. Plant growth and life cycle. (Details of pollination and the sexual reproductive structures of flowers is optional)
2 Vegetative reproduction	Vegetative reproduction. Its importance for agriculture because the daughter plants are all the same.
3 Indigenous plants	Importance of indigenous plants for medicinal and other uses; need to conserve them and their habitats.

4	Animal reproduction	Reproduction in birds, fish, reptiles (which may include theories about dinosaurs' reproduction), amphibians, mammals and at least one insect. The concept of animal life cycles in two interesting cases such as an amphibian and an insect.
5	Habitats for reproduction	Territorial behaviour to secure a breeding or feeding habitat. Habitats that are needed by some of the animals above and the protection afforded to breeding animals by habitats; the impact of loss of habitat.
6	Social organisation in animals	Social organisation of animals and patterns of behaviour. For example, being solitary, pairing for life, or living in packs, prides, herds, troops or colonies. (Link with reproduction and care for the young)

Research on learning and teaching this topic

Many young learners do not feel that growth needs to be explained – for them, it just happens by itself. They do not make the connection between feeding and growth in an organism. Some may say that food or water causes the body of the organism to stretch and so it gets bigger.

Bear in mind that from a science point of view, "growth" means not only getting bigger, but also development and change.

Russell and Watt (1990) describe children's ideas of how a chicken grows inside an egg, or how a caterpillar grows bigger after hatching from its egg. In the case of the egg, the majority of young children believed that the egg contained a complete small chicken that was feeding on the yolk inside the egg. In the case of the caterpillar, if the teacher presses them to think about it, they may say that the caterpillar grows bigger by making room for the food. These learners had seen the caterpillar's droppings (= manure) but the learners did not see those droppings as evidence that the caterpillar **uses** the food to grow and change.

For a very long time in history, people believed that plants grow by eating soil. The question of **how** plants really grow is difficult and Grade 5 learners should begin by accumulating experiences of growing plants for themselves. But in this experience, learners should be challenged to think and make hypotheses about how plants like trees can grow so big.

Note that traditional life cycle diagrams (in the form of a circle) are confusing to learners. Typically, the diagram shows the final stage, i.e. the adult organism, turning back into the egg or the seed. Teachers need to explain carefully that the adult produces the egg or the seed which then becomes the next generation of the organism.

Examples of activities to build concepts and language

Learners can develop these concepts by activities starting from questions such as

- How do plants spread?
- What do plants need, to survive and grow well?
- How would we get many plants of the same kind to grow, as a crop?
- Plants die but from their seed we get more plants. Do the new plants look like the older plants?
- Frogs' eggs do not look like little frogs, so what happens to the egg, until we see an adult frog?
- How do people breed animals like chickens, pigs or sheep on a farm?

Activities can include:

- germinate seeds against the inside of the wall of a glass jar, and record the changes in the seed and then the growing plant every day.
- propagate a clone of a plant from a cutting of the plant (e.g. ginger, coleus)
- hatch silk-worm eggs and observe the caterpillars growing and feeding, until they spin cocoons, metamorphose, hatch, mate, lay eggs and die.
- breed fruit-flies and tadpoles and observe their stages of life; draw pictures to show their life-cycles.
- Learners can mimic or role-play animals’ territorial behaviour

5.3 Atmosphere and weather on planet Earth

Reasons for placing this in Grade 5

Wind, weather and the water cycle are taught to children about this age, in many different education systems. The water cycle concept is a basis for the work on water resources in Grade 6 and the Grade 6 topic ***6.5 Simple astronomy***. The topic deals with the effects of heating and cooling on water, water-vapour and ice, and its concepts are necessary for learners to learn about changes of matter in ***5.6 Heating and cooling***.

At this age it is important that the children should meet certain learning challenges, because they should be ready to begin reasoning about objects and actions without actually handling the real objects or doing the actions. The learners must develop this ability in order to succeed further on in the curriculum. The **Research** section below explains these mental challenges in more detail.

Reason for treating the whole of *Atmosphere and weather* in one Grade

Readers may ask why only **one** of the three sub-strands in the Planet Earth strand (*Our place in Space*, *Atmosphere and weather*, and *The changing Earth*) is presented in Grade 5. The main reasons for doing this are

– to avoid concept and language overload,
– to allow new concepts to develop in a single context and
– to allow learners enough time for projects in which they can display competence in the Learning Outcomes and be assessed in a somewhat authentic context.

Each of the three sub-strands in the *Planet Earth* strand has a number of new concepts (which must be built through repeated experiences), and their new vocabulary. These concepts should be **inter-related around a single context**, for example, predicting changes in the weather and Sun's position that will occur as the season changes. With a single context to think about, the learners can develop concepts and relate new vocabulary to a single set of activities, models and observations.

If the three sub-strands (*Our place in Space*, *Atmosphere and weather*, and *The changing Earth*) were attempted in the same Grade, each sub-strand would get about 2½ weeks, or about 8 hours, of teaching time. Eight hours would allow only superficial teacher-tell coverage of a strand e.g. *Atmosphere and weather*; the contexts of the strands would shift to a new context every 2½ weeks, the concept-building experiences would be minimal and the load of new language would be overwhelming for learners. By the next Grade, few useful ideas from those 2½ weeks would remain in the learners' minds. We should not expect to see significant N.C.S. Learning Outcomes under those conditions.

On the other hand, by doing just one sub-strand per Grade, the teacher or curriculum writer can create a scenario in which the single context (e.g. the differences between seasons) becomes familiar to the learners. Now activities can build on each other over a number of weeks, term's-length projects can be set, learners can integrate understanding from other Learning Areas, and activities can lead to a "culminating performance" (Spady, 1994) or an integrating activity in which the learners can demonstrate their abilities in the Learning Outcomes in a somewhat authentic situation.

For similar reasons, only *The changing Earth* is tackled in Grade 4 and only *Planet Earth and beyond* is tackled in Grade 6.

Concepts	Suggested elaboration
1 Wind is moving air	Wind is moving air (and wind is not caused by moving trees, moving cars, etc.). This concept depends on the concept that air is a substance that exists even when the wind is not blowing, but we know that young learners do not easily think of air as a substance.
2 The wind directions	We describe the directions of winds in terms of east, west, north and south and the direction the wind comes from (e.g. "A south wind is blowing" or "In Cape Town a south-easter is blowing.") So learners must master the four cardinal points of the compass.
3 The shapes of clouds relate to weather	Clouds have different patterns or shapes and often the shapes of clouds are related to the present or coming weather. Learners should know a few of these cloud shapes, their names and the kind of weather they represent. e.g. drizzle, thunderstorm, approaching cold weather, fine weather.
4 Measuring rainfall	We measure rainfall by measuring the height of rain water in a container. Rainfall measurements over many years are useful records for farmers, engineers and weather forecasters. Rain is not the only way the land receives water – melting snow can release large quantities of water.
5 Water changes its state	Water can be in the states of liquid, solid ice and water-vapour. The word "state" is easer to understand than "phase" which is used is several different meanings.
6 Evaporation	Liquid water evaporates and changes to water-vapour, which is a gas. Evaporation happens from the surface of liquid water. We can slow down evaporation or make evaporation go faster. (Link to ***5.6 Heating and cooling***)
7 Condensation	Water-vapour in air can condense from the gas state and form drops of liquid water when it is in contact with cold surfaces. Learners must explain the origin of dew. (Link to ***5.6 Heating and cooling***. Note also that this concept will become very important in Grade 8, see topic ***8.5 The moving particles model of matter***.) Water-vapour can also condense to liquid water when the air has too much water-vapour in it, and so we may see condensation under glass even on a hot day.
8 The water cycle	A "cycle" is a series of events that occur again and again. (Link with concept of "life cycle".) Water changes its states as it evaporates from liquid to vapour and then condenses back to liquid as rain (or sometimes freezes to become a solid in the form of hail or snow) and then evaporates again. These events repeat over and over, and so they are called the water cycle. During the water cycle, the water moves from place to place, for example, from trees to clouds, which drop rain on distant mountains. The total amount of water on Earth does not change. The water a learner washed with today may have some of the water that a dinosaur swam in millions of years ago.
9 The seasons	The seasons are a predictable annual change in weather patterns, in temperatures and length of day. Examples of changes are: plants change appearance and animals change their patterns of behaviour. The position of the rising and setting Sun on the horizon changes. (Note that learners should observe, record and **describe** the changes but do **not** have to **explain** the reason for seasonal changes, as explained in the research section that follows on ***8.3 The atmosphere on Earth***)
10 Air temperatures	We measure the temperature of the air or water using thermometers. Scientists record these temperatures over many years to look for patterns in the weather. These patterns are useful to weather forecasters, farmers, engineers, pilots and sailors. (Learners need to know what a thermometer shows, how it works and be able to use it. Link to ***5.6 Heating and cooling***)

11	Limits of land and of drinkable water	Only about 30% of the planet Earth is land, and all the rest of the planet is covered by oceans. Only about 5% of the land is suitable for people to live on and grow food. Though the oceans contain so much water, it is salty and so people cannot drink it or grow food with it. Only about 1% of all the water on Earth can be used by people, and a third of that water is under the ground.
12	The equatorial regions and the polar regions	The equatorial regions of the planet Earth are warm or hot all year round, and plants grow quickly because of the high rainfall, warmth and sunshine. The polar regions of planet Earth are very cold and parts of these regions are permanently covered in ice. Very few plants can grow there, and these plants are very small.

Research on learning and teaching this topic

One of the key concepts in this topic is water's changes of state. It is these changes of state which are involved in all weather phenomena. The difficulty for learners is that when water evaporates it becomes invisible.

In Grade 5, learners need to develop a kind of thinking which learning theorists call **operational thought**. The essence of operational thought is that the learner increasingly can think about what will happen in a situation by making pictures in her head, whereas she previously needed to have real things in her hands or she needed to "try it and see what happens." This operational thinking is an important ability, but it will not develop properly unless the lessons are planned so as to exercise the learners' "mental muscles".

One kind of operational thinking is called "object permanence" or, in science education, "**conservation of substance**". What this means is that children who have "conservation of substance" immediately realise that if a substance becomes invisible or moves out of sight, the substance still exists. (Young children, who are not yet doing this kind of thinking, see no reason to wonder where the water goes when it "dries up" – for them, it no longer exists and there is no need to explain anything.)

Another kind of operational thinking is called **empirical reversibility** – for example, reversibility means that the child comes to works out for himself, "If I can make water evaporate and disappear, then I could reverse the evaporation and get the liquid water back again."

Sequencing is another kind of operational thinking. Learners who can sequence don't see events as separate observations but they see them in a sequence, where one event leads to another. Water cycles are an example of such a series of events, where temperature changes cause water to evaporate, become water-vapour, then moving air may transport the water-vapour to another place, then water-vapour condenses as temperature decreases, then water droplets merge until they are too heavy to stay suspended among air molecules, and then drops of water fall as rain. "Then . . . and then . . . and after that . . ." is the language of sequencing. This is similar to the language of life cycles.

Good science teaching accelerates the growth of operational thinking. For example, a child may see a wet shirt become dry, yet feel no need to ask where the water has gone – for him, the water has simply gone, disappeared. So the teacher should challenge the child to think about his assumption – does the water no longer exist? The teacher hangs a small wet cloth inside a large, closed glass container and soon drops of water begin to appear on the inside walls of the container. The teacher challenges his learners to explain where these drops are coming from.

Not all learners will be able to work out an explanation, but that doesn't matter – the teacher is confronting them with appropriate challenges which develop their mental abilities.

Russell and Watt (1990) report that learners brought a range of ideas to this conservation problem: for example, an open container of water was left in the room, and after a few days the water level had gone down. The younger children simply said the water had gone, or someone had drunk it. Older children talked in terms of water turning into mist or droplets. Few talked about evaporation.

Now to quote from *Atlas of Science Literacy* (2006)

> Before students understand that water is converted to an invisible form, they may initially believe that when water evaporates it ceases to exist, or that it [*moves to some other place*] but remains a liquid, or that it is transformed into some other perceptible form (fog, steam, droplets, etc.) (Bar, 1989; Russell, Harlen, & Watt, 1989; Russell & Watt, 1990; Krnel, Watson, & Glazar, 1998). With special instruction, some students in 5th grade may be able to identify the air as the final location of evaporating water (Russell & Watt, 1990), but they must first accept that air is a permanent substance (Bar, 1989).
>
> For many students, the difficulty in understanding the existence of water vapour in the atmosphere persists in middle school years [Grade 4-7] (Lee et al., 1993; Johnson, 1998).

3 Other factors in understanding weather

- The New Zealand Learning in Science Project researchers (LISP, 1980) found that almost all children saw the Sun as an important cause of changing weather and related the Sun to evaporation and winds, but some children were much less clear about **how** the Sun causes evaporation and winds (Moyle, 1980). These researchers also found that a significant percentage of learners saw the Moon as a factor that causes changes in weather. In South Africa we have an echo of this in the views of people who will say that when the Moon appears as a "C" shape leaning back, it is "holding water" and so rain will not fall.
- Learners think of weather only in terms of the weather in the place where they live and on that particular day; they seldom have a more general concept of weather as the conditions at any place and at any time.(Flanagan, 2009, pers comm)

4 The meaning of "atmosphere"

In South Africa, the Primary Science Programme (PSP) found that learners did not think of air as a substance that spreads to occupy all available spaces; the learners saw air existing around people's noses and mouths (Dire, 1995, pers. comm.). The PSP teachers had to ask questions such as "Is there air in the cupboard? Under the table? In this cup?"

The Science for All Project found that learners saw air as something different to the atmosphere; "air is what we breathe" or "air is all around us" but these same learners would also say "the atmosphere is up high above us" (Science for All Project observations, 1996).

Examples of activities to build concepts and language

Learners can

- **infer** that air occupies apparently "empty" containers (e.g. after pushing glasses mouth-downwards into water or trying to compress air in a syringe)
- **hypothesise** about what happens when a wet footprint "dries up" (with emphasis on "how could you test that idea?")
- **infer** that they are part of the water cycle by breathing onto cold glass and seeing the condensation there.
- **hypothesise** reasons why water appears on cold surfaces, such as the inside of a corrugated iron roof on a winter night (with emphasis on "how could you test that idea?") (Note that learners' experiences of this Grade 5 will be a basis for understanding ***8.5 The particle model of matter***

- **keep records** of temperature, wind direction and rainfall over a month and look for patterns in the records.
- **identify** real clouds (cirrus, stratus, cumulus, cumulo-nimbus) by **interpreting** pictures of them and relate them to present or coming weather (Note that this may be familiar knowledge in rural children.)
- **interpret** weather records (the other implied process skills here are data-handling, drawing bar-graphs of rainfall, predicting from patterns in line-graphs of annual temperature variation.)

5.4 Fair testing and comparison of materials

Reasons for placing this in Grade 5

This topic extends the learners' concepts of matter and materials (from ***4.4 Choosing and changing materials***) and it provides some enjoyable tasks of comparing materials by hitting, scratching and stretching them[3].

This topic focuses much less on content than the other topics in this Content Map do and is focused on the skill of fair testing. This is fair testing in its simplest form but it prepares the learners for the Grade 6 Assessment Standards on investigating and problem-solving (Learning Outcome NS1).

Concepts	Suggested elaboration
1 A material	Matter is any kind of solid, liquid or gas. When we choose to use one kind of matter (= a substance) to make something, we usually call it a material.
2 Properties of materials	We choose materials because they have the properties we want. The properties of a material are the ways we can describe it. Examples of properties of materials are its colour, smell, hardness, its toughness (how much damage it can take without breaking), its flexibility (how easily it bends without breaking), its strength when we stretch it, or how easily it melts.
3 Comparing materials	To test and compare similar materials, we find ways to compare them fairly. When we compare them, we must use the same method on all of them.

Research in learning and teaching this topic

The main process skill in this topic is **designing fair tests**. A part of this skill is that learners find some way to keep a record of what they do to the objects (such as how the objects were bent, dropped or stretched) and to keep a record of the effects (such as amount of bending, damage or elongation). These records can be in pictures, symbols or written in tables.

This does not necessarily mean using measuring instruments like scales and rulers, because then the problems of using the instruments can override the main focus which is to compare the materials. Instead of using instruments, learners can check that they drop weights onto plastic bottles from the same height, or give them the same number of blows with a hammer, or they might ensure that it is always the same weight that stretches the rubber bands that they are comparing.

Children readily grasp the idea of fair comparisons and are alert for ways to keep everything the same for every test (Science for All project observations, 1997 – 1999). They will even suggest that only learners of the same height should carry out the test, or that the same pen must be used for writing the results!

The pedagogical issue in topics like this is that the teacher must not seek to assess the children's knowledge of some fact, but should assess the extent to which learners can test the materials or compare the materials in a controlled way. In NCS terms, the teacher should be assessing progress in Learning Outcome NS1 *Scientific investigations.*

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[3] This topic should not be given longer than 5 hours, even though learners will happily find many more items to test in this way!

Examples of activities to build concepts and language

Learners can:

- Think of ways to make a fair comparison of different kinds of plastic bottles (of the same shape) for toughness, and then carry out their test. The test could mean filling the plastic bottles with water, putting on the caps and dropping them (always from the same height) and comparing the damage. Or learners might decide to drop a brick on the bottles. Or they might plan a similar experiment with plastic bags full of water.
- Think of ways to **compare** three kinds of glue, while being fair, to decide which is the stronger glue.
- Follow instructions to melt the wax of two kinds of candles and use a thermometer to **measure** the melting temperature of each kind of wax.
- Follow instructions to **compare** three kinds of plastic ruler for flexibility. This might involve holding the rulers down at one end and bending them to flick objects across the room.
- Think of a fair way to **compare** three kinds of wood for hardness. This could mean placing a nail on the wood and dropping a heavy object down a tube onto the nail. Then the learners measure the depth that the nail goes into each piece of wood.

5.5 Energy for heating things

Reasons for placing this in Grade 5

This topic in Grade 5, and the next one, ***5.6 Heating and cooling causes changes in materials*** begin a line of development through Grade 6 (using electricity for heating things) and onward to Grade 7 (ways of generating electricity, which in homes is mostly used for heating water, food and air in rooms). It also takes in the fire safety aspect because fire is such a common cause of injury to children.

Concepts	Suggested elaboration
1 Fuel-burning systems	We can heat materials by using fuel-burning systems like gas, wood and paraffin stoves. The **system** concept is important in this topic; a system is a set of parts that work together. For example, making a cup of tea requires a **system** of a pot or a kettle, water, fuel, and something that will keep the flame close to the water but also be safe for the user. Readers can extend this to another example such as a solar cooker.
2 Energy from the Sun	But we can also heat materials with systems using the Sun's energy. This can involve systems such as solar cookers, magnifying glasses, or systems of mirrors.
3 Sources of energy for heating	Heating changes substances and for this change to happen we must have a source of energy such as air and candle-wax, or air and paraffin, or air and wood, or sunlight. Materials such as candle-wax, paraffin, wood and other substances such as charcoal are called **fuels**. They will burn if they are hot enough and have enough air to burn with. **Source of energy** is the second key concept in this topic. The materials we call fuels (together with air) are **sources of energy**. Of course they are not the only sources of energy we use for heating things – sunlight is another source of energy. Electricity is another source of energy and we will deal with that in Grade 6.
4 The fire triangle: fuel, air, source of energy.	Fire needs three things in order to burn: fuel, air and a source of energy such as a spark, or two objects rubbing together and becoming hot, or an electric current in a wire, or sunlight being focused through a piece of a broken bottle. To stop or prevent a fire, we must remove one of those three things. The "fire triangle" is a way to help learners remember this.
5 Safety with fires	Candles, paraffin, gas and braziers are all dangerous in different ways, and people must know how to work safely with them. Fires may cause people to suffocate and die. This may happen because fires use the air that we need to breathe, and fires produce other gases that we cannot breathe. To be safe when using a fire, we must make sure there is enough air coming into the room, must not sleep with a brazier in the room, and be sure there is no material nearby that can become fuel for the fire. (This concept does not require that learners must know about oxygen gas and nitrogen gas as the constituents of air, which is a mixture of gases.)
6 Emergency action in case of fire.	Everyone should know what to do if their clothing begins to burn: stop, drop and roll. Everyone should know what to do if they are in a burning building: cover nose and mouth with wet cloths, crawl on the floor, touch metal doorknobs only with a thick cloth.

Research in learning and teaching this topic

The concept of energy develops gradually over the course of the GET and FET curricula, as the learners have more and more experiences of using the concept. Energy is a powerful idea because it helps to explain many changes in both living and non-living materials. At this stage, learners probably will not benefit from a formal definition of energy, because it is too general and they still need to explore the specific situations in which we talk about energy.

At this point, you should go down the page to the heading, **Language Concerns**, read that section, and then return to here.

The science concept of energy must develop from the learners' experiences of changes to materials and systems. As we will see in Grade 6 and beyond, the energy concept applies to many different changes in materials and systems; here in Grade 5 we focus on the idea of changing materials by heating them. In this topic, we focus on the idea that materials may get hot when we give them energy. For example, if water in a pot begins to boil, we infer that some source of energy has given energy to the water. **We don't see the energy itself**, we see water boiling, but we **infer** that its energy has increased.

We will go on to explore more changes to materials in topic ***5.6 Heating and cooling causes changes in materials***.

Language Concerns

The word "energy" is used in at least three ways. People use it in everyday conversation, as in "the new school principal is a very energetic person" or "I feel full of energy this morning". "Energy" is also used in a journalistic way by news reporters. For example, a reporter may write "South Africa has an energy crisis" or "We should harness wind energy".

Thirdly, there are more precise scientific meanings of "energy", such as in the sentences "hot things transfer energy to colder things" or "a car battery is a source of energy".

We want all our learners to use the third set of meanings accurately by Grade 9, but both learners and teachers live in a world where people may use the word "energy" in all three ways. We cannot avoid that, so we must enable learners to talk about energy and see that there are these different ways to use the word. The important thing is to provide the experiences, activities and opportunities for **the learners** to speak about energy. Then we begin to move toward the more precise meanings of "energy", Grade by Grade.

The concept of a gas

Gas as a concept will still need developing, even though the concept of gases was included in topic ***4.4 Choosing and changing materials***.

Many learners limit the meaning of "gas" to the propane gas that hisses out of a gas cooker, or for them the word means "electricity" (*igesi*) or has the generalised meaning of energy.   Some learners will regard a gas as just a smell, and not think of a gas as a substance at all (Russell, Longden and McGuigan 1991, p.33-38).

Examples of activities to build concepts and language

Learners can

- Make sun-powered stoves or water heaters (There are many process skills in this activity, such as **making hypotheses** about which system will work best, and **predicting** whether changes to their system will improve its performance.)
- discuss questions such as, if you were selling water, would you charge the same amount for hot water and cold water? Give a reason for your answer. Now develop your reason using words like "changes to the water", "energy", "source of energy", "money you pay for the source of energy", "cheap and expensive sources of energy".
- use burning-glasses (large hand-lenses) to burn paper, start a small fire, or melt substances like wax.
- Investigate burning candles and make **careful observations** of what really happens when the wick lights, and when it is burning steadily. Develop language to describe the connection between air, fuel and heat (e.g. **hypothesising** what will happen if we take away the air, and **planning an investigation** to answer the question.)
- create a list of safety rules for using fire in paraffin stoves, gas stoves (e.g, CADAC, Handigas, Easigas), candles, the *mbawula* (**interpreting** stories of accidents, **predicting** the effect of safety precautions, **interpreting** pictures that show potentially dangerous situations.)
- make a candle-holder that cannot fall over easily or accidentally set other materials alight. (**Hypothesising** reasons why candles fall over or get knocked over, **predicting** the effect of changes to a new kind of candle-holder, **making** the system and **testing** the idea)

5.6 Heating and cooling causes changes in materials

Reasons for placing this in Grade 5

The topic progresses the ideas of topic ***4.4 Choosing and changing materials*** in which learners work with solids, liquids and gases, and ***4.3 The rocks of Earth*** which has the concept of molten rock. The topic reinforces topic ***5.3 Atmosphere & Weather*** in dealing again with water's changes of state. The concepts related to heating materials grow from Grade 5, into Grade 6 where learners must be able to measure temperatures and distinguish melting from dissolving, and then on to Grade 7 where they must solve problems to do with heating and cooling in ***7.7 Controlling heating and cooling***.

The energy concept (which includes heating and cooling) has to be built up gradually over the Grades, as learners talk about the situations in which things gain or give away energy.

So giving the learners a definition of energy is not a help to them because it is too general and abstract – rather, they need many **experiences** of energy systems in which they can talk about the various meanings of the term "energy". However, **for teachers**, a simple definition is that energy is the ability of a system to cause changes in other systems. An illustration: your body is a system (a biological system) and it has energy (from the food you ate). You reach out to the window (a mechanical system), and change it by twisting the handle and opening the window. Your energy goes into overcoming the friction in the handle and displacing the air that was next to the glass.

> At this point you should read the Research section above in Topic ***5.5 Energy for heating things***. Note especially the Language Concerns section.

Another reason for placing this topic in Grade 5 is that the learners are at an age when they should be developing operational thinking. In this topic we have solid substances being heated, then melting to become a liquid and then evaporating to become a vapour (a gas). This process can be **reversed**: if we let the vapour cool, then it becomes a liquid, and if we cool the liquid enough, then it becomes a solid. Children in Intermediate Phase usually do not think of **reversing** a process unless we press them: "We heated the wax until it turned to liquid and then to vapour. Now what will happen if we take away the flame and let everything cool down?"

Another mental ability that children must develop is called **conservation of substance.** Conservation means that they recognise automatically that the quantity of a substance stays the same even if the substance changes shape. This ability matters, because not only do substances change state, they also expand and contract. In this topic we have solids, liquids and gases that expand and contract, yet learners must understand that the quantity of substance has **not** changed, and that **no matter has been created or lost**.

Concepts

Concepts	Suggested elaboration
1 Change of state on heating and cooling	Heating materials can make them change state from solid to liquid to gas. Cooling can reverse those changes of state. If a material becomes hot, if means that it is gaining energy, and when it cools, it is losing energy.
2 Gaining and losing energy	To change materials from solid to liquid to gas, we must give energy to those materials by heating them. When materials cool down and change from gas to liquid to solid, they do so by giving away energy to other things around them, and those other things warm up.

3	Expansion and contraction	Most substances (solids, liquids and gases) expand when they become hot, and they contract when they become cold. (There are a few exceptions to this e.g. synthetic materials such as nylon)
4	Temperature and thermometers	Thermometers use expansion and contraction of materials to show changes in the temperatures of things. Temperature is the way we describe how hot a thing is.
5	Evaporation causes cooling	When liquids evaporate, they take energy from their surroundings and this leaves the surroundings cooler than before. (Link with ***5.3 Atmosphere & weather***, and evaporation of water)

Research on teaching and learning this topic

Erickson (1979) records some common misconceptions children have about heat: they think heat is like air or another gas – for them, heat is a substance that flows into objects and then leaves them again. Also, some children believe that all objects contain a mixture of heat and cold, and the mixture of heat and cold inside an object is the temperature.

In South Africa, the Science Education Project found similar ideas among learners in Grade 8 to 10, who viewed heat as a gas that enters and leaves an object, when the object heats up or cools down.

There was a language complication too, in that "gas" was used as an alternative term for "energy." This might be due to the similarity between the African-language terms for electricity, *igesi / ugezi* and the English word "gas" or even the American term "gas" meaning petrol.

Most learners' ideas about energy begin from the knowledge that "people have energy" – that is, they can move quickly and do work. Linked with this is the idea that we get energy from food. This is quite acceptable as one of the science meanings of energy and we must build on it.

Learners probably have another set of meanings for the word "energy", namely that energy is something that you pay for – to cook, heat water, heat the house – and that energy gets "used up". Usually, the learners are thinking of paraffin, petrol or the value on a pre-paid electricity card. By Grade 7 we have to make sure that they can distinguish between the **energy resource** (such as the paraffin) and the **energy** that we get from it (for example, when we burn it with air in a stove).

Examples of activities to build concepts and language

Learners can develop these concepts by activities that involve process skills such as those suggested in bracket after the examples. Learners can

- rub their hands together until the hands are hot and then transfer that energy to a cool glass (**making inferences** about where the energy came from in the beginning and how it reached the glass)
- bend a piece of wire rapidly back and forth as though they intended to break the wire; their partner will feel the wire becoming hot at the bend. (The concepts are that (a) they have energy in their bodies and (b) can transfer some of the energy to the wire or other objects) (**applying the concept** that for the wire to become hot, it needs an energy input)
- Other materials change their state too. Wax melts but becomes solid again. (**interpreting** pictures of substances expanding and contracting, arranging them in correct order)

- investigate cooling effects as water and other liquids (e.g. meth spirits) evaporate, comparing the cooling effects of water and other liquids that evaporate more quickly or more slowly than water. (**Planning a fair comparison** of two liquids that evaporate and cause a cool feeling on the skin)
- make thermometers using liquid expanding in a tube (**comparing** the expansions when the thermometer is placed in water of different temperatures).
- investigate how materials behave when two materials (e.g. cooking foil and masking tape) are glued together but one expands much more than the other (**predicting** and testing the effect of heating and cooling such composite material).
- discuss examples of expansion and contraction and visible phenomena like telephone lines that hang lower on a hot day, or **hypothesising** why roofs make noises on a cold night, or steel rails have expansion slots.
- observe and explain the changing shape of a plastic container when the air sealed inside it expands and contracts (**making inferences** about the quantity of gas – is there more gas when the container expands?).
- observe sodium hydrogencarbonate (bicarbonate of soda) give off a gas when it is heated. This gas will bubble out of a container if the mouth is connected to a pipe that goes under the water. (The focus of such an activity is the observation that heating causes an interesting change in the solid white powder; the focus is not the chemistry of it.)

Grade 6 Topics

These notes focus on the **science knowledge** in the NCS. But the science knowledge is not the curriculum, and these notes are not a learning programme. The curriculum is about learners using the knowledge to produce outcomes. So these notes are just the basis for learning programmes that build the Assessment Standards for Learning Outcome NS1 ***Scientific Investigations*** and Learning Outcome NS3/Tech3 ***Science, Technology, Society and Environment***, as well as building the Assessment Standards of Learning Outcome NS2

6.1 Environments and water resources

Reasons for placing this in Grade 6

The topic ***5.1 How living things depend on their environment*** was done in Grade 5, and this topic is placed in Grade 6 to continue the development of the NCS unifying statement called "Interaction in Environments" which you see in Layer One. It will be followed by ***7.2 Description of the living and non-living things in a small environment*** to continue development of the same unifying statement.

Concepts	Suggested elaboration
1 Water in ecosystems	Water in an ecosystem supports plant and animal life and biodiversity in many ways. Planet Earth is like a very big ecosystem and all life on Earth depends on its water. However, almost all of the water (97%) is in the sea and neither plants nor land-living animals can use it because it contains dissolved salts. Of the remaining 3% which is fresh water, almost all of it is in the icecaps or under the ground. So only 0.3% is left in rivers, lakes and dams and this is the water we mostly use.
2 Wetlands	Wetlands are habitats for many animals and they act as sponges that regulate the flow of water. Wetlands are stop-over points for certain kinds of birds that migrate every year.
3 Groundwater	Groundwater (= underground water) is a very important resource for humans in South Africa, and groundwater is fed by wetlands and catchment areas.
4 Catchment areas	A catchment area is the land that receives the rainfall or snow-melt that eventually feeds rivers and wetlands. Human activity in a catchment area affects the quality of water that comes from the catchment area.
5 Protecting water catchment areas	As people demand more water to use, the more important it becomes to preserve catchment areas, springs, wetlands, rivers and the groundwater that supplies boreholes. The amount of water on Planet Earth does not change, it just moves from place to place on the planet. But if the water becomes polluted, then the amount that we can use for drinking and growing crops does change – it becomes less.
6 Water supply and sewerage systems	Water supply systems and sewerage systems are basic systems that improve the health of people. Clean water and sewage have to be kept separate even though they usually flow in pipes close together. (Place emphasis on how to avoid damage to water supply and sewerage systems.)
7 Water storage	Ways of storing water and cleaning it (tanks, simple filtration, use of chlorine).

8	More electricity means less water to use.	Electricity generating power-stations take large quantities of water which evaporates after cooling the systems in the power-stations. The coal-mines which produce coal for the power-stations pollute the soil and rivers. Therefore, if we use less electricity, we help to save our water resources. (Link with ***6.8 Energy from electricity***)

Research in learning and teaching this topic

Learners in under-serviced rural areas are often confronted with issues of water resources (including basic chores of fetching water, water sources that dry up, conflicts over water sources, pollution of water by animal and human waste, fears of cholera).

In urban areas with piped water and water-borne sewerage, the problems of understanding water supply are greater. The reason is that learners can open a tap to draw water but have no way of visualising the processes and systems that clean the water and bring it to the tap. In some cases this lack of awareness in urban areas shows itself in taps left running continually, as though learners think that the stream from the tap is simply an indoor river.

Learners may also have no knowledge or awareness of what happens to the water after it goes down the plughole or down the toilet. This lack of knowledge sometimes shows itself in the way users treat sewers as though they were rubbish disposal systems. Water utilities like Rand Water report blockages and breakdowns caused by balls of newspaper, or plastic, or kitchen waste in sewers, and old motor oil being dumped into sewers.

These issues represent a major education task for schools, because the quality of water supplies in South Africa has emerged as the single greatest concern facing our society in the next 20 years. [cite articles from Engineering News]

Examples of activities to build concepts and language

Learners can

- read and **interpret information** on water supply systems, transform the information into models of a water supply system and then add to the model to show where the waste water and sewage goes
- find out, with help from local authorities or farmers, where the school's water comes from and how it is cleaned (if it is cleaned at all). They **interpret** this information by drawing pipes on a map that includes the school. They should do the same for the sewage pipes if the school has water-borne sewerage
- **investigate** a wetland near the school to describe what lives there, where the water comes from in normal times, what happens in times of flood.
- **read and interpret** descriptions of what happens when wetlands are filled in for farming or building.
- clean a river near the school, and **hypothesise** reasons why it became polluted
- make models of underground water and boreholes. They investigate the effect of placing oil or soluble pollutants in the soil. The learners should realise that when rain falls, the pollutants are carried downwards to the underground water.

6.2 Nutrition and digestion

Reasons for placing this in Grade 6

Many of the concepts in the NCS *human life processes* section (topics 6.2, 6.3 and 6.4) require learners to visualise (i.e. work with mental pictures of) processes, structures and systems that we cannot see. For example, to do appropriate tasks they need to visualise the way their muscles are connected to different bones, or visualise food particles being absorbed in the intestine.

This ability to "work with pictures in your head" takes time to develop in children and so these three topics are placed in the last Grade of Intermediate Phase. Placing the three topics together allows teachers to follow a well-known theme like "Me and my body".

Concepts		Suggested elaboration
1	Balanced diets	Our health depends on us eating a balanced diet made up of different food types. A simple classification of food types is: protective foods, foods for growth and repair, and foods for energy.
2	Micro-nutrients	Food must contain micro-nutrients such as vitamins, trace elements.
3	Diets and cultures	Balanced diets have correct proportions of the food types. Each culture has different eating traditions but in past centuries each culture found foods that provided a balanced diet. Modern eating habits have often lost that hard-won traditional knowledge of balanced diets.
4	The immune system	Some foods boost the human immune system and are valuable for people with HIV.
5	The digestive system	The digestive system breaks down food into very small particles (molecules) which can pass through the wall of the intestine; the body absorbs these particles and uses them for protection, growth and repair and energy. (The particles are in fact molecules. See the note below.)

Research in learning and teaching this topic

Learners' basic understanding of energy is in terms of people's ability to move their bodies, getting energy from food, or energy as something that you pay for and that gets "used up"(like petrol or the value on a pre-paid electricity card); therefore activities must address these meanings of energy, and allow learners to put their ideas about them into words.

Learners have difficulty relating the intake of food to growth. The puzzle is seen in the teacher question, "You ate and drank about 50 kg of food and water in the past month; yet you are not 50 kg heavier. Your weight hardly changed, so where did the food go? And what would have happened to you if you had **not** eaten the food?"

Learners also have difficulty understanding how grass can be turned into meat (by a cow, for example) or why eating pumpkin does not make the skin yellow with tiny bits of pumpkin.

The processes in which food is broken down in the digestive system are complex; the processes by which the molecules from the food are taken into cells and used there are even more complex. These processes will be touched on in Grade 9 and done in more depth in Grades 10 -12. The aim in Grade 6 is simply that the learners should understand that their bodies need foods of different types in order to be healthy.

Research on children's conceptions of health are in papers by Brumby, Garrard & Auman (1985) and in Moon, Wetton, & Williams (1985).

Examples of activities to build concepts and language

Learners can, for example,

- investigate diets that help HIV-positive people, using information about the nutrients in a variety of foodstuffs
- interpret a model of the intestine that illustrates how the digestion process breaks down food into such small particles that it can pass through the walls of the intestine. A model can be made with, for example, several layers of stocking/pantihose material.
- compare modern supermarket or fast-food diets and traditional diets
- test foods for starch and fat, using the iodine and paper methods
- investigate and do measurements to find out how much water is in, for example, a cabbage. Learners must **plan an investigation**, use a scale to **measure** masses.

6.3 Plants' and animals' responses to their environment

Reasons for placing this in Grade 6

The reasons for doing this in Grade 6 are the same as for topic 6.2: the teacher can develop a theme like "Me and my body" so that the concepts are linked by a common context.

The suitable activities in this topic build towards the "simple tests and surveys" which are expected in the Grade Level 6 Assessment Standards, Learning Outcome NS1.

Concepts	Suggested elaboration
1 Living things can respond to changes	Living things can respond to changes in their environment. These responses help them or the species to survive by avoiding danger or dehydration, finding food, hatching at the right time, finding mates, etc. (Learners should work with examples of responses to stimuli such as light, sound, touch, vibration, smells, tastes, and consider humans, plants and animals.)
2 The functions of sense organs	Humans and animals have sense organs of hearing, vision, taste, smell, and touch. (The emphasis must be on their functioning and capabilities, rather than on their structure, which will be done in Grade 9.)

Research in learning and teaching this topic

No research available yet.

Examples of activities to build concepts and language

Learners can

- make a map of the parts of the tongue that taste salt, sweet, sour and bitter. They repeat the taste-tests with a number of fellow-learners and learn that results are not always exactly the same. (Process skills are **designing** a **fair test**, **observing**, **recording**, **classifying** substances by taste)
- compare the ability to taste foods like apple and potato when the learner can smell the food, compared with the result when the nose is blocked (**designing a fair test**, **observing**, **recording**, making **inferences**)
- observe the speed with which the pupil of an eye contracts when it is suddenly exposed to light, and compare this with the time the pupil needs to open again in the dark (**observing**, **measuring** and **comparing**)

6.4 How animals and humans move themselves

Reasons for placing this in Grade 6

The reasons for doing this in Grade 6 are the same as for topic 6.2 and 6.3: the teacher can develop a theme like "Me and my body" so that the concepts are linked by a common context. In Grade 9 learners will deal with the human musculo-skeletal system in more detail, and so detail of the skeleton is not needed in Grade 6. However, the human body can provide an example of an endo-skeleton, and in Grade 7 learners will meet the other vertebrate groups of animals with endoskeletons that move themselves by flying, swimming, crawling etc.

Concepts	Suggested elaboration
1 Skeletons and muscles	Humans and animals are able to move their body parts and move themselves from place to place because they have a skeleton and muscles to move the parts of that skeleton. Lessons should deal with the musculo-skeletal system of humans. The emphasis must fall on how the bones are joined so that movement is possible; learners do not need to know the names of many bones.
2 Muscles can only contract	Muscles can only shorten (contract) in order to pull on bones, they cannot push the bones. Muscles move parts of skeletons because they are connected onto different bones and they pull these bones towards each other. The bones stay in place but can move around each other because they are connected by joints.
3 Endoskeletons and exoskeletons	In humans and some animals, skeletons are inside the body (these are called endoskeletons) and in other animals the skeletons are outside, with the muscles inside (exoskeletons). Lessons should deal with at least one animal with an exoskeleton.

Research in learning and teaching this topic

Meaningful learning in this topic requires learners to relate the concepts to their own bodies. Both learners and teachers, when they are asked to feel the bones and muscles in their own arms or jaws, have some difficulty in visualising and drawing the way their muscles are connected to bones and are able to move those bones (*Science for All project* observations 2003). This difficulty seems to be present even when learners have diagrams of these structures to look at.

All learners need to visualise (make pictures in the mind) the internal structures of their bodies. Mathai and Ramadas (2009) found learners in India who were able to give very good verbal descriptions of their body structures but had much difficulty in drawing them or interpreting drawings of them. They explain that the ability to draw the structures is important because it enables the learners to relate the functions of body systems to their structures, consider how function would be affected if the structure were changed, and have more than one way to let the teacher assess their understanding of the body system. A quotation from their paper is useful here:

> Visuals need to be understood and interpreted within a culture and context. In oral cultures exposure to pictures comes about through schooling. Liddell (1997) found that South African children interpreted less from pictures than their Western counterparts, who used pictures as a bridge to language development. They used pictures in a passive form; labelling and linking associated with picture interpretation progressively decreased through the school years. This is an area of pedagogy that needs attention.

(Mathai and Ramadas, 2009. Page 455)

Examples of activities to build concepts and language

Learners can

- feel the muscles in their own arms, calf or jaw, and try to work out where the major muscle is connected, at each end, to two bones. They should then try to draw the bones and muscles. As a further step they can compare their drawings with diagrams the teacher provides. (Process skills are **observing**, making **inferences**, **recording** by drawing, **making hypotheses** which they can then check, **interpreting** models)
- make models of lower legs or arms, comparing their models with the structure of their own arms or legs, and add parts such as rubber bands to represent muscles (**interpreting** observations or drawings to make models, **making hypotheses** to check against the real leg or arm)

6.5: Simple astronomy

Reason for placing this in Grade 6

Astronomy has become a popular topic in science curricula in the past 20 years and many learners have positive attitudes towards it. In terms of the international astronomy research effort, South Africa has a geographical advantage with clear night skies to view the southern sky, and astronomy has been designated by government as an area for extra funding. These are reasons why astronomy was included in the NCS at Intermediate Phase.

However, the concepts in astronomy require the ability to mentally shift one's point of view from the classroom on the surface of the Earth, to a position far out in Space and look back at the Earth and Moon. Research on how children and adults learn this topic, reviewed by Lelliot and Rollnick at Wits University (2008), indicates that age 10 is the **earliest** age at which we should expect children to be able to do this.

Meaningful learning activities in this topic require learners to observe, record and interpret the movements of Sun, Moon, planets and stars. This needs some consistent and independent work by learners, but learners younger than Grade 6 might not be able to organise themselves effectively yet. For these reason we should teach this topic in Grade 6 and not before.

Reason for treating the whole of the sub-strand *Our place in Space* in one Grade

Readers may ask why only **one** of the three sub-strands in the Planet Earth strand (*Our place in Space*, *Atmosphere and weather*, and *The changing Earth*) is presented in Grade 6. The main reasons for doing this are

- to avoid concept and language overload,
- to allow new concepts to develop in a single context and
- to allow learners enough time for projects in which they can display competence in the Learning Outcomes and be assessed in a somewhat authentic context.

To elaborate, each of the three sub-strands in the *Planet Earth* strand has a number of new concepts (which must be built through repeated experiences), and their new vocabulary. These concepts (see the list below) are easier for learners to understand and put to use when they are **inter-related around a single context**, for example, noting and predicting changes that will occur in the sky during a month or a year. With a single context to think about, the learners can develop concepts and relate new vocabulary to a single set of activities, models and observations.

If the three sub-strands (*Our place in Space*, *Atmosphere and weather*, and *The changing Earth*) were attempted in one term, each sub-strand would get about 2½ weeks, or about 8 hours, of teaching time. Eight hours would allow only superficial teacher-tell coverage of a strand e.g. *Our place in Space*; the contexts of the strands would shift to a new context every 2½ weeks, the concept-building experiences would be minimal and the load of new language would be overwhelming for learners. Each sub-strand would not be revisited for perhaps another year and after that length of time, few useful ideas from the 2½ weeks would remain in the learners' minds. We should not expect to see significant NCS Learning Outcomes under those conditions.

On the other hand, by doing just **one** sub-strand per Grade, the teacher or curriculum writer can create a scenario in which the single context (e.g. the objects in the night sky) becomes familiar to the learners. Now activities can build on each other over a number of weeks, term-length projects can be set, learners can integrate understanding from other Learning Areas, and activities can lead to "culminating performances" (Spady 1994) or an integrating activity in which the learners can demonstrate their abilities in the Learning Outcomes in a more authentic situation.

For similar reasons, only one of the remaining sub-strands from *Planet Earth* is tackled in each of Grade 4 and Grade 5.

Concepts	**Suggested elaboration**
1 Earth as a ball in Space	The Earth is a sphere – a round ball – in Space. Space has no "up" or "down" direction. We are so small and the Earth is so big that the Earth looks flat to us.
2 The "down" direction and gravity	The "down direction" for everyone on Earth is towards the centre of the Earth. This implies the concept of **gravity as a force** between the Earth and everything near the Earth, that pulls things towards the centre of the Earth.
3 The Earth is spinning	The Earth-sphere has an imaginary axis from the south to the north pole, and the sphere spins (= rotates) around the axis, once in every 24 hours.
4 The Sun and stars only seem to move.	The spinning of the Earth means that the motion of the Sun and stars across the sky is only an apparent motion, appearing so to us who are actually moving past the Sun and stars.
5 Night and day	Night is caused by the Earth rotating away from the Sun's rays; parts of Earth that have night are in the unlit part of the planet. When it is night-time where we are, people in another part of the Earth are in daylight
6 The time of day differs, around the world.	The time of day is different for parts of the Earth to the east and west of South Africa. To the east, people see the Sun rise before we can see the Sun. To the west, people are still in night while we have sunshine. (Learners do not have to deal with longitude or calculate the hour in another country; just the concept of time difference is needed, with some examples.)
7 The horizon	The horizon behind which the Sun sets is simply the furthest part of the Earth's surface we can see. Over the horizon there is still sunshine. The clocks there may show an earlier hour, too.
8 The Sun marks the east and west directions	We describe directions in terms of east-west and north-south directions. The Sun rises on the eastern side of South Africa and sets on the western side. From the east-west direction we derive the north-south direction.
9 Objects in the sky	The bright objects we see in the night sky are different kinds of objects such as stars, galaxies of stars, planets, meteors, man-made satellites, the Moon. Some of them are relatively close (e.g. meteors burn up in the atmosphere about 100 km above us, while stars and galaxies are at vast distances from us).
10 Objects in the sky shine for different reasons.	The Sun and other stars and meteors make their own light, but objects like satellites, planets, and the Moon receive light from the Sun and reflect it (bounce it onwards) to our eyes. The Moon makes the Earth bright on some nights by reflecting light from the Sun onto the Earth.

11	Stars are still there in the daytime.	We cannot see the stars during the day because the atmosphere scatters the light from the Sun, making the sky blue, and this light is brighter than the light from the stars.
12	The movement of the Moon	The Moon moves in an orbit around the Earth and completes a cycle from full Moon to full Moon every 29½ days. (The Moon also spins on its own axis but it is not necessary to teach this).
13	The changing appearance of the Moon	The Moon seems to change its shape during the 29½ days because we see only the part that the Sun shines on, while the other part has no sunlight on it. From new Moon onward, we see more and more of the part that is lit by the Sun. (The monthly change of shape is **not** caused by the Earth's shadow)
14	The Moon marks special days	People use the changing shapes of the Moon (= phases of the Moon) to mark festivals and special times. (This involves teaching concepts of indigenous knowledge systems.)
15	The stars, navigation and special times.	People use the patterns made by the stars to find north and south at night in order to navigate. The rising of certain star patterns in winter or summer marks special times of the year. (This involves teaching concepts of indigenous knowledge systems.)

Research on learning about the Earth in Space

South African research in this topic has been presented recently by Sanders and Tunzi (2009), Cameron and Lelliott (2006), Kelfkens and Lelliott (2006) and Lemmer, Lemmer, and Smit, (2003). A review of research in how children and adults learn this topic was conducted by Lelliott and Rollnick of Wits University (2008), who reviewed 67 refereed articles published from 1976 to 2005. They find that in British and American studies, teachers and young learners were fairly successful in giving a scientific explanation of why night and day happen, using the concept of the Earth as a ball. But they go on to write that *Throughout the review period, studies have found that although* [students] *are able to describe the Moon phases, most students are unable to explain why they occur, or give a coherent account of the Earth-Sun-Moon system*. However, they also suggest that the reasons for low performance are (a) poor illustrations in textbooks and (b) teachers not using physical models that enable learners to construct the correct mental images of the Earth-Sun-Moon system. In their view, age 10 is the minimum age at which learners should be asked to work with these concepts.

Vosniadou (1991) suggests that the concepts of a spherical Earth, Space, and gravity must be taught in close connection to each other. To quote from the Atlas of Science literacy (2006),

> Students' ideas about the shape of the Earth are closely related to their ideas about gravity and the direction of "down" (Nussbaum, 1985a; Vosniadou, 1991). Students cannot accept that gravity is centre-directed if they do not know the Earth is spherical. Nor can they believe in a spherical Earth without some knowledge of gravity to account for why people on the "bottom" do not fall off. Students are likely to say many things that sound right even though their ideas may be very far off base. For example, they may say that the Earth is spherical, but believe that people live on a flat place on top or inside of it—or believe that the round Earth is "up there" like other planets, while people live down here (Sneider & Pulos, 1983; Vosniadou, 1991).
>
> Elementary school students typically do not understand gravity as a force. They see the phenomenon of a falling body as "natural" with no need for further explanation or they ascribe to it an internal effort of the object that is falling (Ogborn, 1985). If students do view weight as a force, they usually think it is the air that exerts this force

(Ruggiero et al., 1985). Misconceptions about the causes of gravity persist after traditional high-school physics instruction (Brown & Clement, 1992) but can be overcome by specially designed instruction (Brown & Clement, 1992; Minstrell et al., 1992).

Students of all ages may hold misconceptions about the magnitude of the Earth's gravitational force. Even after a physics course, many high-school students believe that gravity increases with height above the Earth's surface (Gunstone & White, 1981) or are not sure whether the force of gravity would be greater on a lead ball than on a wooden ball of the same size (Brown & Clement, 1992). High-school students also have difficulty in conceptualizing gravitational forces as interactions [in other words, they have difficulty understanding that the Earth pulls on the Moon, but the Moon also pulls on the Earth with an equal force, causing tides]. In particular, they have difficulty in understanding that the magnitudes of the gravitational forces that two objects of different mass exert on each other are equal. These difficulties persist even after specially designed instruction (Brown & Clement, 1992).

The Learning in Science Project in New Zealand (1980, Working Paper - Gravity), reported the following misconceptions that many students hold:

✗ Where there is no atmosphere there is also no gravity. This misconception usually arises from images of astronauts seeming to be “weightless” in space, floating near a space-craft and wearing breathing apparatus.

✗ On the Moon there is no gravity. This is probably an extension of the idea above. Among Grade 8 students, approximately equal numbers held this misconception that, compared to the number who held the scientific view that the Moon has gravity, though weaker than on Earth (N= 258). If we think of the model of the Earth-Moon system, half these Grade 8 learners have no explanation for that fact that the Moon does not fly off into Space.

✗ Gravity on Earth results from the spinning of the Earth. These students had formed their own connection between the concept of gravity and the Earth’s spin to form the misconception that if the Earth stopped spinning, we would float off into Space.

✗ Objects that float in water, and birds that fly in the air, do not feel a gravity force.

Examples of activities to build concepts and language

Learners can develop the relevant concepts by activities such as the ones below. Bear in mind that the teacher must structure discussion of these activities and learners must have enough opportunity to discuss the meaning of these activities – otherwise the learners will look busy but will not develop the concepts.

Learners can

- Identify the east-west and north-south directions inside and outside the classroom using the position of the sunrise as reference. They can transfer these directions onto a globe, at the approximate position of the school on the globe (Process skills are **observing**, **recording**, **estimating** right angles between the N-S-E-W directions)

- Learn a star pattern such as the Southern Cross / *Dithutlwa,*and identify a point due south at night. They compare this point with the daylight observations. (**Observing**, **recording**)

- Learners swing a heavy ball (the “Moon”) on a long string around themselves (the “Earth”) and they feel the pull in the string; learners talk about this pull and are able to see it as a model of the gravitational pull that keeps the Moon moving in its orbit around the Earth. They discuss the question of whether the ball (“Moon”) feels the same pull in the string that they do.
- Record the changing shape of the Moon during a month and predict the date of the new Moon (**Observing** and **recording** and **predicting** from a pattern)
- Record the positions of the shadow from a shadow stick and relate clock time to the positions. (**Observing**, **recording** and **predicting later positions)**
- Find information about customs that are set by the phase of the Moon or the positions of certain stars (**Interpreting** information and **communicating** to an audience).
- Design an investigation to decide whether the full Moon is really bigger when it rises than it is later in the night (**Designing** an investigation, **measuring**, **recording** and **evaluating data**).
- Make a model to demonstrate why the Moon changes its apparent shape during the month (**Interpreting** information from diagrams, **predicting** how other people will see the model, **communicating** to an audience).
-

6.6 Melting and dissolving, solutions and mixtures

Reasons for placing this in Grade 6

By the time learners are in Grade 4 and 5, they have experiences of dissolving substances – they have mixed cooldrink powder or made tea – so they have a basis for the concept of dissolving. In Grade 6 we build towards understanding that matter is made up of smaller parts (a "big idea of science" is that matter has a sub-structure – refer to the NCS unifying statements in the boxes, in Layer One). Grade 6 learners should think about, for example, what happens to the sugar when it dissolves in their tea.

In Grade 7 learners have to use the dissolving concept to understand mixtures and to solve problems of separating soluble and insoluble substances.

Another reason for placing this in Grade 6 is that by this stage learners need the cognitive challenges of thinking about two aspects of a situation at the same time. They will need this as they investigate the effects of factors such as temperature on dissolving. This is discussed in the "Research" section below.

Concepts	Suggested elaboration
1 Melting is not the same as dissolving	Melting is a change of state caused by heating, and this is not the same process as dissolving, which is explained in **3** below. (See also the research section below.) In melting, usually only one substance is involved, but in dissolving, at least two substances must be involved, so that one substance can dissolve in the other.
2 Temporary changes.	Melting and dissolving are examples of temporary changes. Solid materials can harden again after melting, and solid solutes can crystallise again after dissolving.
3 A solution is an even mixture.	**Dissolving** means that one substance becomes evenly mixed in another. The even mixture is called a **solution**. The substance with the greater quantity is the **solvent**, and the substance with the lesser quantity is the **solute** (= the substance that gets dissolved). Teachers can use models of particles of solvent and solute to illustrate what happens. In Grade 6 the solvents are usually liquids like water or alcohol, and the solutes are usually solids like copper sulphate or fat. However, we should also mention that air dissolves in water, because this is important in understanding animals that live in water. Fizzy drinks have dissolved carbon dioxide gas in them.
4 Soluble and insoluble substances	It all depends on which solvent we use. For example, some substances are soluble in water and others are insoluble in water; some substances are soluble in alcohol (meths) and other substances are insoluble in alcohol. Teachers can add other examples of different solvents and solutes.
5 Saturated solutions.	Saturated solutions cannot dissolve any more solute and so any extra solute remains undissolved.(Teachers can use bead models of particles to illustrate dissolving and then saturation.) The hotter the solvent, the more of the solute will dissolve, but as the solvent cools, the solute un-dissolves i.e. crystallises.
6 Temperature and grain size are factors in the rate of dissolving.	Most solutes dissolve more quickly if the solvent is warm than if it is cold. Most solid solutes dissolve more quickly if the grain size is smaller. The word "rate" means how fast a mass of solute, e.g. 100 grams, will dissolve.
7 Matter is neither destroyed nor created in dissolving and crystallising	The conservation of matter means that when we can no longer see a solute, it must still exist, but it exists as particles of solute among particles of the solvent. (This means that learners should be able to work out that the mass of solution is equal to the mass of the solute plus the solvent, but see the research section below.)

Research on learning and teaching this topic

✘ Learners confuse **dissolving** and **melting**. For example, if you add a drop of water to a small pile of sugar grains, many learners will say that the sugar is "melting", but the grains are in fact dissolving in the water. Learners should then experience sugar truly melting in a heated container. Note the point above, that in melting, usually only one substance is involved, but in dissolving, at least two substances must be involved, so that one substance can dissolve in the other.

✘ **Learners don't conserve mass** When a powder dissolves in a liquid, half to two-thirds of learners this age will say that the mass of the solution is less than the mass of the solute plus the mass of the solvent (Driver, Guesne and Tiberghien, 1985, p.154). This may be due to the fact that the solute and solvent are often sugar and water, and the sugar disappears in the water. But Moodie and Daweti (1993) found that Grade 8 learners still believed that the mass of the solution was less than the mass of the matter with which they started, even when the solute is blue copper sulphate. From a cognitive development point of view, these learners do not yet conserve mass: they do not yet use the idea that mass never disappears. If they still do not conserve mass by Grade 8 and 9, possibly they won't use the idea that the atoms in a reaction do not disappear but are rearranged.

Cognitive challenges that learners need at this Grade

In this Grade, learners must have the challenge of thinking about two factors in a situation at once.

At a simple level, they need to think about both the **solute** and the **solvent** when the teacher asks them to look at two lists of solutes and solvents and make up pairs that will form a solution.

At a more difficult level, they need the challenge of thinking about two variables when they investigate factors in dissolving. For example, they must hold in mind BOTH the **times** (short, medium or long) it takes to dissolve a fixed quantity of sugar in water AND the different **temperatures** that the water can be (hot, warm or cool).

In another activity, they must hold in mind BOTH the **times** (short or long) it takes to dissolve a fixed quantity of sugar in water AND the **grain sizes** of the sugar (big or small).

These investigations involve the concept of a **fair test** – if they are going to compare dissolving-time for different water-temperatures, then they must keep other factors unchanged (e.g. there must be no difference in the amount of stirring).

However, the fair test investigations need to be completed and discussed as separate lessons; few learners cope with a lesson in which grain size is the independent variable in the first part of the lesson and then water temperature is another independent variable in the next part of the lesson.

Examples of activities to build concepts and language

Learners can

- **compare** substances such as salt, sugar, copper sulphate and chalk powder for solubility in water. The usual way of doing this is to measure how many teaspoons of the substance will dissolve in 100 ml of water, when the water is at room temperature and learners can stir for a minute or longer.

- **observe and record** what happens with other solvents such as meth spirits and thinners, to extend the concept of dissolving, and go beyond solutes in water. Dissolve fatty substances in meths (alcohol) and polystyrene or enamel paint in thinners. Point out that these solute substances won't dissolve in water.
- **investigate** how the factor of water temperature affects the time it takes to dissolve a solid solute. **Tabulate** and **graph** the results. Learners should be able to see and **state the relationship** in the form, "The hotter . . . the quicker. . . ."
- **investigate**, as above, how the factor of grain size affects the time it takes to dissolve a solid solute.
- **investigate** air dissolved in water and in a qualitative way **investigate** the effect of temperature on the quantity of air dissolved in water.
- **use a bead model** to discuss the similarities between a crystal of potassium permanganate dissolving in water and a clump of red beads amidst white beads, being shaken and spreading out until there is an even mixture of both colours. (Here the beads act as an analogy for what might be happening in the invisibly-small world of molecules. Later, in Grade 8, the beads will be given specific meanings as atoms of different elements, and they will be part of a model that is used to predict and explain.)

6.7 Energy from electricity

Reasons for placing this in Grade 6

By dealing with electricity in Grade 6, we promote strong linkage between Natural Sciences and Technology. In Grade 6 Technology, learners must do projects using electric circuits as part of their Systems and Control strand. Technology lessons can benefit from the more conceptual approach of Natural Sciences, and Natural Sciences learning is deepened as learners must use their knowledge in Technology to make something that really works.

Grade 6 is probably the earliest Grade in which we can expect learners to reason about circuits with several ideas in mind (they must understand the need for a complete circuit, they must visualise charges going around the circuit, link the cell providing energy to the bulb getting hot, understand the reasons for the design of a switch) and do some tasks that require problem-solving.

This topic builds on a basic conception of energy that many learners have – energy is what you pay for to heat things. We pay to heat the house in winter, to cook food, or to boil water. In this topic, we use (and pay for) electricity to heat resistance wires and the filaments inside bulbs.

Electricity is sometimes done in lower Grades, where the younger children get much satisfaction from making their bulbs light up. These experiences can be motivating to Grade 4s but one would not get the conceptual understanding or hypothesising that is possible when the children are older.

Concepts	Suggested elaboration
1 Complete circuit	A bulb (or other electric device) will work only if it is in a complete circuit. This means that a cell must be connected in path of conducting materials that goes from one terminal to the other terminal, and the bulb must be in that conducting path. Learners must work with cells, bulbs, conducting materials, switches.
2 Energy transfer from cell to parts of the circuit.	The complete circuit makes it possible for the cell to transfer energy to the bulb. If the bulb glows, it is because the filament is white-hot and the energy to heat it comes from the cell.
3 Electric charges flow around the circuit, and this flow is a current.	Current is a flow of electric charges, but we can say that current is a flow of "electricity" because that saves us expla ining atoms and charges. See the language note on "electricity" below. In Grade 6 Natural Sciences, only series circuits are required, but in Grade 6 Technology, learners will have to work with parallel circuits too. The Natural Sciences and the Technology teachers need to plan for this.
4 Conductors and insulators.	Metals are good conductors of electric current. Graphite (pencil carbon) will also conduct, though not as well as most of the metals. Insulators are materials that are very poor conductors; they stop current flowing and are used to prevent current flowing where we do not want it to flow (e.g. to people's bodies).

5	Electric systems do useful work for us.	Electric systems include circuits that heat things, make sounds, turn motors, give out light or send radio signals (e.g. cellphones). Learners should work with at least one other output device such as a motor or beeper.
6	Inputs and outputs in electric circuits	An **input** to a circuit is energy plus e.g. someone pressing a switch. An **output** is any response to that input e.g. sound from a beeper (a warning), movement of a fan motor, or a light that goes on.
7	Safety with "mains" electricity	Learners need a simple understanding of dangers of ESKOM "mains" electricity supply e.g. awareness that metal objects such as kitchen sinks may conduct mains electricity. (Knowledge of earthing and earth-leakage devices are not required at Grade 6)
8	High and low voltages	Understanding the relative safety of high and low voltages, and the different sorts of appliances that work at 1.5 V, 9 V, 12 V, 220 V, 11 000 V, 33 000 V. Include street installations such as transformers (= "danger-boxes")

This topic must both reinforce and be strengthened by the Grade 6 Technology content, in the Technology ***Electrical Systems & Control*** strand.

Research in learning and teaching this topic

Grade 6 work on electricity begins a conceptual development path that will go right through to Grade 12. Cohen, Eylon and Ganiel (1982) describe conceptual problems which learners experience with this topic, even in Grade 12, and argue that they arise from a teacher focus on current in circuits and learners' inability to use the concepts of energy and voltage.

This section should be read together with the corresponding sections on electricity in Grade 7, 8 and 9, on pages 84, 111 and 138. References are, for example, the working papers of the Learning in Science Project in New Zealand (1980), Bradley and Stanton (1986), Cohen, Eylon and Ganiel (1982), Moodie (1988) and Shipstone (1985).

The main conceptual development task for the Grade 6 teacher in this topic is to establish a link in the learners' minds between energy transfer to parts of a circuit and the source of energy. This is called the "energy-emphasis" approach and is different to the traditional current-emphasis approach.

The energy-emphasis approach also begins with the concept of a complete circuit but focuses on the energy-transfers which happen when the circuit is completed. When the bulb glows, or the nichrome wire gets very hot, the learners have to think about questions such as "Is this hot bulb giving off energy?", "Where is the energy coming from?", "Where is it going to?" and "Will another cell make the bulb even hotter?" and "How long can the cells keep on giving away their energy to the bulb?" and "The cells are getting warm – what does that tell us?" The emphasis is on the cell as the source of energy, not current. Later, in Grade 7 to 9, the emphasis includes a person who must give his/her energy to crank a dynamo to make a bulb light.

Of course the concept of current going around a circuit is needed in Grade 6 and onwards, but the learners should work with the concept that the cell stores energy and the cell's energy is being "used up" or given away to the resistors, which then give it away to the surroundings. The current flows around the circuit and is not "used up" but it is the energy that the cell gives to the current that is "used up" (transferred to the bulbs).

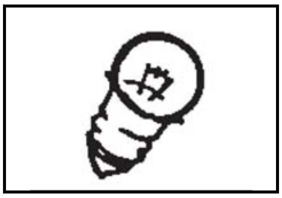
The traditional current-emphasis approach begins with the concept of a complete circuit but thereafter it focuses on the concept of current. Many learners quickly form a picture of the cell as the "giver" and the load or output device (e.g. bulb, motor or heater) as the "receiver". The cell gives something which learners may call electricity, power, volts, current or "juice" and it goes on giving it until the something is all "used up". The learners' mental picture is of a water-tank, tap, garden hose and a sprinkler. When the tap is opened, the tank lets water runs down to fill the hose; when it reaches the sprinkler we see the spraying action. The water is "used up" at the sprinkler.

This is what we may call the **"cell-is-like-water-tank" misconception.** Learners who think like this will also see no reason why a bulb needs two wires connected to it. For them, it should need only one wire, just as the sprinkler needs only one hose[4].

Difficulty caused by the construction of torch-bulbs

The torch-bulbs that we normally use in teaching electricity encourage the idea that a bulb is a "receiver" that needs only one wire to work.

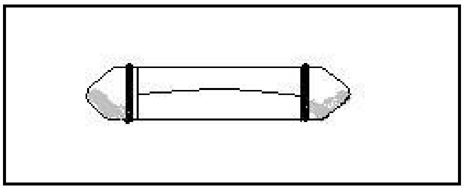
Figure 7 *A torch-bulb looks as though it needs only one wire to work.*



As you see in **Figure 7**, the bulb has a contact at the bottom but it is not obvious that the screw part is also a contact. In addition, the connections to the filament are hidden inside the screw contact, so that learners can't see the continuous path of conducting material.

Shipstone (1985) recommends giving learners festoon bulbs (**Figure 8**) in the beginning, because they have obvious contacts at either end and a straight filament between the contacts. However, learners should also see a cut-open bulb and work with diagrams such as **Figure 9** below.

Figure 8 *A festoon bulb that is used in some cars (12 V) and motorcycles (6V). Do not confuse these with car fuses, some of which look similar.*



Household incandescent bulbs (not the energy-saving lamps) that work at ESKOM's 220 volts have two obvious contact points and the path of the current is much easier to see.

Language and terminology concerns

"Electricity" is a word with many meanings – it is what you pay ESKOM for, or it is energy for cooking, or it is something that makes your clothes crackle when you pull them off, or it is something that goes around circuits in wires. These multiple meanings are a difficulty for learners, so the teacher should explain that even though people use the word "electricity" in different ways, in Grade 6 lessons "electricity" will mean the stuff that flows around the circuit.

The terms "open circuit" and "closed circuit" are technically correct in science but may be confusing to learners. Some learners will say *Vula igezi* ("open the electricity") meaning "switch on the circuit". Using the scientific term, we would say "**close** the circuit" to mean "switch it on".

A similar problem occurs for the science term "**open** the circuit" which means "switch it off", confusing to a African-language child who might say *Vala igezi* ("Close the electricity")

When teachers code-switch between English and African languages they should be careful if using terms like *amandla* and *ugesi* which connote power and electricity but do not have the specific meanings that science concepts require.

Further notes on teaching and learning this topic are in the Grade 8 and 9 sections. Grade 6 teachers should be aware of these notes for Grade 8 and 9 because good teaching in Grade 6 can

[4] Most Grade 6 learners soon accept that they should connect two wires to a bulb but remain unsure of the reason! Osborne and Freyberg (1985, pages 15 – 27) describe various misconceptions that these learners develop to make sense of the two wires that go to the bulb.

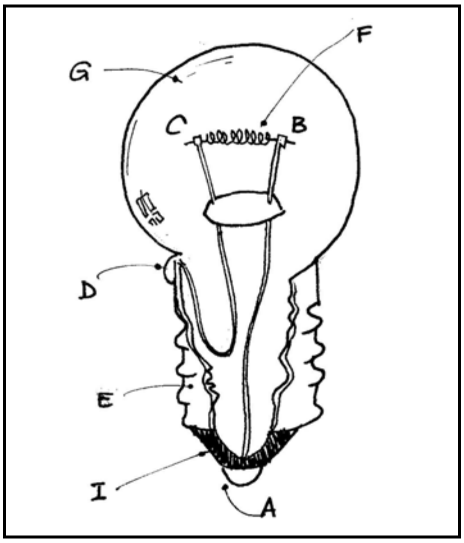
build a coherent conceptual grasp of circuits that will carry them through senior phase and the FET phase.

Examples of activities to build concepts and language

Learners can

- use loose wires, a cell, and a bulb and try various ways of making the bulb light, then turn on and off. They do drawings of their connections to record arrangements that work and those that do not work. (Process skills are **hypothesising** what will work, and **recording** the connections that work and do not work.)
- investigate the effect of adding more cells to their circuits, and link the increased temperature of the bulbs or nichrome wire to the number of cells. (**Infer** that more cells give more energy.)
- examine a torch bulb carefully, using a cut-away diagram, and trace the conducting path through the bulb. Bulbs like these are technically known as MES bulbs (Micro Edison Screw). They compare the MES bulbs with the festoon bulbs used in some car and motorcycle indicator lamps. They must work out that an MES bulb has two contacts – the screw part and the solder knob at the bottom, separated by an insulator. They should compare this bulb with a normal house bulb – the incandescent type, that has two clear connection knobs on the bottom.

Figure 9 *A cutaway diagram of a torch-bulb that reveals the internal connections.*



- use three or four cells to heat a conductor (such as a very thin iron wire, nichrome wire, very narrow strip of foil, graphite from inside of a pencil) until the learners can feel the heat. Learners should also realise that the bright glowing filament in the bulb is white-hot, even though the glass feels merely warm. Conceptually, learners should make a strong association between the cells and their ability to give energy and heat the conductor. (Of course, domestic incandescent bulbs made to work at 240 volts are too hot to touch, and teachers should use this fact to illustrate the generalisation that electric current heats conductors.)
- test a variety of materials to classify the materials as good and poor conductors, using a bulb in a circuit. (**Sorting** and **classifying**)
- make circuits using a variety of conducting materials other than copper wire; they note the possibilities for accidental contact with ESKOM mains voltage and kitchen sinks, steel windows or bare wires. They note the dangers of illegal connections, especially where these wires are lying on the ground.

Grade 7 Topics

> These notes focus on the **science knowledge** in the NCS. But the science knowledge is not the curriculum, and these notes are not a learning programme. The curriculum is about learners using the knowledge to produce outcomes. So these notes are just the basis for learning programmes that build the Assessment Standards for Learning Outcome NS1 ***Scientific Investigations*** and Learning Outcome NS3 ***Science Society and Environment***, as well as building the Assessment Standards of Learning Outcome NS2

7.1 Simplifying the great variety of living things on Earth

Reasons for placing this in Grade 7

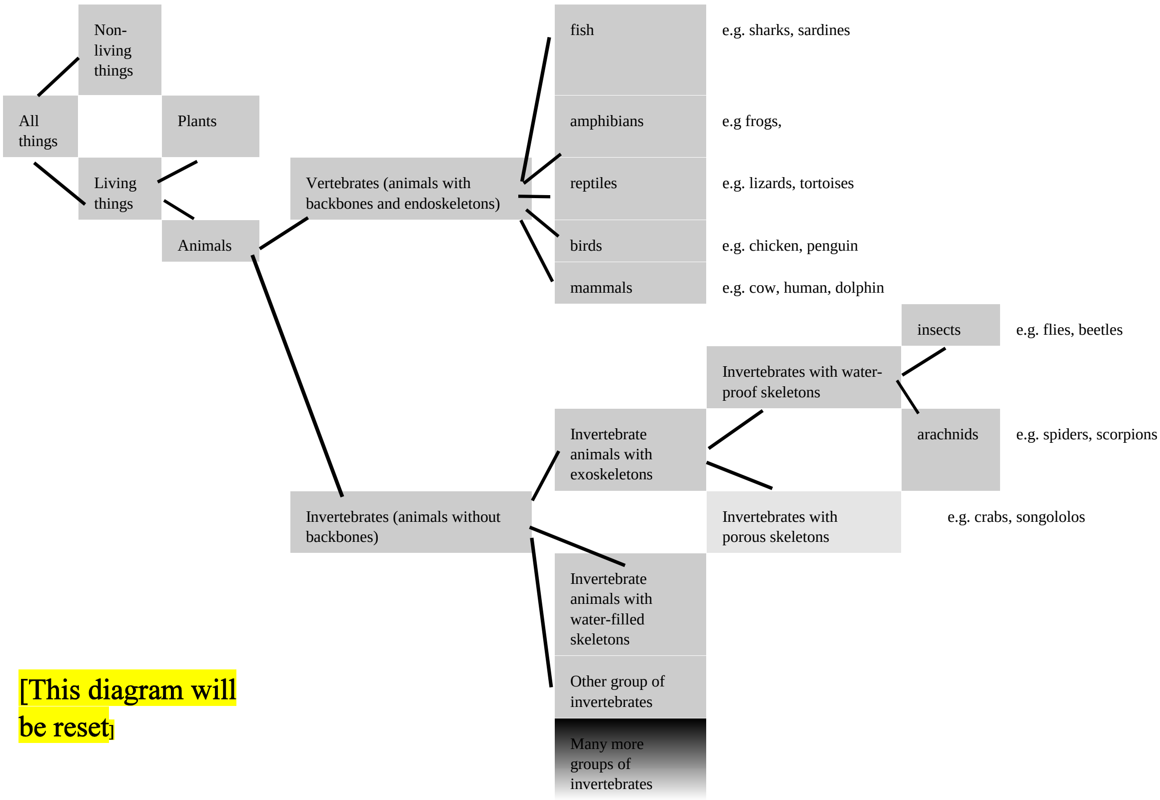
This topic deals with the classification of plants and animals, using the main groups of each. For many years the topic was taught in Grade 7 and experienced primary school teachers with this knowledge are a valuable resource in the system. The topic lays the foundation for biologically-correct descriptions of ecosystems, that begin here in Grade 7 and will continue through FET.

Classification is one of the Learning Outcome NS2 Assessment Standards, *Learners categorise information to reduce complexity and look for patterns* and is also listed as a process skill, namely *Sorting and classifying*.

The learners should already have some practice in the skill of sorting things (from their Grade 6 electricity) in which they had to test and sort substances as conductors and non-conductors, and Grade 4 work (in which they should have sorted leaves or animals by some visible characteristic such as leaf shape or number of legs).

The skill of classifying applies also to the Grade 8 chemistry topic in which learners must deal with the complexity involved in classifying the materials known as elements, compounds, solids, liquids, gases, metals and non-metals.

Concepts		Suggested elaboration
1	Vertebrates and invertebrates	Classifications of animals as vertebrates (animals with backbones) and invertebrates (animals with no backbones)
2	Classification of the vertebrates	The vertebrates are classified into fish, amphibians, reptiles, birds and mammals. Note visible differences in structure and differences in reproduction but use distinguishing characteristics to classify these classes of animals (e.g. only birds have a covering of feathers – they have wings but so do bats, which are mammals. Only mammals have mammary glands, etc.).
3	Classification of some invertebrates	The invertebrates have no backbones but have an exoskeleton instead. Examples of invertebrates include insects, arachnids (e.g. spiders) and crustaceans (e.g. crabs). A classification of all the invertebrates is not needed.
4	Classification diagrams	The groups of animals can be shown in classification diagrams such as the following:



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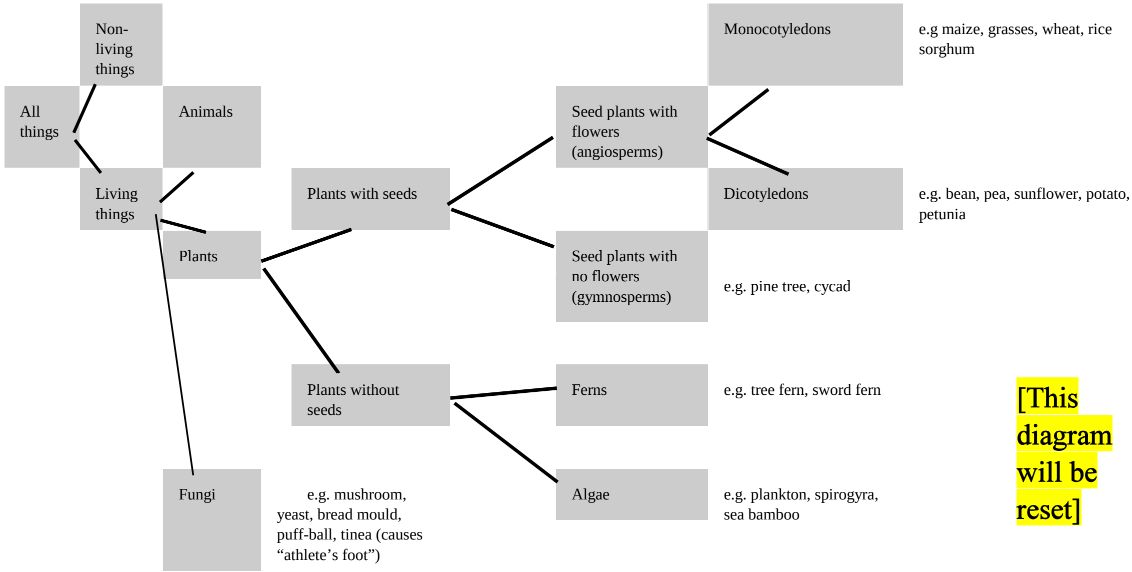
5 The fossil record	The fossil record in South Africa gives evidence for different kinds of animals and plants that lived long ago, in particular parts of SA. This is evidence that life and conditions on the surface of Earth have changed through very long periods of time.(Link with ***7.4 The structure of the changing Earth***, below.)
6 Plants with seeds and without seeds	Plants are classified as seed plants and plants without seeds.
7 Classification of the seed plants	Seed plants are further classified as angiosperms (which have their seeds in ovaries) and gymnosperms (which have no ovaries and carry their seeds in other ways). Angiosperms are further classified into monocotyledons and dicotyledons, and each of these groups has distinguishing characteristics.
8 Classification of plants without seeds	Plants without seeds are, for example, the groups algae and ferns. Fungi are interesting organisms too, but botanists don't call them plants put them in a group by themselves, as you see in the diagram.
9 Reproduction of angiosperm plants	Angiosperm plants reproduce from seeds. Seeds will form only if the flower has been pollinated. Insects are important agents of pollination for many plants and so they are a vital part of most ecosystems.
10 Vegetative reproduction	Some angiosperms can also reproduce vegetatively, and do not depend on forming seeds. This is important in farming, because crop production is easier and more predictable with this form of reproduction.

11 Classification diagrams — The groups of plants can be shown in classification diagrams such as the following



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Research on learning and teaching this topic

Learners and teachers may have different meanings for common words, and the teacher often does not realise that a word may create a different picture in the mind of the learner than the one the teacher intended. A word like "animal" has a common everyday use (e.g. "No animals allowed in the shop") and a scientific use (in science, both people and spiders are classed as animals). Many people have a restricted idea of an animal as a four-legged, furry mammal that walks on land, while in science the word "animal" includes living organisms such as birds, earthworms and sea anemones. (Bell, 1981; Bell & Barker, 1982; Tema, 1989; Villalbi & Lucas, 1991; Braund, 1991, 1998).

People commonly use the word "plants", meaning the plants that a gardener or farmer works with, but in science the word "plant" includes trees – many learners would not use the word "plant" to describe a tree, nor to describe lawn grass. So here, again, the learners' concept of "plant" has to be expanded and the word "plant" must be given a broader meaning than we give it in everyday use.

The most basic distinction in the classification system is Living Things *vs* Non-living Things, but many learners do not give these words the same meaning as the teacher does. We know that many learners see some non-living things as living – fires, rivers or clouds, for example. Fires can move, need air, start little new fires, they consume materials, and so on. From the scientists' viewpoint we might think it is obvious that fires, rivers, etc. are non-living, and are abiotic factors in an ecosystem. If the teacher assumes that the science meaning is obvious to the learner, the teacher might never realise that the word "living" calls up an image in the learners' minds that is different to the idea the teacher is trying to teach.

Learners find it difficult to group animals in a scientific classification system Some learners find it hard to understand the concept of "distinguishing characteristics". For example, having wings is **not** a distinguishing characteristic of birds because bats and many insects have wings. A distinguishing characteristic of birds is that they have a body covering of feathers - something no other animal group has. As another example, they may incorrectly use the number of legs, or body shapes, when explaining why they consider something to be a vertebrate or an invertebrate (Bell, 1981; Braund, 1991; Sanders and Du Preez, 2002).

Aquatic mammals such as dolphins and whales are often incorrectly classed as fish because they live in water and have fish-shaped bodies, and fin-like appendages (Trowbridge and Mintzes, 1988; Braund, 1991, 1998; Sanders and du Preez, 2002). Organisms with "fish" in the name are often incorrectly grouped as fish, even if they are not (e.g. neither starfish and jellyfish are fishes) (Ryman, 1974; Trowbridge & Mintzes, 1988; Sanders and du Preez, 2002). (Jellyfish are in fact classed as coelenterates and we do not deal with that group of animals in the GET phase.)

Vertebrates with thin, flexible bodies are often incorrectly grouped as invertebrates because their bodies do not seem to have a backbone (e.g. eels, snakes and fish) (Ryman, 1974; Braund, 1991, 1998; Sanders and du Preez, 2002).

Small creeping / crawling invertebrates are often incorrectly grouped as insects, even if they have more than six legs, which is a distinguishing characteristic of insects (e.g. woodlice, which are crustaceans, and spiders, which are arachnids). (Braund, 1991, 1998; Sanders and du Preez, 2002).

Will these difficulties that learners have in understanding classification go away if we give more detailed definitions? Probably not. It seems that the personal meanings that learners put into science terms have a strong effect on their learning, even after hearing clear explanations from the teacher. This is a quotation from some research with South African learners by Sanders and du Preez (2002):

> *A cross-sectional survey was used to investigate the ideas of 55 Grade 7 learners before they were taught about animals, and 36 Grade 11 learners who had been taught about classification and animal diversity at the end of their Grade 7 year, and about animal diversity again at the start of their Grade 11 biology course. Although the Grade 11 learners' ideas more closely approximated those of scientists, a large number of learners at both grade levels still showed a poor understanding of what an animal is, and how different animals are classified into taxonomic groups.*

Learners need to work with many examples of classification, and the activities below make some suggestions.

Examples of activities that develop concepts and language

Learners can

- think of examples of classification in everyday life, e.g. the way foods are grouped in supermarkets, the way clothes are grouped in shops, the way words are grouped in dictionaries. People classify things to make them easier to find or use; scientists who study living things classify them because there are many millions of different kinds, and they have to simplify their information.
- sort common objects into groups and subgroups, so they get the idea of using a range of different distinguishing features (e.g. they can sort **sweets by the distinguishing characteristics of** hard vs soft, wrapped vs unwrapped, red vs not red, chocolate vs not chocolate. Another exercise involves classifying **nuts, bolts, screws, cup-hooks and washers:** gold-colour vs silver-colour, with thread vs no thread, hole vs no hole, blunt ends vs sharp ends, hexagonal-head vs circular-head, hook vs no hook)

- sort living and non-living things, and explaining their reasons in detail, to emphasise the distinguishing characteristics of something being “living”
- use simple classification keys to identify an unknown animal when given a picture of the animal
- play games like “twenty questions”, in teams, that involve guessing the animal by asking appropriate questions. (These games mimic a dichotomous key, because the person who is “on” may answer questions only with a “yes” or a “no” depending on whether the characteristic mentioned in the question is present or absent.)
- use the above tasks to develop simple dichotomous keys
- identify plants as monocotyledonous plants or dicotyledonous plants, by their distinguishing characteristics such as petals in multiples of three, vs petals in multiples of four or five.

7.2 Describing the living and non-living things in a small environment

Reasons for placing this in Grade 7

This section is an application of the work done in topic **7.1** above, on classification of living things. The learners should know how to read the classification diagrams such as those in topic 7.1 and be able to make some judgement about the kinds of organisms they find in their study area.

The learners need to study an area, hopefully near the school, and produce a description of the non-living parts as well as the living organisms using the classification systems they have learned. The level of data-collecting and communication that we should expect is **description and classification of the parts** rather than a description of the **interdependencies,** because learners cannot directly observe the relationships in a mini-environment in a short time (for example, we can **infer** that a food chain exists but we might not actually see the different species feeding off each other on one visit to the area).

The activity will be determined by the resources available to the teacher. However the following concepts should be part of the discussion and reporting:

Concepts	Suggested elaboration
1 Habitats for different organisms	The biotic and abiotic surroundings of the living things that the learners find in the study area. The habitat for small organisms might be just an area near a tree, but for larger organisms it might be the tree, some rocks and a place where dew collects in the morning.
2 Living and non-living parts of the environment	Learners should identify biotic (living) and abiotic (non-living) components of the mini-environment such as the trees and other plants, insects that live near the plants, birds, lizards, etc. The soil has living organisms in it too. The non-living components include light/shade, water, the air (which may be hot or cool)
3 Reproduction and life cycles	Learners should be aware that all the living things are there because their "ancestors" reproduced successfully, and that reproduction is going on all the time. Some organisms like butterflies have short life cycles, while other like trees have long life cycles. Learners will usually infer the reproduction from evidence in the study area (e.g. spider egg cases, fly maggots, dragonflies mating, butterfly eggs under leaves)
4 Food chains and food webs	Learners should be aware that each animal they find has to eat something and can be eaten by something else. Concepts they should be using by now are **consumer**, **producer**, **food chain**, food **web**,
5 Remains of dead plants and animals	Remains of dead plants and animals are recycled in nature and become part of the micro-nutrients in the soil.
6 Interdependence	Learners should realise that all the living and non-living things depend on each other in many different ways and the learners should try to hypothesise these interdependences.

Research in learning and teaching this topic

The research that is quoted for the Grade 5 topic **5.1 How living things depend on their environment** is still relevant here. The reader should refer back to that section.

Examples of activities to build concepts and language

Learners can

- take soil samples from different parts of the study area and separate the components by letting them settle out in a jar of water (Process skills are **observing**, **measuring** and **recording** in drawings)
- sift dry soil looking for remains of dead ants, moths, etc. They draw them and try to identify them (**observing**, **recording**, **inferring**)
- map the area and colour in the parts which get shade all day, get no shade all day, etc. They compare the plant life in the shaded and unshaded areas (**observing**, **recording**, **comparing**, **inferring**)
- put out bottle traps buried in the soil to catch nocturnal crawling insects and collect them alive in clear glass bottles and try to draw them (**observing** and **recording**)
- create a classification diagram of the animals that use the area, based on the animals they actually see, or remains of animals and the footprints of animals that have passes through the area (**classifying**).
- imagine that one of them is a butterfly or a lizard trying to survive in the study area, and it gives a TV interview to a learner who is the reporter (**inferring**, **interpreting**).

7.3 Changes that happen to young people in puberty; understanding sexuality and human reproduction

Reasons for placing this in Grade 7

Learners from age 11 onwards begin to experience change in their body shape, their sex organs and in their emotions as they enter the stage of life called puberty. These changes give them the awareness of becoming a different person from the child they used to be; the changes in puberty may cause pleasure but also anxiety and these changes need to be interpreted for them by adults. The great majority of learners are already exposed to information about sex from undesirable sources such as cellphone porn, TV shows, magazines, internet or friends who seem knowledgeable but may be disastrously ignorant. While sex is a topic of conversation that most parents avoid, it is certainly part of learners' conversation and often involves jokes, teasing, mockery and exploitative relationships between them.

There is much research to show that many Grade 7 learners are already sexually active or are experimenting (AIDS Research Institute, 2003; LoveLife, 2007). Many have already been abused sexually by adults, are exchanging sex for money or have been coerced into prostitution. Tragically, many have sexually transmitted infections including HIV, or have produced babies.

For the reasons above, the Grade 7 science curriculum should meet learner's needs for a positive and reliable interpretation of puberty and sex, where learners can base their discussions on correct biological information. While the Life Orientation curriculum may deal with moral and value issues, Natural Sciences has this particular contribution to make. The Life Orientation and Natural Sciences teachers can fruitfully work together on this topic.

Concepts	Suggested elaboration
1 Physical changes in boys and girls in puberty	Physical growth and changes that are triggered from about age 11 to 16 for girls and about age 13 to 18 for boys, by maturing endocrine glands; new production of hormones and the beginning of menstruation, erections, "wet dreams", body hair, pimples, etc.
2 Normal development	The range of normal physical development (height, weight, sizes of external reproductive organs). The range of ages for normal development – puberty can begin as early as 11 or as late as 17 years.
3 Psychological and emotional changes in puberty	Growing sense of being an individual person in the world, the need to make personal choices, have self-respect. Importance of respect for the opposite sex and accepting social constraints on sex. Being physically ready for sex does not mean engaging in sex, the need for respect and developing the capacity for caring relationships, the profound meaning and consequences of making a baby and bringing another human into the world.
4 Variation in humans	Variation in the human race, such as skin colour, type of hair, etc. is normal. Physical characteristics give us no basis to judge people's intelligence, character or worth.
5 Menstruation, fertile stages.	The meaning of menstruation, fertile stages of the cycle.
6 Sex and conception	Sexual intercourse, conception (briefly, since this will be done in more detail in Grade 9).

7	Pregnancy and birth	What happens during pregnancy, factors that affect the health of the unborn baby. What happens during birth.
8	Myths about sex	Misconceptions and common myths about methods to have sex but avoid pregnancy.
9	Contraception	A few methods and their relative effectiveness.
10	STDs	Sexually Transmitted Infections/Diseases (STIs/STDs) including HIV/AIDS.

Research on learning and teaching this topic

Doidge, Radley and Lelliott (2008) report on research with about 100 teachers from a range of Gauteng schools who had already taught human reproduction in Grade 7. They report overwhelming agreement among the teachers that this topic belongs in Grade 7, for most of the reasons set out above.

The topic is done in Life Orientation, from a perspective of relationships, behaviour and moral values; Natural Sciences must maintain a focus on values too, but it can help the learners understand the physical reasons why they have strong emotions, sexual urges, conflicted relationships with the opposite sex. It helps them understand the changes happening to classmates of the opposite sex. So the two Learning Areas should complement each other, and learners should do integrating tasks for assessment.

Some teachers feel privileged to teach children this knowledge, while others feel very anxious about it. In all cases, teachers do need good personal preparation so that they are aware of their own attitudes, and so that they can explain matters clearly, using correct science vocabulary. They should be able to see through the "street-wise" information that some learners have, and see the misconceptions and anxieties that children have about sex. Teachers need to accept children's curiosity or desire to shock them, but still maintain their own right to privacy and self-respect. There are organisations like FAMSA, Family Life Centre, LoveLife, LifeLine, etc. which offer this kind of teacher training.

Doidge *et al* (2008) found that there is an initial stage when the discussion of sex is "let out of the box" and then as the topic unfolds, the class enters a second stage of more normal teaching and learning – what the learners saw as a forbidden topic can now be talked about and misconceptions can be dealt with.

In the initial stage, learners may react with inappropriate jokes or behaviour, or attempt to shock the teacher, or show signs of anxiety if, for example, menstruation is going to be discussed in front of boys. The school management should remember that the learners reach a second stage if the teacher perseveres: he or she must insist that everyone uses correct science words for all body parts and processes, expect clear answers to questions, have learners work with accurate diagrams of reproductive organs, do normal assessment of Learning Outcomes using the Assessment Standards. The teacher needs the skill to convert a learner's provocative joke or remark into a factual discussion and the sensitivity to know that behind a learner's questions and jokes there may be a deep concern that the child would like to address.

Examples of activities to build concepts and language

Learners can

- **measure, record and graph** a range of heights – finding an average for ht class, and making the point that probably *nobody fits the average and all differ in some way* (this is important for these learners who are anxious about how they compare with their peers in height, weight, musculature, looks, and many other aspects).

- **interpreting data** on average heights and **graphing** the heights of girls and boys between ages 1 and 20. (Girls *on average* grow taller than boys at around age 11 - 14 and then boys *on average* overtake them at about age 15.)
- **reading text** about male reproductive organs and **interpreting the text** by labelling diagram with the correct terms; repeat with female reproductive system
- discuss myths about menstruation and **interpret** lesson information to provide scientific reasons for answers
- discuss myths about ways to have sex but not get pregnant, and provide science reasons for answers
- discuss the kinds of pressure that children put on others to experiment with sex and hypothesise reasons why it is difficult to withstand.
-

7.4 The structure of the changing Earth

Reasons for placing this in Grade 7

This topic is about understanding forces and processes that are changing the planet over very long periods of time. Understanding these processes requires learners to visualise the planet and the parts of it in three dimensions, and to think about time, which is the fourth dimension.

These ideas and mental images are challenging for learners in Grade 7 but this topic can help to develop their thinking, if it is well taught. Their thinking abilities will be needed again when Planet Earth concepts come up for the learners in Grade 8 (***8.4 Exploring beyond planet Earth***) and Grade 9 (***9.5 Minerals and mining in SA***).

The topic ***9.5 Minerals and mining in South Africa*** is kept for Grade 9 because it offers such valuable opportunities for dealing with the environmental and economic issues, social justice issues and wise use of Earth resources; the Grade 9 Assessment Standards for Learning Outcome 3 and the Critical Outcomes require learners to work with such ideas. The minerals and mining topic would overload Grade 7 but leaving it to Grade 9 means that the learners, then aged 14 to 16, are more ready to deal with value-laden debates.

Grade 7 does not have a separate topic on the *Weather & atmosphere* sub-strand because that content gets more support in Grade 8 where the learners begin some chemistry and deal with gases of the atmosphere. However, hot and cold weather, ice, rain and wind play very important roles in changing the surface of the Earth (in weathering and erosion by wind, water and glaciation) and so we can deal with them in this topic, ***The structure of the changing Earth***.

A science learning programme should not try to deal with all the sub-strands of *Planet Earth & Beyond* in each Grade. If the three sub-strands (*Our place in Space*, *Atmosphere and weather*, and *The changing Earth*) were all attempted in each Grade, each sub-strand would get only about 2½ weeks, or about 8 hours, of teaching time. This time allows only superficial teacher-tell coverage of any topic; the contexts of the topics would keep shifting, the concept-building experiences would be minimal and the load of new language would be overwhelming for learners. We should not expect to see learners showing progress in outcomes under those conditions.

Concepts	Suggested elaboration
1 The planet Earth is shaped like a sphere	The Earth is like a round ball, and we live on the outside of the ball or sphere.
2 Gravity force pulls us towards the centre of the sphere	This means that the “down” direction for every person points towards the centre of the Earth, no matter where that person is on Earth.
3 The planet has a structure of a geosphere, hydrosphere and atmosphere.	The **geosphere** is all the rocky parts of Earth, which has layers, namely the lithosphere (crust), the mantle and the core. The **hydrosphere** is all the watery parts (oceans, rivers, lakes, wetlands, underground water and the water that circulates through the atmosphere in the water cycle) and the **atmosphere** is all the air plus those gases such as ozone which exist far above the surface.

4	The geosphere has an outer lithosphere, a much thicker mantle and a core which consists mostly of iron and is very hot.	The planet is not hollow; the land and sea-bed are part of a rocky shell or crust called the **lithosphere**, a much thicker shell of rock called the **mantle** and a **core** which consists mostly of iron and is as hot as the surface of the Sun. (Learners should know that the thickness of the lithosphere compared to the whole diameter of the Earth is relatively the thickness of the skin on an apple compared to the diameter of the whole apple.)
5	The hydrosphere and biosphere.	The water in the oceans, lakes, rivers and the underground water comprise the **hydrosphere**. The hydrosphere, atmosphere, the soil and all living things that interact with the water and atmosphere comprise the **biosphere**.
6	Sun as the source of energy for life in the biosphere	Our Sun radiates the energy that plants need for doing photosynthesis, and so it is the source of energy for life of plants and all other organisms in the biosphere.
7	Sun as the source of energy for movement and change in the atmosphere and lithosphere.	The Sun also causes movement and change in the atmosphere (e.g., by evaporation, wind and the movement of hot and cold air masses), in the hydrosphere (e.g. rain, wind that brings rain, winds that move water to form ocean currents) and in the lithosphere (e.g. weathering, erosion and deposition by wind, water).
8	Plate tectonics	The crust of the planet (the lithosphere) lies on top of a thicker layer of hot rock called the mantle. The crust is made up of very large pieces called crustal plates or tectonic plates, most of them bigger than continents. These plates drift in different directions, at about the speed that a person's nails grow.
9	Evidence that persuaded scientists that the theory of plate tectonics was correct.	Learners need examples of discoveries that led scientists to accept the theory of plate tectonics. The first clues were seen in the maps of Africa and South America, where the coastlines of the two continents seem to fit together. Later, for example, scientists found a split at the bottom of the Atlantic ocean with undersea volcanoes that are producing lava on the sea-floor. This split runs all the way from the north Atlantic down into the southern ocean. This helped to explain why the rocks and fossils in SA and South America are of the same kind – the two continents are on plates that were joined long ago but they have been pushed apart.
10	The energy to move the plates comes from the hot core of the Earth.	The concept of convection currents in the mantle, rising away from the hot core, explains why the hot interior of the Earth causes the plates to move (Link: This concept, convection, is developed also in ***7.7 Controlling heating and cooling – Conduction, convection and radiation***)
11	Earthquakes and volcanoes occur mostly in areas where the edges of plates are in contact or are moving apart.	The plates exert enormous forces on each other at their edges where they meet. Where the plates push against each other, faulting, folding, uplift and the creation of mountain ranges may occur. Earthquakes and volcanoes also occur where the plates are moving apart, but these areas are mostly under the sea.
12	Earthquakes	Where plates' edges are in contact but cannot move, potential energy is stored between the parts of the crust that are pushing against each other. Earthquakes result when the movement finally does happen and the energy is released. The time during which the potential energy builds up may be hundreds or thousands of years.
13	Volcanoes	In these places where plates push against each other we often also find volcanoes; these volcanoes result from the disturbances in the crust along the moving plate boundaries, plus the heat of the Earth's interior which melts rock in the mantle.
14	Processes that change the surface of the Earth.	The surface of the Earth is being changed by processes that push up mountains, deposit sediment or produce lava flows from volcanoes. At the same time, the surface is being changed by processes that flatten mountains and move Earth materials down to the bottom of the sea (such as weathering and erosion, slip, or glacier action). Earthquakes and floods can change the surface very quickly, while volcanoes may cause both sudden and gradual changes.

15	Deep time	Planet Earth is over 4 billion years old. Most processes that change the Earth occur very slowly, but over very long periods they bring about very great changes. For example, the bottoms of ancient seas have been pushed up and are now the tops of high mountains.
16	Earth's magnetic field and the magnetic compass	The Earth has a magnetic field. We can use a magnetic compass to find the approximate direction of the north and south poles. The force which the Earth's magnetic field exerts on a magnet is not the same force as gravity. (A learning programme should link topics 7.5 and 7.6. In ***7.5 Mixtures and ways to separate the substances*** learners use magnets to separate parts of a mixture that contain iron. In ***7.6 Energy transfers in systems***, learners deal with contact forces and the non-contact forces, gravity, magnetic, electric forces)

Research on learning and teaching this topic

For anyone to learn this topic meaningfully, they must be able to

(a) mentally move themselves off the planet and view it from far out in Space. They must imagine themselves looking back at where they are in SA, and at all the other parts of the planet that the teacher is talking about. However, we know from the Nussbaum (1985) work that many learners agree that the Earth is a ball in space but still think of themselves on a flat part somewhere *inside* the Earth, or they dis-associate the teacher's ball-shaped Earth from the place where they live, which does *not* look ball-shaped. This type of finding was confirmed by others such as the Primary Science Programme in this country.

(b) visualise processes which have happened slowly over an unimaginably long time of millions of years, and which still happen so slowly that people cannot perceive them, and that will continue into an unimaginably far future.

The National Association of Geoscience Teachers in the USA publishes a journal called *Geoscience Education* Research articles can be found at http://serc.carleton.edu/nagt/jge/abstracts/index.html

We may expect certain typical difficulties in understanding the structure of the changing Earth. For example, most learners (and adults) find it hard to understand . . .

✓ that it is **true**: People do not fall off the Earth, downwards into Space. "Downwards" in fact means "towards the centre of the Earth" because that is the direction of the gravity force.

✓ that it is **true**: If people could make a hole downwards into the Earth, and made it deep enough, the hole would go through the centre of the Earth and bring them upwards, out of the Earth, in another country (or perhaps under the ocean) on the other side of the Earth.

✓ that it is **true**: Continents, like Africa, are moving. The continents we see on a map are the thicker parts of huge plates of rock which "float" on denser, deeper rock that is flowing in some direction, on a convection current in the hot mantle rock.

✓ that it is **true**: Some mountains were once the bottoms of seas, but the sea-bottom was pushed up to form the mountain.

✓ that it is **true**: The mountains they see are not ever-lasting; the mountains got their shapes because the rain or ice has eroded them, and the missing rock and soil is now in river valleys or in the sea.

✓ that it is **true**: The rocks they see were not always like this; the rocks are being weathered and small pieces are being removed from them.

In addition to these ideas which are difficult for anyone to grasp, learners develop some of their own **misconceptions**.

- ✗ Learners see stones as different to rocks; "rocks" are heavy and large, while "stones" are small and lighter. They do not see stones as pieces which have come from rock. (Learning in Science Project, Working Paper 17, 1982)
- ✗ Stones which have been polished (e.g. gravestones, kitchen counters) are not seen as a natural substance but man-made (Learning in Science Project, Working Paper 17, 1982). This confusion is increased now because artificial granite surfaces as well as artificial (man-made) boulders have become popular in gardens and public buildings.
- ✗ Finally, to quote from *Atlas of Science Literacy* (2006):

> Misconceptions about the causes of gravity persist after traditional high-school physics instruction (Brown & Clement, 1992) but can be overcome by specially designed instruction (Brown & Clement, 1992; Minstrell et al.,1992).
>
> Students of all ages may hold misconceptions about the magnitude of the Earth's gravitational force. Even after a physics course, many high-school students believe that gravity increases with height above the Earth's surface (Gunstone & White, 1981) or are not sure whether the force of gravity would be greater on a lead ball than on a wooden ball of the same size (Brown & Clement, 1992). High-school students also have difficulty in conceptualizing gravitational forces as interactions [In other words, they have difficulty understanding that the Earth pulls on the Moon but the Moon also pulls on the Earth with an equal force, causing tides]. In particular, they have difficulty in understanding that the magnitudes of the gravitational forces that two objects of different mass exert on each other are equal. These difficulties persist even after specially designed instruction (Brown & Clement, 1992).

In **Examples of activities** below, there are some suggestions for dealing with some of the conceptual difficulties.

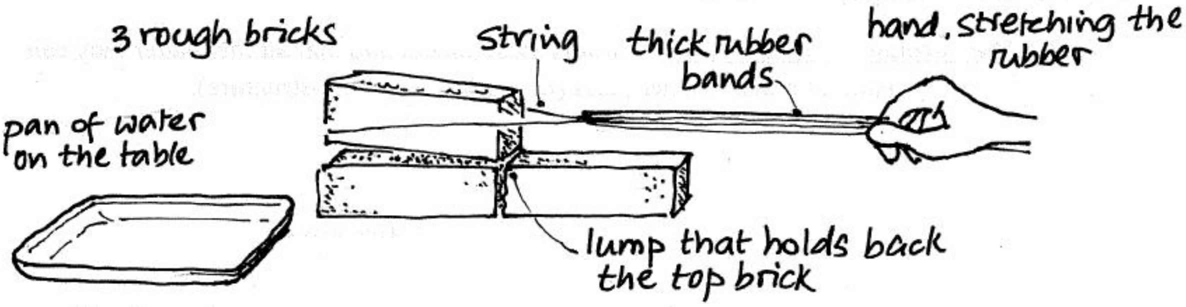
Examples of activities to build concepts and language

Learners can

- build models of the Earth using play-dough or clay with different colours; these models should show the core, mantle and crust in their relative thicknesses or diameters. The teacher provides cross-section diagrams of the interior structure of the Earth. (Process skills are **interpreting** information that the teacher provides, **estimating** the relative thickness of the crust, mantle and core in the model.) Learners should always draw at least the equator and African continent on the model, and then outline South Africa and make a mark to identify the place where their school would be.
- **observe** and **interpret** a model of convection in the hot mantle rock. The teacher heats a thick fluid like porridge in a glass container so that learners can see the upward movement of the hot parts. (Skills are **predicting** what will happen to the porridge at the cool edges of the container, or how a piece of dry porridge which lies on the top surface, will move. Another skill is **recording in a diagram** the observed movement of the porridge to show the convection flows.)
- make models of volcanos that show hot substances being pushed up through layers of sand or some other material like porridge. (Skills are **observing** detail, **recording**, **interpreting** the model.) Note that the common models of volcanoes (using liquid soap, red colouring, bicarbonate of soda and vinegar to make a froth coming out of a model mountain) represent almost nothing of a real volcano. A real volcano is not a surface feature on the Earth; it comes from heating and expansion of magma at depths of about 50 km below the surface.
- **observe** demonstrations of models that represent crustal plates being pushed together or sliding past each other. See **Figure 10**. In these models, the teacher **slowly** exerts force on one of the "plates" by means of say, strong rubber bands, until the plates slip suddenly. The shock of the "earthquake"

can be observed in ripples in a tray of water next to the model. Learners relate this to plate boundaries that have slipped causing earthquakes in e.g. Pakistan or the undersea quake that caused the Indonesian tsunami at Christmas in 2004.

Figure 10 *A model of a crustal plate that is being pushed over another plate. The bricks represent the upper and lower plates and the stretched rubber bands represent the tectonic force that is trying to move the top plate. The top brick has got stuck, but if the teacher keeps on slowly stretching the rubber more and more, the top brick will suddenly jerk to the right. The movement will cause ripples on the water surface in the pan, representing the waves that move through solid ground.*



- make models of a terrain which has layers of hard and soft rock. These models use soft and hard materials (such as a layer of sandy mud, topped by a layer of clay that gets quite hard). Learners erode these layers with water or by blowing on them, and observe and sketch the patterns and shapes which remain. These shapes will represent valleys and mountains.
- study photos of the Cape fold mountains which show the very clear folding of rock strata – these strata were folded as one plate pushed into the plate on which South Africa now exists. They model this meeting of the plates using two thick blankets to represent the plates. (**Interpreting** information by using models)

7.5 Mixtures and ways to separate the substances in mixtures

Reasons for placing this in Grade 7

From Grade 3 up to this point, the learners have had plenty of experiences of the differing properties of substances. The properties are interesting in themselves, but now they are critical because the learners have to solve problems of how to separate substances that are mixed together.

Grade 7 learners are capable of defining and solving the separation problems without recipes from the teacher , and they get great satisfaction from solving these problems. In Grade 7 there is enough time for them to work on such problems and make the links with Technology. The activities need only simple apparatus, which primary schools can probably provide.

For topic ***8.5 The particle model of matter*** learners must understand that all the matter they can handle and see is really made of much smaller parts (i.e. matter has a sub-structure).

	Concepts	Suggested elaboration
1	A mixture is made up of two or more substances that have different properties	In Grade 7 the term "made up of" does not include elements that are chemically bonded – that will come in Grade 8.
2	Differences in properties	If we know how the properties differ, we can plan a method to separate the substances. In Grade 7 we can assume that only physical methods are needed
3	Physical methods of separation	Include hand-sorting, using a magnet, sieving, filtration (a filter is a much finer sieve), evaporation, distilling, chromatography. Note that these methods are arranged approximately in order of decreasing size of the particles of the substances. See activities below.
4	Separation methods applied in problems of recycling waste materials.	This is a good topic for school-based curriculum development. Local authorities use different methods to separate and recycle waste. Some local authorities have no programme for separating and recycling waste, and the learners may see evidence of this around their town.

Link: Learners will use magnets for some of the separation problems, and they will need to understand magnets in topics ***7.4 Structure of the changing Earth*** and ***7.6 Energy transfer in systems***. The magnetic field will be a concept in Grade 8 electricity again.

Link: Learners should begin to think about the particles that are too small to see (i.e. they should be challenged to think on the microscopic scale, because this is what they must do in ***8.5 The particle model of matter***. See the note below on activities.)

Research on learning and teaching this topic

To date, we have found no published research on learning and teaching this topic.

However, the topic provides excellent challenges that develop Learning Outcome NS1 (. . . ***learners able to act confidently on their curiosity about natural phenomena, investigate relationships and solve problems in science, technology and environmental contexts***) and are easy to assess. The topic also provides good evidence for the Learning Outcome NS3 Assessment Standard, ***Understanding***

sustainable use of Earth resources because it lends itself to problems of recycling waste materials. There are also many opportunities for integration with Learning Outcomes Tech1, Tech2 and Tech3.

Examples of activities to build concepts and language

The activities should set challenges for learners that can be tackled by, for example, hand-sorting, using a magnet, flotation, sieving, filtration (a filter is a sieve, but with a much finer mesh), evaporation, distilling, chromatography.

Note that these methods are arranged roughly in order of decreasing size of the particles of the substances – see the note below on hypothesising about the nature of the particles.

Teachers must bear in mind that when they challenge learners to judge the size of particles they are laying foundations for understanding the particle model of matter in Grade 8 and onwards.

Learners may

- **make hypotheses** about the differences in the properties of the substances in a mixture
- **predict results and test ideas** about how the different substances will behave if one or the other separation method is used
- **evaluate** the purity of the substances they get and improve their methods of separation
- **make hypotheses** about the behaviour or size of the particles that are too small to see (e.g. some particles like copper sulphate particles pass through filter paper but other particles like sand grains will not; learners should do drawings to show their ideas of what the filter-paper looks like under a microscope, or do drawings to show what they think happens to particles of water that evaporate from a salt solution and then condense as pure water in a cooling jar. Assessment should focus on the learners ability to generate hypotheses about the particles, rather than on them knowing the correct explanation)

7.6 Forces, energy sources and energy transfers in systems

Reasons for placing this in Grade 7

This topic deals with basic ideas of contact and distance forces which are needed in ***7.4 The structure of the changing Earth*** (gravity, tectonic forces and geomagnetism) or will be needed in ***8.4 Exploring beyond Planet Earth*** (gravity) and ***8.7 Cells and electrical circuits*** (electricity).

This topic then extends the concept of forces to introduce the concepts of systems and energy. The energy concept builds on the electricity topic done in Grade 6, ***6.7 Energy from electricity***, by showing how ESKOM provides the energy for appliances.

From here onwards, the focus is that we should be using renewable sources of energy for our needs, and not wasting available energy. This theme is continued in the next topic ***7.7 Controlling heating and cooling: conduction, convection***.

Concepts	Suggested elaboration
1 Forces	Forces as pushes and pulls that two bodies (= objects) exert on each other.
1.1 Contact forces	Contact forces, in which the two bodies must touch each other in order to push or pull on each other .
1.2 Field forces	Field forces, also called non-contact forces or forces-at-a-distance, in which bodies push or pull each other without being in contact. These are the magnetic, electrical and gravity forces (Link: magnetic force with geomagnetism and compasses in ***7.4 Structure of the changing Earth***)
2 Forces act in pairs	Forces always act in pairs, whether these are contact or non-contact forces. The force of object A on object B = the force of B on A, but in the opposite direction. (Link: Gravitational pulls within the solar system and the Earth-Moon system.)
3 Energy	The word "energy" is a name for the ability of people and animals to exert forces that move things and change things. Non-living things can also exert forces that cause change and movement, and so non-living things can also have energy. Energy is not a substance, it is just a number that scientists use to measure a change that happens in a system. **For teachers only**: At Grade 9, learners can have this explanation of why energy is just a number. A system with energy can do some work (which we measure) and after it has done the work it has less energy (the energy is less by the amount of work that was done). Scientists use the joule as the unit of measurement to measure the work that was done and in this way they describe the energy that the system gave out.
4 System	Concept of a system, as a set of parts which interact and transfer energy, each part transferring energy to the next part and to the surroundings. The energy causes changes in the system and in the surroundings. (Include at least four examples of systems. These can be mechanical, thermal, electrical or biological systems. **Very simple examples** of these are, respectively, a human using a catapult, a stove and pot of water, a cell and buzzer, and a plant we grow to feed a horse which pulls a cart.)
5 Kinetic energy and potential energy	Concept that energy is available in just two forms: potential energy and kinetic energy. Potential energy (P.E.) is the energy which a part of a system has due to its position or configuration (e.g. a stretched rubber band, ready to snap back to its normal shape, has P.E.). Kinetic energy (K.E.) is the energy which a part of a system has due to its motion (e.g. a small stone that was shot from the rubber band has K.E.).

Chemicals can also have P.E., for example a firecracker or a petrol-and-air mixture. The P.E. is stored in the way the atoms are shaped and are able to react with each other. Learners will do more of this in Grade 8 but teachers can discuss it now and do some activities (safely!)

Hot things have energy, and the energy is in the K.E. of the fast-moving atoms and molecules (which are too small to see).

6 Energy transfers between parts of a system

In a system which receives energy, parts that receive it first, transfer (= pass on) some of the energy to other parts. At the end of the transfer, the first part of the system has less energy and the other part has more energy. (See examples of activities, below.) Notice that the NCS shifts the emphasis to systems and energy **transfers**, and makes little reference to energy transformations, because there are only two forms of energy.

7 Energy is never lost, it becomes less available to us.

The energy that we put into a system does not disappear. All of it is transferred to different parts of the system or the surrounding environment of the system. Systems always give out less useful energy than we put into them, because some energy is always wasted in heating up the surroundings. The wasted energy is no longer available for our use.

8 The national electricity supply system

The national electricity supply system is a system that transfers energy from sources such as coal, nuclear material, falling water or wind, to dynamos (= generators). These dynamos then transfer energy to electrons (which we can call simply "the electricity" in Grade 7) in the wires of the national supply grid which then transfers energy to many types of appliances. The "grid" is the web of powerlines and transformers that cross the country.

9 Renewable and non-renewable energy resources

SA has both renewable and non-renewable sources of energy to drive generators. Non-renewable sources include coal and oil. Renewable sources include hydro power (from the energy of falling water), wind power and power from biofuel. Sunlight is a renewable energy source to generate electricity directly (from photo-voltaic cells) or it can replace electricity (for example, in solar water-heaters). Wood can be a renewable energy source for heating, if it is used in a sustainable way.

10 Environmental impacts of using energy sources

Many methods of using sources of energy have negative impacts on the environment and so people always need to use energy in the least wasteful way, and use the sources as little as they can. (For example, link to topic ***6.7 Energy from electricity*** : to generate electricity from coal power-stations, ESKOM must use huge quantities of water. The coal comes from mines that have great impacts on water quality and other parts of the environment. If we demand more electricity supply, we will need more coal-mines.)

Research on learning and teaching this topic

Typical misconceptions and conceptual problems for learners are

✗ Learners do not extend the concept of energy beyond their personal experience that they sometimes "have energy" or "lack energy". It is reasonable and useful for learners to think of energy in terms of their own ability to run, jump or work, but we must extend their thinking beyond this. See *Energy and human movement*, below.

✗ Learners think of energy as a substance that gets "used up" – in fact it is neither a substance nor does it get used up. See *Energy conservation versus conservation of available energy resources*, below.

✗ Learners are confused by the idea of energy being "transformed" or "converted". See *Energy is not a substance that can be transformed into other substances*, below.

Energy and human movement

Children almost always associate the word "energy" with human movement and work (CLIS Project, 1986) and that is a useful understanding to build on, in every Grade. The NCS Core Knowledge section has the statements in Foundation Phase , *When we say we feel "full of energy", we mean we feel ready to move fast or do a lot of work. People who do not have enough food or the right kind food to eat, feel tired and lack energy.*

A teaching sequence should build on this but then introduce cognitive challenges by asking for example, "A loaf of bread gives you energy. Now does the bread have the same amount of energy when is on the table and when it is high up in an aeroplane and it can fall down onto someone's head?" The learners then have to distinguish the ideas of energy from food and energy from the physical arrangement of objects.

"Energy conservation" versus "conservation of available energy sources"

In GET the focus is on conserving energy **sources** like oil and firewood, and the environmental impacts of using them. However, many learners confuse "conserving electricity" or "conserving energy resources like oil" with "conservation of energy" (LISP, 1980).

In FET, learners will meet the term "law of conservation of energy". This is a big abstract idea of science and states that energy cannot be created or destroyed. They will learn that we cannot do anything to "conserve energy" because it is always conserved. All the energy at the beginning of an interaction is still there at the end. However, the energy that was in some parts of the system is now in other parts of the system (or in the surroundings). Energy does not get used up – what actually gets used up is **available** energy **sources** like oil, coal or firewood.

In GET the best approach is to stress that energy does not get used up; instead, the energy is first in one part of the system and then it is passed on to other parts of the system. In fact, energy is **transferred** from one part of a system to other parts, and with each transfer it becomes more spread out and more difficult for us to use. (See the box alongside.)

The scientists view

For example, a tank of petrol in a car, together with the air it can burn in, has P.E.. The engine transfers the energy from the petrol+air to the K.E. of the whole moving car, and this is useful work.

But the energy that came from the petrol+air is now also in the hot metal of the engine and the brakes, the disturbed air behind the car, the hot tyres and the hot road. As these parts cool down, the energy transfers to the surrounding air and warms it up.

So all the energy is still there but slightly-warmed air is not very useful to anyone.

(Note that the **petrol** was used up **but not its energy** – its energy was just spread to the surroundings.)

Energy is not a substance that can be transformed into other substances

Textbooks and teachers in past decades often used the terms "the forms of energy", "energy transformations" and "energy conversion". The "forms of energy" language reinforces the misconception that energy is some kind of substance that can be transformed into other substances. These terms are commonly used in conversation and in newspaper articles, but are not helpful in classrooms where learners are trying to understand the big ideas of energy and systems.

Tests often asked learners to name the **forms** of energy (Ellse, 1988) and the examiner expected answers like electrical energy, gravitational potential energy, mechanical energy, spring energy, chemical energy, chemical potential energy, heat energy, light energy, sound energy, wind energy, solar energy, nuclear energy, food energy. Such tests are problematic because

(a) learners could never be sure how many "forms" there were – only the teacher could decide.

(b) the names of the "forms" are usually ambiguous – was a candle flame chemical energy? Light energy? Heat energy? Only the teacher could decide this, too. The learners could not work it out for themselves.

(c) the names are usually wrong – the candle flame gives light because electrons in oxygen and wax are being excited to high energy levels and then they emit photons of light as they form new bonds, so perhaps the candle flame should really be called an example of electrical energy.

The NCS avoids the term "forms of energy" and focuses on **systems** – electrical systems, gravitational systems, mechanical systems, chemical systems, biological systems, thermal (heating) systems, optical (light) systems, sound systems. Now learners can look at systems (preferably real ones on the desk, or in pictures) and do their own reasoning about where the energy is going in the system. The teacher should ask

"Which part of the system received energy in the beginning?" or

"Which part has received energy now?" and

"Where is useful energy going to waste?" and

"How could you stop some of the useful energy becoming useless?" and

"When we give energy to a system, can we ever get more energy out of the system than we put in?"

Why does it matter how we speak about energy?

This topic has emphasised the importance of using language carefully in the science lesson, to speak about types of systems rather than "forms of energy". But newspapers, TV scripts and some textbooks will continue to write about "energy transformations", "types of energy" and "converting energy into other forms". We cannot control this because, outside the classroom, we live in a world where people communicate in whatever way they think suitable for their hearers. However, inside the classroom, we can control our own language for the sake of helping our learners grasp concepts like "energy" and "systems".

Examples of activities to build concepts and language

Learners can:

- investigate forces of attraction and repulsion between magnets, and look for a pattern in the way North and South poles attract or repel each other. They can do the same for bodies that have electric charges on them, and look for a pattern in the way positive and negative charges attract or repel each other. (Process skills are **planning an investigation**, **looking for patterns** and **stating the relationships**)
- do and discuss activities with simple systems in which energy is transferred from one part to another. For example, a hand bends a ruler (ruler has P.E.) and the ruler flicks a paper pellet across the room (now the pellet has K.E.). Another example: the wax of a candle and the oxygen in air have P.E.; when the wax and oxygen burn, some of this energy is transferred to a beaker of water above the flame (the water particles gain more K.E. and we see bubbles forming in the water). (Process skills are **interpreting** the situation by **applying the concept** of potential or kinetic energy, **predicting** what will receive the energy and where the energy will then be transferred.
- identify the energy inputs to each part of a system, the outputs and losses to the surroundings. The systems could include a bicycle and dynamo; a learner must turn the pedals by hand to spin the bicycle wheel, and use the dynamo to light bulbs.

- make a model of the national electricity supply system, using a battery of torch cells to represent the ESKOM power station. Learners extend bare wires to cross the classroom, and they connect more and more bulbs in parallel to understand the effect of overloading the national grid.
- identify renewable and non-renewable sources in a picture showing different kinds of human industry.
- trace energy flows through an ecosystem, identify which parts get the energy from the Sun first, which parts get some of that energy next and then identify all the parts of the system that have some energy at the end of the process.

7.7 Controlling heating and cooling: conduction, convection and radiation

Reasons for placing this in Grade 7

Heating is one of the ways to transferring energy from one part of a system to another part, and this topic builds on ***7.6 Energy transfer in systems***. (Of course, it also depends on topics 5.5, 5.6, and 6.7.)

Most children know that we can heat things in more than one way, and this topic unpacks their existing knowledge. It provides opportunities for investigation and problem-solving (Learning Outcome NS1), using simple equipment, and links very effectively with Technology LO1–3. Learners should do design projects in this very important topic because the wastage of available energy resources is a critically important issue for South Africa, and will be so for the whole of their adult lives. These design projects (such as making systems to heat water using the Sun) allow us to develop and assess investigations (Learning Outcome NS1), application of concepts (Learning Outcome NS2) and how well learners understand sustainable use of Earth resources (Learning Outcome NS3).

To **explain** conduction, learners would need the particle kinetic model of matter, which is done formally in Grade 8. However, in Grade 7, without knowing the particle model of matter, they can certainly **describe** conduction and plan investigations to compare different conductors. In this Grade they should spend the time on investigating, describing the phenomena of conduction, convection and radiation, and applying the concepts.

Concepts	Suggested elaboration
1 Heating is a transfer of energy	Heating is the process by which energy is transferred in a system, from hotter to cooler parts. A hot object cools down, and the surroundings near the hot object warm up, until everything in the system is at the same temperature.
2 Three ways of heating things	A hot object (= a hot body) can heat up other objects in three ways: by conduction, by convection and by radiation. (**The following is for teachers and is not required for learners until they are in Grade 9**: We can also heat things by **working** them mechanically and electrically. Bending a piece of wire back and forth by hand is mechanical working and will make the wire very hot at the bend. We can also heat a conductor by working on it electrically, i.e. by passing a current through it. All five of the methods heat a substance by making its molecules and atoms move faster.)
2.1 conduction	Conduction is the process of transferring energy through a material from hotter parts to cooler parts. The energy from the hot part raises the temperature in the cooler parts, further and further away (we might say the energy “travels”). But the material itself does not move.
2.2 convection	Convection is the process in which a material is heated, expands and the material itself moves upward; the upwards movement creates a flow of the substance. For example, warm air expands and rises up through cooler air; this convection current of air will heat up the air near the ceiling of a house.
2.3 radiation	Radiation is the process of transferring energy through empty space. We can feel radiated energy if we stand near a fire; if we hold up a hand in front of our face, the face feels colder in the shadow behind the hand. Sunlight in fact reaches us through 150 million kilometres of empty space and warms us. The radiation concept needs careful attention because it will be developed further in Grade 8, ***8.8 Light, sight and radiation*** in Grade 10 *Waves and Light*, and in Grade 12 *The Electromagnetic spectrum.*

3	Conductors and insulators of heat	Properties of materials relevant to heating and cooling: Some materials are good conductors (e.g. metals) and others, like plastics, are poor conductors. (Poor conductors are good insulators.)
4	Good and poor reflectors	Some materials are good reflectors (e.g. silvery, shiny surfaces) and others are poor reflectors (e.g. matt black surfaces). When good reflectors receive radiated energy they do not heat up quickly because they reflect the radiated energy away; poor reflectors heat up quicker because they absorb the radiated energy instead of reflecting it away. Objects with good reflecting surface do not radiate energy quickly when they are hot, so they stay hot longer. Objects with poor reflecting surfaces (e.g. matt black surfaces) radiate energy much more quickly when they are hot, so they cool down more quickly than good reflectors.
5	Clever design saves energy sources	These concepts above must be applied to problems of conserving usable energy; the problems may be in heating and cooling homes, or in cooking or heating water. Learners should be able to apply concepts in this topic to help them control of conduction, convection and radiation. See the *Examples of activities* section below.

Research on learning and teaching this topic

Typical misconceptions and conceptual problems

✘ Learners think of heat as a substance that flows in and out of things. This is often linked with the idea that heat is a "form of energy", and the energy is like a substance. A learner may say "heat is a gas that comes into the water from the flame" (refer to the Research section in ***5.6 Heating and cooling***)

The simplest way to limit this misconception is to use the word "heat" as a verb - e.g "we want to heat something" or "The flame is heating the water" or "We can heat this metal by rubbing it on another piece of metal."

✘ Learners can say what conduction means when thinking about hot stoves heating a pot, for example, but they do apply the concept of conduction when thinking about their own skin sensations of hot and cold. For example, a barefoot learner might say that a cement floor is cold but a carpet on the floor is warm. (Now see box on the right.)

The scientific view is that during the night the floor and the carpet must have cooled to the same temperature. The reason why the floor feels cold is that it quickly conducts heat away from a bare foot, while the carpet is an insulator and conducts heat from the foot only very slowly.

✘ When they have to think about radiation, learners find it hard to remember that surfaces which radiate well also absorb energy well. For example, black surfaces are good for both absorbing and radiating energy. On the other hand, silver surfaces do not absorb radiation well, because they reflect it. They are not good radiators, and that is the reason why metal teapots are coated with shiny chrome metal. One way to help these learners is to use the analogy of a gate – black or dark surfaces are like a wide gate for radiated energy, because it comes in easily and goes out easily. The opposite is true for silver or light-coloured surfaces (Malcolm, 1997, pers.comm.).

The suggested approach in GET

The NCS at GET is focussed on energy for development, rather than on a sophisticated understanding of physics, and that is why the unifying statements in the NCS policy document (see Layer One) are:

Energy is transferred through biological or physical systems, from energy sources. With each energy transfer, some of the energy becomes less available for our use, and therefore we need to know how to control energy transfers, and

Energy is available from a limited number of sources, and the sustainable development of countries in our region depends on the wise use of energy sources

So the Grade 7 approach to energy and systems keeps the focus on technological problems and development. This offers many rich and interesting tasks that can be planned in consultation with the technology teacher. These tasks are also rich in assessment opportunities.

Examples of activities to build concepts and language

Learners can

- **investigate** a paraffin stove when it is heating water and **hypothesise** ways of making the whole system more efficient (i.e. to waste less energy in useless heating).
- make food in a “wonder-box” (insulated cooker) and **apply concepts** of conduction, convection and radiation to explain why it can cook food without continuous energy input.
- measure the amounts and costs of fuel and calculate the cost of boiling a litre of water, using electricity, wood, paraffin (planning a **fair comparison**).
- **investigate** or **interpret information** about solar-powered systems such as photo-voltaics that drive radios, LEDs, etc., and solar furnaces for processing materials or generating steam.
- **investigate**, **design**, **make**, **evaluate** and **improve** systems such as solar water heaters, solar distillers, solar food driers.
- **investigate** the design of houses, **interpret** information and **apply concepts** of conduction, convection and radiation to this context. Relate good and bad design to the costs of heating and cooling a building.

Grade 8 Topics

These notes focus on the **science knowledge** in the NCS. But the science knowledge is not the curriculum, and these notes are not a learning programme. The curriculum is about learners using the knowledge to produce outcomes. So these notes are just the basis for learning programmes that build the Assessment Standards for Learning Outcome NS1 ***Scientific Investigations*** and Learning Outcome NS3 ***Science Society and Environment***, as well as building the Assessment Standards of Learning Outcome NS2

8.1 Interdependence in ecosystems

Reasons for placing this in Grade 8

This topic and the next one, ***8.2 Natural selection and adaptation*** continue to build two of the NCS's "unifying statements" which you saw in the introduction, namely ecosystems (*Organisms in ecosystems are dependent for their survival on the presence of abiotic factors and on their relationship with other organisms.*), and continuity and change (*The huge diversity of forms of life can be understood in terms of a history of change in environments and in characteristics of plants and animals throughout the world over millions of years*). The concept that organisms in an ecosystem are interdependent is not easy for learners to apply, because the learners need to keep several aspects in mind at the same time. For this reason we leave this topic to Grade 8 and then, in Grade 9, extend the concepts to micro-organisms and natural selection in micro-organisms.

Concepts	Suggested elaboration
1 Ecosystems have biotic (living) parts and abiotic (non-living) parts.	The biotic parts are, for example, elephants, trees, fungi, humans, micro-organisms or insects, and the abiotic parts are, for example, the soil, water, air, light, warmth/cold. The organisms' effects on the ecosystem are called the biotic **factors** in the ecosystem and the effects of the abiotic parts are called abiotic **factors**. Water is a very important abiotic factor – the total amount of water on Planet Earth does not change, but it moves from place to place and changes its state.
2 The Sun provides the energy for life in an ecosystem. Photosynthesis.	Green plants can use energy from light to carry out a chemical reaction called photosynthesis; this reaction produces starch from water and carbon dioxide. Plants can transform the starch into cellulose (to build their structures such as stems) and into other substances that plants need for their life processes. (The details of the reactions are not required, just the inputs of light, water and carbon dioxide and then the production of starch.)
3 Producers and consumers	Plants are the producers of food while other organisms (i.e. animals) are the consumers of food in an ecosystem. Only green plants can produce their own food because they are the only organisms that can carry out photosynthesis.
4 Herbivores, carnivores and omnivores	Some animals eat only plants (or plant parts or remains of dead plants) while some animals eat only other animals (or remains of dead animals). Some animals eat both plants and animals. These animals are called, respectively, **herbivores**, **carnivores** and **omnivores**. Carnivores that hunt other animals are **predators**, and the animals they eat are the **prey** of the predators.

5	Respiration releases the energy in food	Consumers use the energy from food by a process called respiration (no details of the respiration reactions, except for the fact that it needs oxygen and produces carbon dioxide and water). Plants also need energy to grow and so they also respire.
6	Food chains and food webs	In an ecosystem, we usually find many food chains and food webs. Energy from food passes up the food chains and up the food webs. Carnivores are higher up in a food web than herbivores, because carnivores eat herbivores. Most carnivores have to eat less than herbivores because carnivores get more energy from the animals they eat, while most herbivores need to eat large amounts of plant matter to get the energy they need.
7	Energy flows in an ecosystem	We can trace the flows of energy in an ecosystem, as energy is transferred from one part of the ecosystem to other parts. For example, energy from the Sun is transferred through plants, which become food for animals, which die and become food for decomposers.
8	The role of micro-organisms	Micro-organisms and other decomposers have a vital role in maintaining the fertility of the soil by cycling nutrients.
9	Survival	Organisms that live in an ecosystem will all die from some cause such as being eaten, or lack of water, lack of food, disease, and so on. Some individual organisms survive longer than others of the same kind (e.g. some leopards in a population of leopards survive longer than the other leopards). Also some kinds of organisms survive better than others in their environment (e.g. in a desert, meerkats survive better than leopards).
10	Adaptations of organisms	Organisms have features which increase their chances of survival in their particular habitat. These features are called adaptations. Examples of plant adaptations are roots and leaves that enable plants to live in very dry places, and seeds that are adapted for dispersal by animals or wind. Examples of animal adaptations are camouflage, mimicry, or mouthparts that enable the animal to eat particular kinds of food.
11	Interdependence	Each organism in an ecosystem depends for its life and reproduction on the life and reproduction of many other organisms, as well as on many abiotic factors. We say that the many parts of an ecosystem are inter-dependent. This means that a change in any one part affects all the other parts. (Link this to the definition of a system in *Energy & Change* topics)
12	Humans are part of the Earth ecosystem	Humans take resources from ecosystems for their own needs. But if they take resources from an ecosystem without understanding the interdependencies in it, they can destroy the ecosystem. Though we need natural resources, we are part of an ecosystem ourselves and have to understand how each part of the natural world depends on the functioning of other parts.
13	The value of ecosystems	Ecosystems are valuable to humans in terms of our survival on this planet, but also in terms of cultural practices and traditions, recreation and spiritual values. They also have great economic value as job-creators in tourism.

Research on teaching and learning this topic

The main idea that learners should get from this topic is that in an ecosystem each part needs all the other parts – even though we don’t know all the connections between them. Therefore everyone should care about any changes that we see to the environment, knowing that it will affect all the living things in some way and non-living parts of the environment too. That is the basic understanding and attitude our learners must have as a result of our teaching.

Beyond that, Grade 8 learners should be able to create food chains and food webs from information they are given. They should be able to show, in diagrams and on visits to the school's ecosystem site, that they know how the abiotic factors of soil, air, sunlight and water interact with the living things. They must understand that the health of the ecosystem depends on the organisms being able to reproduce. They must also understand that reproduction of an organism is affected by changes in the biotic and abiotic factors in the environment.

Having said that, we must recognise that the concept of interdependence is not easy to understand because we are asking learners to think about the effects of two, three or four aspects on each other, and keep them all in mind at the same time.

From the *Atlas of Science Literacy* (2006) we have this:

> Middle-school and high-school students may believe that organisms are able to effect changes in bodily structure to exploit particular habitats or that they respond to a changed environment by seeking a more favourable environment (Jungwirth, 1975; Clough & Wood-Robinson, 1985a).
>
> Some middle-school students think dead organisms simply rot away and no longer exist. They do not realize that the matter from the dead organism is converted into other materials in the environment. Some middle-school students see decay as a gradual, inevitable consequence of time without need of decomposing agents (Smith & Anderson, 1986). Some high-school students believe that matter is conserved during decay, but do not know where it goes (Leach et al., 1992).

Munson (1994) has a good review of learners' misconceptions about ecosystems. For example, some learners incorrectly believe that

- ✘ Organisms higher in a food web eat **everything** that is lower in the web (Crawley & Arditzoglou,1988; Griffiths & Grant, 1985). The science view is that organisms higher in a food web feed on **some** organisms lower in the food web.
- ✘ Varying the population of an organism will only affect the others that are directly connected through a food chain (Griffiths & Grant, 1985; Munson, 1991) or they incorrectly believe that varying the population of an organism may not affect an ecosystem, because some organisms are not important (Munson, 1991). The scientific conception is that varying the population of an organism affects the entire ecosystem.

Examples of activities to build concepts and language

Learners can

- match animals' adaptations to the kind of food each animal eats.
- match plant adaptations to the plants' habitats.
- test a soil sample for micro-organisms by testing the air in a closed jar for carbon dioxide (a product of the micro-organisms' respiration).
- partially cover leaves of a growing plant to prevent light reaching them, and then test the leaves for the presence of starch.
- engage in simulations or role plays that explore issues in the use of ecosystem resources. For example, issues might be economic benefits of coastal mining *versus* tourism, or using agricultural land for biofuel crops.
- Interpret and analyse information about specific methods of using resources in a sustainable way e.g. woodlots, permaculture, sustainable use of wood and charcoal (link with ***7.6 Energy Transfers in systems***).

8.2 Natural selection and adaptation

Reasons for placing this in Grade 8

This topic builds on topic ***8.1 Interdependence in ecosystems*** and goes more deeply into the concept of adaptation which was begun there. The topic is left until Grade 8 so that learners are more able to do abstract thinking; the concept of natural selection can be tricky because it requires the learners to hold a number of ideas in mind at the same time to reason out a conclusion.

Concepts	Suggested elaboration
1 Population	A population is all the organisms of a particular type that live in an ecosystem. (An ecosystem usually has many populations of different kinds of organisms. All the populations together are called a community i.e all the living things of all kinds that live in that ecosystem.)
2 Factors that affect a population	Any population in an ecosystem is affected by various factors such as predation, drought, climate change, abundance of food, diseases.
3 Variation in a population	Variation in a population means that individual organisms in that population are not exact copies of a parent but differ from their parents, by random chance. On rare occasions these differences offer an individual a better chance of survival when the population is affected by heavy predation, drought, etc. (An example of **variation**: a characteristic of goats is that they are covered with hair. An individual goat might have brown hair instead of white hair – this would be a **variation** in the "goats-have-hair" characteristic.)
4 Natural selection	**Natural selection** offers an explanation of how populations adapt to their habitat. Natural selection in a population is the process by which the individuals with favourable variations are better adapted to survive, and have more offspring, so that the favourable variation is passed to future generations and becomes more common in the population. Organisms without the favourable variation may die sooner, or have fewer offspring. Their variation eventually becomes reduced in the population. The long-term effect is that the population as a whole changes because it has more of those individuals with the favourable variation, and fewer of those without the variation. (Lessons should include animal adaptations to habitats in equatorial and polar regions, in order to link with ***8.3 The Atmosphere of Earth***, point 8.)
5 Extinctions	Extinctions can be natural and they can be man-made. Mass extinctions happened in the distant past, but humans in this century are driving species to extinction at a faster rate than nature did long ago.

Research on teaching and learning this topic

Note that in Grade 9 teachers do not have to teach evolution as such. That is left for the FET phase. Adaptation has been in the South African science curriculum since 1982 and so it is not new. The NCS just takes the logical step of studying natural selection as the process by which organisms become adapted to particular ways of eating, camouflage, means of escape or hunting, or ability to survive in dry or wet climates – in other words the different environments in which they are able to survive.

Teachers need to build **three basic ideas** in their learners' minds: (a) all living things reproduce; this means that each kind of living thing comes from ancestors that were reproducing millions of years ago, and the ancestors go back more generations than we can count, (b) each individual differs slightly from its parents, in random, accidental ways – this is called variation, (c) some individuals are likely to live longer than others, or have more offspring, because they have some small difference that gives them an advantage in the struggle for life. These lucky ones have more chance of reproducing. Their small advantage might be reproduced in their offspring too. So when we find an adaptation in one kind of organism, that adaptation is the result of tens of thousands of generations of parents and offspring, some of which died early without offspring and some of which survived a little longer to reproduce and pass on their favourable adaptation to their offspring.

From the *Atlas of Science literacy* (2006) we have:

> Middle-school and high-school students may believe that organisms are able to effect changes in bodily structure to exploit particular habitats or that they respond to a changed environment by seeking a more favourable environment (Jungwirth, 1975; Clough & Wood-Robinson, 1985a).

✗ In other words, learners may incorrectly think, for example, that acacia trees that live in dry environments grow long deep roots because they "went to find water" deep down under the ground. Or they may incorrectly think, for example, that polar bears (which have thick, white fur) moved out of a warm environment to the cold Arctic regions because the snow and ice suited them better.

✗ Some incorrectly believe that an individual organism changes its body in order to cope with a certain kind of food (e.g. giraffes got long necks because they spent so much time stretching to reach high branches)

✗ Some learners may confuse metamorphosis in insects with adaptation. They think that an egg hatches into a crawling larva because it finds a source of food in e.g. green leaves, and then the larva pupates to become an insect such as a butterfly because another source of food e.g. flower nectar, is available.

✗ Some learners think that species of animals just adapt each time the environment changes and in this way they become better and better adapted. Some of these learners may believe incorrectly that modern animals (especially humans) cannot really become extinct (Evans, 2006).

✗ Some learners incorrectly see adaptation as a mutation in an individual. Perhaps they have seen movies which shaped their ideas. For example, in *Spiderman* an ordinary man is bitten by an radioactive spider, mutates and quickly develops into the hero Spiderman.

Language concerns

Paradoxical jargon (terms which have different meanings in everyday English and in science, or which has different meanings in different branches of science) confuse learners. For example, the terms "population", "host", "consumer" and "producer" have very different meanings in science to their everyday English meanings (Sanders and Mogodi, 2000) as does the word "selection". This causes confusion for the learners, especially when teachers are not aware, when they use these words in science lessons, that learners have a very different meaning in mind.

Examples of activities to build concepts and language

Learners can

- identify variations among class-mates e.g. some have the ability to roll their tongues and others do not
- take part in simulation games in which they must compete to find objects like matchsticks in the grass. However, the grass is pale brown and some matchsticks are painted blue while other matchsticks are the same colour as the grass. More of the pale match-sticks "survive" the hunt.
- sequence a series of cards which, when in the correct order, describe the changes in the peppered moth population in industrial Britain.

8.3 The atmosphere on Earth

Reasons for placing this in Grade 8

In Grade 5 the learners work with concepts in weather, evaporation / condensation and the water-cycle in topic ***5.3 Atmosphere and weather*** while in Grade 6 they have to think about what lies higher than the clouds as they do ***6.5 Simple astronomy*** . In Grade 6 and 7 (in ***7.4 The structure of the changing Earth***) they have to grapple with the idea of the Earth as a ball in Space, and the idea that we live on the surface of that ball. They also learn about the constructive and destructive forces that shape the Earth such as weather, floods and erosion. In this unit they deal in more detail with the atmosphere in which that weather happens.

Concepts	Suggested elaboration
1 The atmosphere	The atmosphere is all the air around the planet, from the deepest mines to about 100 km above us; compared to the diameter of the Earth, this is a very thin blanket of air. The atmosphere is less dense but also colder as one goes higher. The gas molecules are more spread-out as one goes higher, and so breathing becomes more difficult at high altitudes. (Learners do **not** need to master the concept of density of a gas; it is enough for them to know that people find difficulty in breathing enough air when they climb high mountains or go up in aeroplanes, and that the air high up does not press on surfaces as much as it does at lower altitudes.)
2 The air is a mixture of different gases	The air is a mixture of different gases; the main gases are nitrogen and oxygen, very small quantities of carbon dioxide and argon, and variable quantities of water-vapour. (Note the link with the section on making and identifying gases in ***8.6 Elements and compounds***)
3 Earth's atmosphere protects living things	Fast-moving objects constantly bombard Earth, coming from deep Space. These heat up and burn as they move through the atmosphere. The Sun's radiation includes harmful rays, but these are absorbed and scattered by the upper layers of the atmosphere.
4 Greenhouse effect	The "greenhouse effect" is the natural temperature-regulating effect of the atmosphere that keeps Earth within the temperature range that is suitable for life.
5 Enhanced greenhouse effect	The atmosphere has retained increasing quantities of heat because human industrial activity is adding additional quantities of gases such as methane and carbon dioxide; these gases are trapping the heat. The temperature increase is known as the "enhanced greenhouse effect" and it seems to be responsible for global warming which is causing climate change.
6 Global warming and climate change	Global warming is the world-wide increase in average temperatures on land, sea and air. Global warming is causing the climate to vary much more than in the past. This may mean hotter summers and colder winters for some parts of the planet. The total amount of water on Planet Earth does not change but in future more rain may fall in some places and less rain in other places, than used to fall in the past. The changes in rainfall patterns and temperatures will affect crop production and the kinds of diseases that are common in certain areas. Climate change will result in water shortages in certain parts but more flooding in other parts. In the longer term, as the ice-caps at the north and south poles melt, sea levels will rise and the sea will flood low-lying cities and agricultural areas. This in turn will cause large-scale movements of people and great social and political instability.
7 Climates	The climate is different in different parts of the world; this is a result of the way the radiation from the Sun is spread out over the far north and south parts of the Earth, but concentrated in the tropics (**Note**: Concepts of global wind or air circulation patterns are optional. That section will typically be an FET geography topic.)
8 Adaptations of living things to climates	Plants and animals have adapted to these different climates, and are distinctly different in the different regions of the world.

Research on teaching and learning this topic

✘ Many learners incorrectly believe that the tropics are warmer because they are closer to the Sun – this looks obvious if a lamp (the "Sun") is held near a globe. However, the real situation is that the Sun is so far away that its distance from the equator and the poles is virtually the same.

✘ Learners incorrectly think that ozone is a greenhouse gas and causes global warming. In fact, ozone is not responsible for global warming – it is a gas which absorbs the energy carried by ultra-violet radiation from the Sun, high in the atmosphere, and helps to protect living things from the cell damage that ultra-violet radiation can cause.

✘ Other learners may incorrectly say "The ozone hole is letting in too much sunlight which causes the problem of global warming". In fact, the ozone hole is not a hole but a thinner part of the layer. Extra ultra-violet radiation is passing through this thinner layer. It makes only a small contribution to global warming but can cause damage to living cells.

✘ Some learners, who can correctly answer questions about the water cycle, still do not understand that the total amount of water on Earth is constant – we cannot make more water.

✘ Some learners and many adults say "The Sun's orbit is not a perfect circle and so the seasons are the result of the Earth moving closer to the Sun or further away from the Sun". This is not the reason for seasonal changes. We have summer and winter because the Earth's axis is not vertical in space but slightly tilted. At one stage in a year, during the Earth's orbit around the Sun, we in the southern hemisphere are exposed to the more direct rays of the Sun and have summer, while the northern hemisphere gets only glancing rays of the Sun and has winter. Six months later, the Earth has completed half its orbit and the northern hemisphere has summer while we have winter.

The reason why the N.C.S. (at GET level) did **not** include the causes of the seasons is given in the research cited below, in *Atlas of Science literacy (2007)*:

Students of all ages (including college students and adults) have difficulty understanding what causes the seasons. Students may not be able to understand explanations of the seasons before they reasonably understand the relative size, motion, and distance of the Sun and the Earth (Sadler, 1987; Vosniadou, 1991). Many students before and after instruction in Earth science think that winter is colder than summer because the Earth is farther from the Sun in winter (Atwood & Atwood, 1996; Dove, 1998; Philips, 1991; Sadler, 1998). This idea is often related to the belief that the Earth orbits the Sun in an elongated elliptical path (Galili & Lavrik, 1998; Sadler, 1998). Other students, especially after instruction, think that [summer and winter differ because] the distance between the northern hemisphere and the sun changes because the Earth leans toward the Sun in the summer and away from the Sun in winter (Galili & Lavrik, 1998; Sadler, 1998).

Examples of activities to build concepts and language

Learners can

- build models of the planet from a ball of newspaper, cover it with plain paper and draw the continents on it (or cover it with a photocopy of a world map). When they colour in the continents and the oceans, they are forced to notice that there is much more ocean than land. Working from information they find, they colour in the tropical regions, noting where they are and hypothesising reasons why they are around the equator but not at north and south polar regions.
- cover the Earth model in panty-hose to represent the atmosphere. They should note how thin the layer is compared to the size of the Earth
- interpret a model of the Earth-Sun system in which light from a bright lamp or a large mirror to reflect the actual Sun falls normally onto the equator of a globe. The learners should compare the intensity of the light over the poles and over the equatorial regions and show comprehension by sketching the situation. (The lamp or mirror should be more than 5 metres away from the globe to avoid the misconception that the poles are cold and the tropics are warmer because the poles are further from the Sun and the tropics are nearer to the Sun. At 5 m the difference in distance from "Sun" to poles and Sun to tropics is not significant.)

8.4 Exploring beyond Planet Earth

Reasons for placing this in Grade 8

The research on this topic (see the section below) tells us two things. Firstly, astronomy fires the imagination of many learners, they are interested and show positive attitudes towards science (or at least, this part of science). Secondly, the ideas in this topic need time and suitable activities in order to develop. For that reason, the topic is placed in Grade 8 rather than Grade 7, to allow some extra time for mental growth.

In Grade 7 the learners have engaged with the concepts of the Earth as a rocky planet, with a hot core, a crust that moves and re-shape the surface of the planet all the time. They know that the planet has an atmosphere, seas and a magnetic field. They can use this knowledge to understand that Mercury, Mars, Venus and the Moon have a similar structure to the Earth but differ from the Earth in very important ways that make life possible on Earth. These rocky planets contrast with the gas giant planets such as Jupiter and Uranus.

This topic should be placed at the end of the Grade 8 year. Then the learners should have a sense of our planet as the great ecosystem we all depend on. They should have greater knowledge of the chemistry of the gases oxygen, hydrogen and carbon dioxide, photo-synthesis, nutrition and other life processes like respiration. They will also know something about non-contact forces like gravity and geomagnetism. They should have met photo-voltaic cells and electric circuits including apparatus that can send signals; their knowledge of these aspects allows teachers to set interesting projects on how to send people to explore the planets or the Moon. These extended projects allow teachers to assess learners' competence in the outcomes in a more authentic context.

Reason for treating the whole of sub-strand *Our place in Space* in one Grade

Readers may ask why only one of the three sub-strands in the Planet Earth strand (*Our place in Space*, *Atmosphere and weather*, and *The changing Earth*) is presented in Grade 8. The main reasons for doing this are

– to avoid concept and language overload,

– to allow new concepts to develop in a single context and

– to allow learners enough time for projects in which they can display competence in the Learning Outcomes and be assessed in a somewhat authentic context.

To elaborate, each of the three sub-strands in the *Planet Earth* strand has a number of new concepts (which must be built through repeated experiences), and their new vocabulary. These concepts (see the list below) are easier for learners to understand and put to use when they are **inter-related around a single context**, for example, exploring the Moon or solar system. The learners can develop concepts and relate new vocabulary to a single set of activities, models and observations. If the three sub-strands (*Our place in Space*, *Atmosphere and weather*, and *The changing Earth*) were attempted in one term, each sub-strand would get about 2½ weeks, or about 8 hours, of teaching time. Eight hours would allow only superficial teacher-tell coverage of a strand e.g. *Our place in space*. The sub-strands would shift to a new context every 2½ weeks, the concept-building experiences would be minimal and the load of new language would be overwhelming for learners. Each sub-strand would not be revisited for perhaps another year and after that length of time, few useful ideas from the 2 ½ weeks would remain in the learners' minds. We should not expect to see significant N.C.S. Learning Outcomes under those conditions.

On the other hand, by doing just **one** sub-strand per Grade, the teacher or curriculum writer can create a scenario in which the single context (e.g. exploring the solar system) becomes familiar to the learners. Now activities build on each other over a number of weeks, long-term projects can be set, learners can integrate understanding from other Learning Areas, and activities can lead to a "culminating performance" (Spady 1994) or an integrating activity in which the learners can demonstrate their abilities in the Learning Outcomes in a somewhat authentic situation.

Concepts	**Suggested elaboration**
1 The Earth in Space	The Earth is a rocky sphere in limitless Space which has no "up" or "down" directions.
2 Gravity force	Gravity as a force pulling objects towards the centre of the Earth; gravity makes it difficult to escape from Earth into Space. Gravity is the force that acts between all objects.
3 The "up" and "down" directions	Up-and-down directions on Earth are determined by the direction of the gravitational force, which is towards the centre of the Earth. But there is no "up" and "down" in Space.
4 Objects in the sky	Differences between objects in the night sky (stars, galaxies, planets, meteors, man-made satellites, Earth's Moon and moons around planets); relative distances of these objects from us and from each other
5 Solar system	The solar system, with the Sun (a medium-sized star) at the centre, eight planets, and outer dwarf planets and thousands of asteroids and some comets. (Pluto is now called a "dwarf planet"). The gravity force between the Sun and all the other objects keeps them moving in orbits around the Sun. The inner four planets are rocky, while the outer four planets are mostly gas and liquid
6 Orbits	The paths of Earth and other planets moving around the Sun are called orbits; their orbits are almost circular. The Sun has so much mass that the gravity pulling force between Sun and planets keeps the planets moving in their **orbits**, instead of moving off into Space. The outer planets feel this gravity pull even though they are billions of kilometres from the Sun.
7 The Earth is unique.	Earth is unique in the solar system as the only planet on which life exists, as far as we know. Earth, of all the planets, has the right temperature range, water, oxygen to support life as we know it. The Sun provides the energy for all life on Earth.
8 Earth's Moon	The Moon moves in orbit around the Earth, while the Earth and Moon together move in orbit around the Sun. The Moon is a rocky sphere, and too small to have enough gravity to hold an atmosphere. We never see the far side of the Moon.
9 Eclipses	Eclipses of Sun occur when the Moon passes between the Earth and Sun. Eclipses of the Moon occur when the Earth passes between the Moon and the Sun.
10 Phases of the Moon	The Moon's shape seems to change over the period of 29½ days. The change in shape is a result of the Sun's light striking a smaller and smaller part of the Moon that we can see. It is not caused by the shadow of the Earth.

11	Investigating Space with telescopes	Telescopes such as the Southern African Large Telescope (SALT) in the Cape can receive light from deep Space and study far-away objects there; the light from them may have taken millions of years to reach the telescope.
12	Exploration of the solar system	Scientists are exploring the Sun and planets in our solar system with robotic craft; these craft are controlled by radio signals from Earth and they send back pictures and data to Earth.

Research on learning and teaching this topic

South African research in this topic has been presented recently by Sanders and Tunzi (2009), Cameron and Lelliott (2006), Kelfkens and Lelliott (2006) and Lemmer, Lemmer, and Smit, (2003).

Some of the main issues in learning and teaching follow, below:

The ability to mentally shift one's point of view

Probably the major difficulty learners have in understanding this topic lies in the need for them to mentally move themselves away from the Earth, which is a frame of reference centred on what they can see (named the "ego-centric viewpoint" or "what I see is the only way everyone sees") and visualise motions and forces in a system as though they were viewing it from outside, far off the Earth. Unless they become able to do this, chalkboard diagrams of the solar system or eclipses may not connect with the pictures in the minds of Grade 8 learners.

Ideas of the Earth in bottomless Space

Nussbaum (1985) has identified 5 "notions" or sets of ideas that children hold about the Earth in Space and describes the frequency with which learners in different Grades in Israel, Nepal and California use the notions. Learners form the notions below, as they try to make sense of the information they get about the Earth in Space (notions 1 to 4 are wrong, not acceptable science):

1 ✗ the Earth is round but it is flat, like a coin.

2 ✗ We live inside a ball made of two hemispheres; the lower one is rocky, and we live on it, while the sky forms the upper hemisphere and this is where the Moon, Sun and stars are.

3 ✗ The Earth is a ball, but a ball which is somehow suspended in space; it should actually fall down and objects should fall off the Earth into the southern sky.

4 ✗ Some children understand that the "down" direction points to the Earth's centre but still see "down" as some absolute direction in space which means that Earth has a top and a bottom and objects would fall out of the bottom of the Earth if a hole were made right through the Earth.

5 ✔Some children have an acceptable understanding of the Earth in unlimited Space and they visualise the gravity force pulling all objects toward the centre of the Earth. (However, less than half of 50 Israeli Grade 8 learners saw Earth in this way after they had been taught the facts.)

Scale – relative sizes and distance

Lelliott & Rollnick (2008) point out that learners must be given some understanding of the vast distances between bodies in the solar system, to understand that Earth and other planets are moving very fast in their orbits through space yet appear to us to move very slowly. Most diagrams in textbooks show the planets far too large and much too close together and learners must do activities that give them a true understanding of the scale of the planets and their orbits.

Eclipses of the Sun and Moon

As regards the Earth-Sun-Moon system, there is commonly confusion about eclipses of the Moon and phases of the Moon. Learners and adults persist in the belief that the Moon, when it passes through its phases, is partly in shadow because the shadow of the Earth is falling on it (Sanders and Tunzi (2009)

Three-dimensional models can help learners towards a correct understanding of the relationships.

The importance of models

The findings above may sound discouraging but many learners can understand these ideas if they are taught using models. Flanagan, the director of the Johannesburg planetarium, finds that models are more effective if the learner is part of the model himself/herself (Flanagan, pers.comm 2003). For example, the learner is part of the model if she pretends that her head is the Earth. When she turns to the left (i.e. in the way the Earth spins) towards a light that represents the Sun, she sees the Sun "rise" over her left cheek and "set" over her right cheek. Her teacher can then build on this model with questions such as "Think of your nose as South Africa; when your nose points towards the lamp, that is like midday in South Africa. On which part of your head would it be midnight?"

Gravity forces

To quote from the Atlas of Science literacy (2006),

> Students of all ages may hold misconceptions about the magnitude of the Earth's gravitational force. Even after a physics course, many high-school students believe that gravity increases with height above the Earth's surface (Gunstone & White, 1981) or are not sure whether the force of gravity would be greater on a lead ball than on a wooden ball of the same size (Brown & Clement, 1992).
>
> High-school students also have difficulty in conceptualizing gravitational forces as interactions [in other words, they have difficulty understanding that the Earth pulls on the Moon, but the Moon also pulls on the Earth with an equal force, causing tides]. In particular, they have difficulty in understanding that the magnitudes of the gravitational forces that two objects of different mass exert on each other are equal. These difficulties persist even after specially designed instruction (Brown & Clement, 1992).

Examples of activities to build concepts and language

These activities must be organised with process skills in mind (especially **interpretation of models**) and they must provide a context for *learners* to talk about their thinking and how the model may have changed their thinking (see Sherrod and Wilhelm (2009)). Activities which are not explored in learners' talk are ineffective in building concepts.

- Modelling the relative sizes and distances of planets in the solar system, using the playground and a table of actual sizes and distances.
- swinging a ball on a long string to give a sense of how gravity pulls planets into circular orbits around the Sun. The activity could add a second ball going around on a much longer string to model the orbits of two planets.
- modelling the motion of the orbiting Moon around a spinning Earth, using learners to represent the Earth and Moon, or using a ball held at arm's length by a learner, to observe the changing phases of the Moon.
- modelling an eclipse of the Sun and an eclipse of the Moon, noting what causes the shadow in each case.
- modelling the phases of the Moon, using a bright light for the Sun, noting the differences between the shadows in an eclipse of the Moon and in the phases of the Moon.
- comparisons between Earth and another planet with regard to its atmosphere, gravity, length of year, physical structure.
- designing and modelling a base station for exploring the Moon or Mars
- Planning the systems needed to sustain the crew of a space-craft on a long voyage to another planet.

8.5 The moving particles model of matter

Reasons for placing this in Grade 8

In this topic learners' thinking should move from description to explanation. The work on matter and materials in Grades R-7 was mainly **descriptions** of what matter is like and what it does. Now in Grade 8 we expect learners to begin **explaining** why there are differences between kinds of matter and explaining how matter changes. To explain these things, learners need the set of ideas called the Moving Particles Model of Matter, also known as the Particle Kinetic Model. You see this set of ideas in the Concepts section, below.

The model is powerful in that it can explain very many different phenomena. But it is abstract (we can't see what particles do) and to use it, learners will need to keep several aspects of the model in mind at the same time (such as points 3 to 7 below), remembering which ones are relevant and how they apply. This kind of mental ability is called formal operational thinking and for most people it is hard to do. That is one reason why the Particle Model is left until after Grade 7.

To understand the Particle Model in Grade 8 and onwards, learners in Grades R to 7 must build a very good base of experiences with matter in other topics. They need to **describe their own observations** of melting and solidifying various substances, stretching, bending and testing the strength of materials, evaporating and condensing liquids, noticing how smells spread without help, compressing air in a syringe, dissolving solids in liquids, seeing coloured liquids diffuse through other liquids, seeing mixed colours separate on a paper chromatograph.

These experiences will increasingly begin to raise the questions "why are substances different from each other?" and "Why do these changes happen?" The Particle Model provides consistent explanations for events like those above.

Concepts

Points 1-7 below are all aspects of the Model. This model is **a set of ideas**, expressed in sentences. (In the activities, we also need **physical models** of moving particles to make the sentences meaningful.)

Concepts	Suggested elaboration
1 Most matter is made of molecules	Matter (i.e. any substance) is made of molecules, and molecules are too small to see. Molecules are made of atoms that pull each other together by forces between them. In other words, atoms usually stick to each other, forming molecules. (A very few substances, such as the noble gases, exist as a collection of separate atoms. More often, atoms of the same kind are bonded together as a giant molecule. For example, copper atoms are strongly held together as a giant molecule extending in all directions, forming a hard piece of copper.)
2 Atoms	Atoms are very small objects that stick together to form the molecules that form the matter that we can see or handle. Atoms are so small that we cannot see them. About 1 000 000 would fit side by side between the millimetre marks on a ruler.
3 Atoms and molecules are called particles.	From Grade 8 onward, the term "particle" has the special meanings of "molecule" and "atom". "Particle" no longer refers to a small piece of bulk matter. (Bulk matter means matter we can see.) For example, "a water **particle**" means a water **molecule**. A very small drop of water that you could hold in your hand (i.e. bulk matter) is made up of millions of billions of water molecules. The drop could expand, freeze or flow. However, one water molecule does not expand, freeze or flow. Expanding, freezing or flowing are words that describe changes that happen to bulk water

4	Between particles there is empty space.	Any empty spaces between particles of matter are truly empty – the spaces do not contain air; they contain nothing.
5	Forces between particles can attract and repel them.	Particles mostly attract each other, and may stick together. However, they will also repel each other if they are pushed too close together. This repulsion is easiest to feel and visualise if we try to compress a gas.
6	Particles are always moving.	Particles move all the time, in any direction, without ever stopping and without being pushed. (The energy for this movement is continually supplied by radiation from the Sun and the Earth's own internal energy that keeps the planet warm.)
7	Particles move faster when given energy.	When we heat bulk matter, what we really do is to make the particles of matter move faster. Our skin sensation – "eish, that cup feels hot" – is really the result of the cup's fast-moving particles causing particles in our skin to move faster. Conversely, when bulk matter becomes cold then the particles that make it up move more slowly.
8	Physical changes in matter	Using the Moving Particles Model, learners should be able to explain changes of state (phase changes), why there are differences between solids, liquids and gases, and also perhaps compressibility of gases, dissolving, diffusion, and heating by conduction.
9	Models in science	In science a model can be a physical object, or a set of ideas in words and pictures, or a set of mathematical equations. By the end of the topic, learners should have the concept of a model: a model is a simplified representation that helps us understand a complicated phenomenon.

Research on learning and teaching this topic

The Particle Model of Matter is an essential set of ideas for understanding how matter changes and why different kinds of matter have certain properties. Many learners can repeat some of these ideas but still find it very hard to apply them to simple events, such as water-vapour condensing to form liquid water. However, the Particle Model of Matter begins to make more sense to learners if teachers use it repeatedly to explain how matter behaves and if they challenge learners to **explain** what is happening in bulk matter.

We can **describe** what bulk matter does – we can see or feel it – but to **explain** how matter behaves, we need to think about what its particles are doing. Let's introduce two useful concepts here: **macroscopic** observations-and-descriptions, and **microscopic** explanation.

"Macroscopic" refers to the observations we can make on bulk matter and the ways we describe its behaviour. "Microscopic" refers to the particles which we cannot see. ("Microscopic" does not mean that we can see individual particles with a microscope – particles are too small to be seen with a microscope.)

An example of a physical change is bulk matter expanding. We can make **macroscopic** observations, measurements and give a macroscopic description. But to explain why expansion happens, we need explanation at the **microscopic** level: the matter expands because its molecules move faster and further apart.

Let's take a chemical change. Mercuric oxide decomposes to mercury and oxygen if it is heated. That is a change in bulk matter, and it is a **macroscopic description**. The **microscopic explanation** is that the mercury atoms and oxygen atoms in the mercuric oxide molecules move faster and faster until they break apart. Then the oxygen atoms form oxygen molecules and the mercury atoms stick together in drop of mercury, which is a giant mercury molecule. We can represent this chemical change in a **symbolic description** :

$$2HgO_{(solid)} \xrightarrow{(heating)} 2Hg_{(liquid)} + O_{2\,(gas)}$$

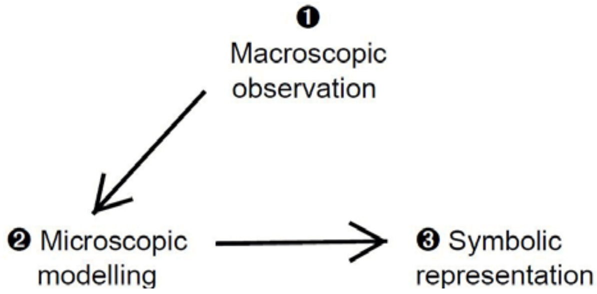
Many teachers mistakenly go straight to the chemical equation with their learners, but that symbolic description will not give the learners an understanding of how the substance mercuric oxide changes when it is heated. They first need to see real mercuric oxide powder, see it being heated, see small drops of mercury forming and bubbles of the gas coming up through water. That gives them a **macroscopic understanding** that mercuric oxide decomposes and other substances are formed.

But then they need to imagine what is happening to the atoms and molecules in the test-tube – they must use models of atoms and make model molecules of mercuric oxide, break them apart and re-form them as molecules of oxygen and mercury. Then they should do drawings of these molecules, until they have an understanding of the changes at **microscopic level**.

Only after that should they begin to work with the symbols and write chemical equations.

Figure 11 shows these three ways of understanding the change. Notice which understanding comes first, which is second and which is third.

Figure 11: *We move from macroscopic to microscopic to symbolic ways of knowing about changes.*

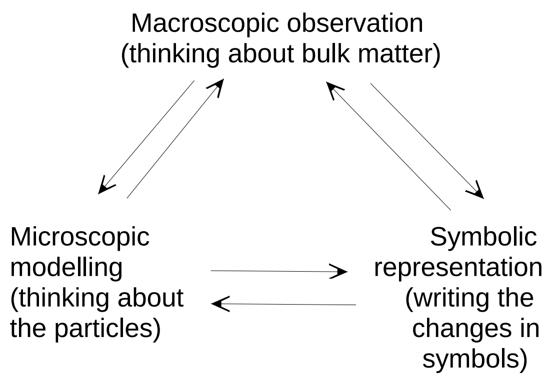


In Grades R to 7 learners need many rich MACROSCOPIC experiences of matter: matter expanding and contracting, melting and solidifying, liquids evaporating and condensing; gases being compressed, solids dissolving in liquids, and so on.

Provided that teachers have given learners plenty of activities to talk, write and draw diagrams about these macroscopic changes, they can then also move towards the microscopic understanding in Grades before Grade 8. Teachers can use models of matter – beads, marbles, polystyrene balls – and show how we can make comparisons between the ways these "particles" behave and the ways bulk matter behaves (how they both flow, for example, or how different coloured beads mix or "dissolve" in each other.)

Now in Grade 8 we must guide learners into the microscopic ways of thinking and talking about matter, while always coming back to the macroscopic understanding of bulk matter. Notice the both-directions arrows in **Figure 12** – the arrows mean that teachers must continually challenge the learners to move mentally between the three ways of thinking and talking about matter.

Figure 12: *Later, learners should develop the habit of looking at changes in all three ways.*



The kind of language that teachers use is very important in helping learners understand the macroscopic and the microscopic ways of understanding.

Words for macroscopic description	Words for microscopic explanation
a solid melts	molecules move out of their position in the arrangement, their movement energy overcomes the attractive forces between them (NOT “the molecules get soft”)
a liquid evaporates	molecules on the surface escape from the attraction of other molecules around them (NOT “liquid molecules change into gas molecules”)
the air is hot and expands	the air molecules have a lot of kinetic energy and move faster and further apart (NOT “the air molecules are hot” and NOT “the air molecules expand”)
you can compress a vapour	you can push molecules of vapour closer together even though they are moving fast (NOT “you can compress molecules of a vapour”)

The learners’ ability to think with the Particle Model of Matter grows only slowly. Teachers should use it repeatedly through Grade 9 and beyond.

From the *Atlas of Science Literacy* (2006) we have research about American learners (in South African terms, “elementary school” means grades R to 5, and “middle school” means Grades 6 to 8):

> Elementary- and middle-school students may think everything that exists is matter, including heat, light, and electricity (Stavy, 1991; Lee et al., 1993). Alternatively, they may believe that matter does not include liquids and gases or that they are weightless materials (Stavy, 1991; Mas, Perez, & Harris, 1987). With specially designed instruction, some middle-school students can learn the scientific notion of matter (Lee et al., 1993).
>
> Middle-school and high-school students are deeply committed to a theory of continuous matter (Nussbaum, 1985b). Although some students may think that substances can be divided up into small particles, they do not recognize the particles as building blocks, but as formed of basically continuous substance [...] (Pfundt, 1981).
>
> Students at the end of elementary school and beginning of middle school may be at different points in their conceptualization of a "theory" of matter (Carey, 1991; Smith et al., 1985; Smith, Snir, & Grosslight, 1987). Although some 3rd graders may start seeing weight as a fundamental property of all matter, many students in 6th and 7th grade still appear to think of weight simply as "felt weight" – something whose weight they can't feel is considered to have no weight at all. Accordingly, some students believe that if one keeps dividing a piece of styrofoam, one would soon obtain a piece that weighed nothing (Carey, 1991).
>
> Students of all ages show a wide range of beliefs about the nature and behaviour of particles. They lack an appreciation of the very small size of particles; [they] attribute macroscopic properties to particles; [they] believe there must be something in the space between particles; have difficulty in appreciating the intrinsic motion of particles in solids, liquids and gases; and have problems in conceptualizing forces between particles (Children's Learning in Science, 1987). Despite these difficulties, there is some evidence that carefully designed instruction carried out over a long period of time may help middle-school students develop correct ideas about particles (Lee et al., 1993).

Examples of activities to build concepts and language

The topic actually requires formal operational thinking and so it is difficult. By Grade 12 learners should be able to think with up to five aspects of the model in mind at the same time, while following rules for how those aspects work, and doing it abstractly because the particles cannot be seen.

But younger learners can make progress if we use **physical** models well. When we demonstrate and then put physical models in their hands or act out physical models, they can build mental pictures of how particles interact with each other. The learners are not only using models to understand the microscopic world of particles, they are also learning what a model is and how to learn with it – this ability to use models to understand physical and life sciences will become more and more important when they go into FET.

Learners can

- hold onto each other and model the behaviour of molecules in a solid (vibrating but remaining in a set arrangement). Learners also model the faster movement of molecules as they receive energy – learners begin to move apart and finally run about at some distance from each other (i.e. the substance they make up is being heated so that it melts and then evaporates) Then, of course, the learners model what happens as the “vapour” cools down – particles come nearer to each other and eventually the forces between them hold them together and they form a liquid.
- model a crystal of solute dissolving among particles of water – some learners clump together as a “crystal” while other learners run about and bump them until the clump of “crystal” learners is broken up. (The process skill is most of these activities is **interpreting a model**)
- use tapioca balls to represent particles and build crystals with them. Note the regular shapes that result and compare these shapes with the shapes of real crystals.
- place polystyrene beads in an up-turned loudspeaker connected to a radio. Note how the beads move faster and faster as the radio volume is gradually increased. This gives learners a mental picture of a liquid being heated; the particles move faster until the ones on the surface fly up.
- watch a crystal of potassium permanganate dissolve in cold water. They need the opportunity and time to watch a phenomenon like this at macro level and think what is happening at micro level; they must have time to talk about it and draw pictures of it. They can demonstrate understanding by predicting what will happen if the crystal were dropped into hot water instead of cold water. (Process skill is **predicting** from a model)

<u>8.6 Elements and compounds</u>

Reasons for placing this in Grade 8

This topic depends on Topic ***<u>8.5 The moving particles model of matter</u>*** above and must be integrated with it. The Moving Particles Model of Matter is the thinking tool that learners need to make sense of the reactions they will encounter in chemistry from here on.

This is placed in Grade 8 because elements and compounds as a topic has been taught at this Grade for decades, and wherever Grade 8 teachers are familiar with it, they are a valuable resource in the education system.

Concepts	Suggested elaboration
1 Pure substances	This topic deals with elements and compounds as **pure** substances; this is different to the topic, ***<u>7.5 Mixtures and ways to separate the substances</u>*** which dealt with **mixtures** of substances. A mixture is not a pure substance. Pure substances can be solids, liquids or gases. Some of the solids are metals and other solids are non-metals.
2 Most pure substances are compounds.	Most pure substances (e.g. pure water H_2O, pure carbon dioxide CO_2, pure salt NaCl) are **compounds**. Compounds can break down into other pure substances called **elements** (e.g. water can break down into oxygen and hydrogen, which are both elements). There are only about 100 pure substances that are elements but millions of pure substances are compounds.
3 Compounds can break down	Decomposition reactions can break down compounds into elements. Heating and electrolysis are two methods of breaking down (= decomposing) compounds.
4 Elements will not break down into other substances.	Elements are pure substances, made of just one kind of atom, whereas compounds are made of two or more kinds of atoms. We cannot tell whether a substance is an element or not just by looking at it; chemists have tested many substances in various ways and have found out which ones are elements. There are only about 100 elements but millions of compounds. Most of the elements are metals and some are non-metals.
5 Elements can react to form com-pounds.	A chemical reaction is a change that results in a different substance being formed. For example, iron reacts with oxygen to form a new substance, a compound called rust (iron oxide). The substances that react are called the reactants and the substances that are produced in the reaction are called the products. In a particular compound, the elements are always in the same ratio. For example, the compound water always has twice as much of the element hydrogen as the element oxygen; in other words the water molecule always has two hydrogen atoms to one oxygen atom.
6 Chemical reactions	Molecules are made of atoms that stick together. Atoms stick together because a **bond** has formed between the atoms, which means there is a force holding them together. When a compound breaks up (de-composes), its molecules break up because the **bonds** between atoms are broken, and then **new bonds** are formed between different atoms, making different molecules, which comprise a new substance. This change is called a chemical **reaction**. A chemical change has happened. (In a physical change, such as boiling, bonds between atoms are not formed or broken. The molecules stay the same.)
7 Reactions of common gases	We can produce and collect the gases oxygen, hydrogen and carbon dioxide by setting up reactions in suitable apparatus. Learners should learn the properties and reactions of the compound CO_2 and the elements, O_2, H_2, N_2, Cl_2 ; this knowledge helps us distinguish the gases and identify them.

Research on learning and teaching this topic

The “Research” section in topic ***9.7*** describes an example of research by Andersson (1986) who documents learners’ views about a common chemical change.

For a learner who is beginning chemistry, the main difficulty can be the feeling that an unlimited number of strange substances can come into the lessons, and they might react in any number of ways which are quite unpredictable. When chemical equations appear, the chemistry becomes even more strange – the equations look like the symbols of algebra but apparently do not work in the same way as algebra.

The *Harry Potter* books – which are popular with many children – tell of young Harry and his friends being trained in magic at Hogwarts Academy. They learn magic spells that turn rabbits into frogs and so on. None of them know why the spells work, but they must memorise books full of spells and must practice saying the magic words.

For many learners, chemistry is also like magic – some substances change into other substances and only the teacher or the textbook knows what really happened.

Now to help the learners also know what really happened, we have to

(a) work systematically and build their understanding of changes in substances on the macro and the micro scale. Only when learners have begun to understand the events in those macro and micro representations, can we begin to introduce symbols like O_2 and H_2O.

(b) help learners see patterns in the ways substances react. While there are many substances and many possible reactions, the number of patterns is limited and small enough for learners can hold them in mind. In Grade 9 chemistry, we will focus on building the patterns of reactions.

A very useful concept that clarifies chemistry is the difference between physical and chemical changes. In physical changes, we can end up with the substances we began with – in making mixtures like solutions, in separating mixtures, in heating and cooling, in melting, solidifying, evaporating, condensing substances, the substances can be brought back to their original state. In chemical changes, we end up with substances that have different properties to the substances we began with.

Language and concept issues

- The word “**product**” Note how important it is to explain to learners that a product in science is a substance that results from a reaction while in maths a product is the result of a multiplication and in technology a product is something that a person designs and makes.
- Some chemistry words refer to primary concepts such as “copper” (we can see and feel copper, so it is a primary concept). Other words like “metals” are secondary concepts. The word “metal” refers to a class of substances, and copper is just one example of that class. Now “elements” is a tertiary concept because it refers to a larger class of substances that includes metals. There are metal elements and non-metal elements – and copper is one example of the metal elements.

  This discussion of language is important because reminds us that the learners must sort out problems of classification such as: is copper a metal or an element - or both? Is there a difference between a metal and an element? If so, what? Is electrolysis a decomposition or a reaction - or both?

Examples of activities to build concepts and language

- Make a collection of different elements and compounds (all of them pure substances), which are solids, liquids and gases, and include both metals and non-metals. Label them with common names, chemical names and chemical formulae and display them. (A clear glass test-tube full of air can **represent** a gas like CO_2 if you can't get the real gas.)

  Allow learners to handle and examine them and become familiar with the range of elements and compounds. Learners should learn the names of specific substances (e.g. sodium carbonate) and the names of classes of substances (e.g. elements that are metals, such as copper, and compounds that are gases, like carbon dioxide). They need to do activities that require sorting and classifying the substances. These activities can be designed as games, like "Twenty questions" and quizzes. The learners have encountered classification before, in Grade 7 (See topic 7.1) so the activities will not be entirely strange.

  Notice that these activities are **not** simply memorisation; the assessment standard is Learning Outcome NS2- *Categorising* and the teacher must help the learners to organise their knowledge of substances by classifying them.

- Heat sodium hydrogencarbonate to produce and collect CO_2 and test it with lime water, or a small candle in a beaker. (Learners **predict** the products of the reaction, or **infer** from the changes in lime water what the gas is)
- Decompose water by an electrolysis reaction. (Learners **observe** the different quantities of each gas, and **predict** the results of tests they can do on each gas, and **infer** from the results what gases have been given off in each test-tube. Then they use beads to **model** the reaction and understand why there is more hydrogen gas than oxygen gas.)
- Use beads or beans to model a number of oxygen molecules and hydrogen molecules, and then re-arrange them to model the products when they react to form water.
- Decompose copper sulphate or copper(II) chloride. (Learners **hypothesise** what substances are collecting on each electrode, collect the pinkish substance from the negative electrode and **design a test** to check the idea that it is copper. They **model** the reaction with beads, using the idea that the particles in the solution have positive and negative charges.)
- Electroplate a metal badge or ring with copper from a solution of a copper salt.
- Interpret information about the uses or importance of gases CO_2, O_2 in health, industry, environment, etc. Link CO_2 to climate change in topic ***8.3 The atmosphere on Earth***

8.7 Cells and electrical circuits

Reasons for placing this in Grade 8

In Grade 7, which is taught mostly in primary schools, electricity appears as part of the more general section on energy transfer in systems, so the teaching and learning of the topic does not require circuit boards, voltmeters or ammeters. Grade 8 classes are predominantly in secondary schools where this equipment is used across all the Grades to Grade 12, and where teachers possibly have a better background in science.

This topic in Grade 8 should link with the Grade 8 topics ***8.5 Particle Kinetic Model of Matter***, and ***8.6 Elements and compounds*** (in electrolytic decompositions).

The *Systems and Control* Assessment Standards in Grade 8 Technology require electrical circuits with two or more input or control devices and the activities in Grade 8 Natural Sciences need to support that challenging section in NCS Technology.

Concepts	Suggested elaboration
1 Cells are a source of energy	Cells as chemical systems that are sources of energy. Cells store substances that can react if an external circuit is connected across the terminals. Cells give potential energy to electric charges, which will flow if a complete circuit is made. Here in Grade 8, teachers may use the word "electricity" instead of "charge". Alternatively (and this is not a requirement) teachers may explain that atoms have even smaller parts in them, and these smaller parts are called electrons. Electrons have negative charge and there are also parts of atoms that have positive charge, so we sometimes just use the word "charges" to cover both positive and negative parts of the atoms in a material. Charges are responsible for the little shocks we feel and the sparks we see when we pull off nylon clothing in dry weather.
2 Complete circuits	The concept that a complete circuit is needed to make a bulb light. The circuit is a conducting path, from one terminal of the cell/battery, along wires, through the filaments of incandescent bulbs, and back to the other terminal of the cell/battery. Switches are a convenient way to complete or break the circuit.
3 A voltage causes a current	Concept that an energy source such as a cell creates a **voltage**, by giving potential energy to electric charges. This potential energy may result in the charges flowing along conductors and thus having kinetic energy. This flow of charges is called a current. A current is a flow of electric charges. When a current flows in a series circuit, the amount of current is the same everywhere around the circuit. ("Voltage" does **not** require a formal definition of potential difference.) The more cells are added, the brighter the bulbs glow. This means that energy is being given off faster when more cells are connected. (The cells are added in series i.e. positive terminal connected to negative terminal of the next cell.)
4 Resistance	For a particular battery, the current is smaller if the resistance in the circuit is higher, and the current is larger if the resistance is smaller. Resistance is treated qualitatively – it is a property of the kind of conductors that the current has to flow through. Learners need only know that all conductors have some resistance. Some conductors have low resistance and others have high resistance. (Only in Grade 9 do the learners have to calculate resistance and compare resistors to determine the factors that make resistance high or low.)

5	Resistors	Resistors are parts that people put into circuits in order to control the current . For example, dimmer switches are made with resistance wire and a person can control the current and the brightness of the lights by turning the knob of the dimmer switch. Bulbs and heating wires or elements in kettles, heaters, etc. are made to have a certain resistance.
6	Effects of current	(a) A current heats a conductor and this of course is what we want in a bulb filament. However, learners must experience the heating effect in other conductors such as nichrome wire. Here, make the link with the topic ***8.5 The Moving Particles Model of Matter*** , as follows: the current through the bulb filament makes the filament wire hot. With one cell, the filament might be red-hot, with two cells it glows orange and with three cells it glows white-hot. From the Particle Model we know that as the filament glows hotter and hotter, the particles of the filament are vibrating faster and faster. So, the faster the particles vibrate, the more energy they have and the whiter is the colour of the light. (b) A current causes a magnetic field around it, and this can be used to make an electromagnet. (c) A current can decompose certain compounds in solution. (Link the chemical effect of current to decompositions in ***8.6 Elements and compounds.*** Note that it needs energy from the battery to decompose the compound, and so the separated elements must have more energy than when they are combined in the compound.)
7	Other output devices	Learners should connect at least one other output device such as beeper, LED, electromagnetic relay or a motor. (In support of Technology *Systems & Control*, or else relying on Technology)
8	Series and parallel circuits	A series circuit provides only one path for current, but a parallel circuit provides two or more paths for current. (For Grade 8 learners, parallel circuits need have only two bulbs in parallel, but connect three in parallel if possible.) The total current from the battery **decreases** when more resistors are added in series, but **increases** when more resistors are added in parallel.
9	Short-circuit paths	Short-circuit as a low-resistance parallel path. **Fuses** and **circuit-breakers** reduce the danger of high currents that can overheat wires.
10	Environmental impacts	Environmental impacts of used, discarded batteries and electricity generation by coal-fired power-stations.

Research on learning and teaching this topic

As for the other Grades, energy and energy transfer are the most useful concepts in understanding circuits. The Grade 6 research section refers to the **energy-emphasis** approach, and recommends **not** using a current-emphasis approach. The energy-emphasis approach focuses on energy transfer from energy sources e.g. cells, dynamos) to resistors (e.g. bulbs, motors, heaters, solenoids, conducting solutions).

There is much evidence that learners have great difficulty in distinguishing between voltage and current (Shipstone, 1985, p.44). Many learners see voltage as part of the current, and that the current is the cause of the voltage. (In fact the truth is exactly the opposite – the voltage is what causes the current to flow.)

This section should be read together with the corresponding sections in Grade 6, 7 and 9, on pages 63, 84 and 138. Children's understanding of electric circuits has been researched extensively, both in SA and other countries. References are, for example, the working papers of the Learning in Science Project in New Zealand (1980), Bradley and Stanton (1986), Cohen, Eylon and Ganiel (1982), the Science Education Project in South Africa (1988) and Shipstone (1985). Shipstone lists many other useful references.

Here follows a summary of learning difficulties extracted from the literature.

✗ The current-causes-voltage-misconception

Learners reason that the voltmeter across a resistor shows a reading because there is current flowing in the resistor. This misconception leads them further down the wrong path: knowing that a cell of say, 1.5 volts, will light their bulb, they expect that a 1.5 V cell will always cause the same current. Then they are not able to explain why the current is smaller when another bulb is added in series or bigger when another bulb is added in parallel.

This misconception might be avoided by the energy-emphasis approach, focussing on the energy-and-voltage concept in teaching circuits, rather than emphasising the current concept.

✗ The-current-reaches-the-bulbs-one-at-a-time misconception

The learners reason that the switch is like a tap and the battery like a tank of water. When the "tap is opened", current comes from the cells like water filling a hose and reaches the bulbs one after the other, beginning with the bulb nearest the "tank". This misconception results in learners asking themselves, "How does the room light come on so quickly when I flip the switch? Electricity must travel very fast!"

Another effect of this idea (implied in Shipstone, 1985, p. 44) is that learners ask "Why does the current increase if there are parallel resistors? The current does not know that there are parallel resistors ahead, until it reaches them."

Teachers must emphasise the concept of an electrical circuit as an **electrical system**. A system is made up of parts that work together and in that system (like all other systems) a change in one part affects all the other parts. So a change in resistance (like pressing a switch, or adding a resistor) at any point instantly affects the voltages and currents everywhere in the circuit.

> The scientific view is that all the charges, everywhere in the circuit, feel the push from the cells at the same time, and they all begin to move at the same time.
>
> (To be more accurate, the push is transmitted along the charges in the conductors at the speed of light, in such a tiny fraction of a second that we cannot notice it. However, while the push travels from each charge to the next charge at the speed of light, the charges themselves move quite slowly along the conductors, at only a fraction of a millimetre per second.)

✗ The current-is-used-up-the-bulbs misconception

By Grade 8, perhaps half of the learners will develop the misconception that more charge (or more current) flows into a bulb than flows out of it. They expect that an ammeter will show a higher reading on the side of the bulb near the positive terminal of the cells than on the other side. They reason that "something is getting used up" and think that it must be the current.

Again, this misconception might be avoided by focusing on the energy-and-voltage concept in teaching circuits, rather than emphasising the current concept. It is the energy of the charges that gets "used up" (actually, energy is not "used up" but is transferred to the resistors and from there transferred to the surroundings).

✗ The “resistor-gets-tired-from resisting-the-current” misconception

Some learners see the resistor as “having a power of resisting”, which is “overcome” by the current. These learners reason that if the current through a resistor is large, it means that the resistor “used up its energy in fighting the current” (Moodie, 1995).

Learners that use this misconception can have serious difficulty in understanding circuits.

> The scientific view is that the resistance of a piece of material depends on the way its atoms (and electrons in them) are held together. Electrical charges give off some of their energy as they are pulled through the atoms of the material and so the material becomes hot.
>
> It is true that when a resistor becomes hot, the faster random movement of its own particles slows the electric charges that are moving through the resistor and so the current flow is reduced. So the hotter the resistor material, the higher its resistance.
>
> But the material does not have its own “energy to resist a current”.

Language and terminology concerns in this topic

Strictly speaking, a current is defined as the rate of flow of charges, and therefore one would say that ‘there **is** a current in a conductor’, or a ‘current **exists** in a conductor’. However, if we speak of *currents flowing* it helps learners to imagine or “see” charges flowing around the circuit.

“Current strength” is an expression that appears often in lessons and textbooks. However, it is better to say simply that a current has become bigger or smaller, or “the current is 0.8 ampere”, because “strength” has no clear definition and learners will confuse it with the well-defined terms power, force and energy.

Teachers need to use the terms “voltage”, “charges”, “current” and “energy” (and “power” in Grade 9) accurately. These terms are not equivalent. For example, we say we have a voltage **across** a resistor but we have a current flowing **through** a resistor.

When teachers switch between English or Afrikaans and African languages they should be careful of using terms like *amandla* and *ugesi* which connote power (or energy, or force or electricity) but they do not have the specific meanings that science concepts require.

Examples of activities to build concepts and language

Learners can

- use loose wires, cells and bulbs to light their bulbs, and identify arrangements that work and arrangements that don’t work. (They develop the concept of a complete circuit.)
- make simple electrochemical cells, join them in series, and use them to light LEDs. They note the changes in the metal plates as the reaction proceeds until the LED no longer lights. They link these chemical changes to energy being transferred to the LEDs.
- connect bulbs in series and in parallel. They find a way to keep one bulb glowing while the other is switched off. They note how the total current (i.e. the undivided current) increases when the bulbs are connected in parallel and how the total current decreases when they are connected in series.
- work on tasks such as placing switches that will switch off all the bulbs in a circuit or each bulb individually. (The Technology and the Science teachers should plan to co-ordinate activities and assessment.)
- identify a short-circuit in a circuit-board and in a circuit diagram, observe the effects of the short-circuit and change the circuit to include a fuse that melts when the short-circuit occurs. (Conceptually, they should understand that a short-circuit is a parallel path with nearly-zero resistance that allows the current from the source to become very big.)

8.8 Light, sight and radiation

Reasons for placing this in Grade 8

This topic follows on from the section on radiation in topic ***7.7 Controlling heating and cooling: conduction, convection and radiation***. It also links with ***8.7 Cells and electrical circuits***. Radiation is a mechanism that transfers energy away from fast-moving particles, through empty space or through substances. In Grade 12 learners will learn about electromagnetic waves, as the actual mechanism for transferring the energy away from a radiating body, but in Grade 7 and 8 it enough for them to sense the radiation of heat on their skins and light in their eyes.

They need some understanding of how the eye works in Grade 8, because light cannot be understood without understanding how the eye works. But in Grade 9 the eye will be done again as part of the human nervous system.

The approach to light is qualitative; the only mathematical aspect is the measuring of angles of incidence, reflection and refraction.

Concepts	Suggested elaboration
1 Light travels through space	Light is radiated from luminous objects, or reflected from objects, and travels through space. Unlike sound and other vibrations, light does not need a substance (a medium) to travel in. It can travel through empty space (a vacuum). The speed of light is about 300 000 kilometres per second.
2 Vision and the eye	Light enters the eye and stimulates the specialised nerves in the retina, which send impulses to parts of the brain and so cause our perception of light. Learners need a model and a simplified diagram of the structure of the eye, in order to understand how light from an object enters the eye and creates vision in the brain. Learners should also understand ray diagrams.
3 Light is energy that is being transferred by radiation	Light is a type of radiation similar to the radiation that comes from hot objects. (In topic ***7.7 Controlling heating and cooling: conduction, convection and radiation*** , learners should have realised that as an object gets hotter and hotter, they can first feel it radiating, and then see that it begins to give off light. Both heat and light can travel through empty space as well as through air – the sunlight travels 150 million kilometres through empty space and warms us.) We can sense heat radiation in our skin because skin has suitable kinds of nerves. As the temperature increases, the nerves in our eyes can sense the light radiation that comes from a hot object. Energy is being transferred by radiation from the hot object to the nerves in skin and eyes.
4 Transparent and opaque substances	Light can pass through transparent substances like glass, but it is absorbed and/or reflected by opaque substances like steel. Shadows are areas of a reflecting surface which light does not reach.
5 Light striking a surface.	Light, when it strikes a surface of a substance, can be absorbed, and/or reflected and/or refracted.
5.1 Absorption at a surface	Every kind of substance absorbs some of the energy of light; even transparent substances absorb a little of the energy of light. Absorption rules are the same for light and radiated heat. For example, matt black surfaces are good absorbers of both light and radiated heat, and so they are poor reflectors of both light and radiated heat. (Refer back to ***7.7 Controlling conduction, convection and radiation***)

5.2 Reflection at a surface	When light strikes a reflective surface, the angles of incidence and reflection are equal. If the surface is smooth, all the light is reflected in the same direction, but if the surface is rough, the reflected light is scattered. The image that is formed in a flat mirror is laterally inverted (left and right appear as their opposites) and the image appears to be at the same distance behind the mirror as the real object is in front of the mirror.
5.3 Refraction at a surface	When light travels through air and enters a transparent medium (i.e. a transparent substance) like glass, water or perspex, at an angle, the light changes direction towards the normal in the new medium. When light travels out of that medium, back into air, it changes direction away from the normal.
6 Dispersion and the colours of the visible spectrum.	Prisms can refract white sunlight into the colours of the rainbow, which is called the visible spectrum. The blue and violet parts of the light are reflected the most, the orange and red parts the least and the other colours fall in between violet and red. This splitting up of white light is called dispersion. A rainbow appears where light comes from behind the observer and falls onto droplets in the air, which refract the light and disperse it into the colours of the rainbow. (**Not required**: total internal reflection and ray diagrams showing dispersion in the droplets)
7 The infra-red part of the spectrum.	The skin has nerves that respond to the energy of an invisible part of the spectrum called infra-red (heat radiation) while the human eye has nerves that respond to the different energies of the different colours of light..

Research on teaching and learning this topic

We have a considerable amount of research available on this topic. References are for example, Slinger, Anderson and Smith, (1983), Osborne, Black, Smith, and Meadows,(1990), Guesne (1985), Stead and Osborne (1980), Osborne and Freyberg (1985).

Some common learner ideas that need special attention by the teacher are the following:

✗ Light fills the room just like air fills the room or water fills a bath.

✗ sight is a power that goes from the eye to an object, or light simply brightens an object enabling the eye to see it, or else light activates the eye in some way.

Light travels

The fundamental conceptual issue that a teacher must deal with is the idea that light travels. For many learners, light does not travel, it just exists. For these learners, light in a room is a "bath" of light (Guesne, 1985); light just fills the room, in the way that air does. They do not think of light as energy coming into the room from a source and bouncing off things in the room. (For these learners, it is meaningless to say, "Light travels in straight lines"!) When the teacher asks, for example, "How far does the light from a candle travel?" learners may reluctantly say that in a dark room it travels as far as the wall, but in daylight it does not travel far from the candle (Stead and Osborne,1980).

Scientists' understanding of light

Some objects give out light; these are objects such as candle flames, glowing bulbs, or the Sun.

Other objects reflect light, but they are not themselves light-givers or sources of light.

Light travels away from luminous (= light-giving) objects and off reflecting objects at 300 million metres per second. (This happens too fast for us to see – a pulse of light would go from Johannesburg to Cape Town and back 100 times in one second)

Light will travel away from a luminous object or a reflective object without stopping, and in the same direction, unless it strikes another object.

We see because light from the Sun or a lamp reflects off things and travels into our eyes

> **Scientists' understanding of light**
>
> The eye receives light from reflecting objects and from luminous objects. The lens of the eye focuses the light onto the nerves inside the eye and these nerves create the sensation of seeing, in the brain.

The second fundamental conceptual development task for the teacher is to deal with seeing. Most learners do not find it necessary to explain how we see - as far as they are concerned, we **do** see and that is all there is to it; no further explanation is necessary. When the teacher presses the issue, and asks for example, "how do you see the page of your book?" three kinds of explanation may emerge from the class. The first is that the eye sees because sight goes out from the eye (they may draw an arrow going from the eye to the page). The second is that light simply brightens things, making the page stand out against the background, and so light assists the eye in this way. The third is that light from a source like a window does enter the eye but it activates, "switches on" or empowers the eye to see. What is usually missing is the idea that light **from the page** enters the eye (Guesne, 1980; Ngakane and Moodie, 1993).

The authors of the LISP work, Stead and Osborne (1980), conclude:

> *If children do not appreciate that light travels, that some objects simply reflect light rather than produce it, and that light must enter the eye to enable us to see, then much of what we teach about light must be [...] very confusing. [...] Before teaching that light travels in a straight line, we may first need to teach that light travels. That how far it travels does not depend on whether it is daytime or night-time even though it may appear to travel further at night. Before teaching ideas about reflection and refraction, we may need to teach about sources, reflectors and how it is that we are able to see things.*

Difficulties with ray diagrams

Student have difficulties with ray diagrams, especially if we ask them to explain reflection or refraction with the aid of a ray diagram. The use of rays may run counter to their commonsense view (or misconception) that light just fills the room, the way air does - so why draw arrows? Traditional ray diagrams are themselves part of the problem, because they usually show only the rays that are relevant to the reflection or the formation of an image by a lens. The learner gets no explanation of why all the other possible rays have disappeared from the diagram. Better ray diagrams will indicate that light still radiates in other directions as well (Moodie and Ngakane, 1993).

It is important for learners to remember that rays drawn on paper are just the way we **represent** the direction of light's travel. Rays are just our models, and light does not really consist of rays.

Real and virtual images can be hard to understand

The image that learners can form on a screen, using a pinhole camera or a magnifying glass (convex lens) is called a **real image**: the image of the Sun will really burn a hole in paper, or the image will really change a photographic film. But images formed by flat reflecting surfaces have no real existence and they cannot be caught on a screen. They are called **virtual images**. Learners have difficulty accepting the fact that their reflection (image) formed by a water surface or a by a shop window seems to be below, rather than on the water surface or on the window glass.

Understanding why things have their colours – this is more difficult than one might expect.

The idea that coloured **objects** have their colour because they absorb or remove the **other** colours of light is difficult. The idea that colour **filters** also remove certain colours is even more difficult, and can be left to FET.

Language concerns

Teachers need to be aware of learning difficulties that may result from multiple meanings of the English word “light”. In English, we may use “light” to refer to the entity that transfers energy as it travels through space but also use it to mean a lamp, as in “a bedside light”. Using African language terms might make things easier for some learners; in Zulu and Xhosa, *ukukhanya* means the energy of light and *isibane* means a lamp. In Sotho, *lesedi* means the energy and *lebone* means a lamp. In this topic, it might be helpful to use words like *ukukhanya* or *lesedi*, meaning the energy that travels through space, before making general use of the English word “light”.

Examples of activities to build concepts and language

Learners can

- make a model of an eye, based on the pin-hole camera and then using a lens in place of the pin-hole. They **investigate** the images that are formed on a sheet of paper that represents the retina.
- use a burning-glass (a convex lens) to heat objects, or burn holes in paper. The concepts here are energy transfer from the Sun to the paper, the energy transfer is both heat and light, and building the idea that light and heat travel – in this case, they travel from the Sun.
- discuss the light from a candle in the veld at night; they consider questions like “from what distance can a person see the candle?” and “does the light stop anywhere?” and “how far does the light travel?”
- use a ray-box and protractor to compare the angles of incidence and reflection at a mirror surface
- use a ray-box to trace rays from the edges of an object, reflecting them off a mirror. When the mirror is removed and the ray paths are extended, the learners see the reason why the image seems to be as far behind the mirror as the object is in front
- explain why objects under water appear closer than they really are, using ray diagrams..

Grade 9 Topics

These notes focus on the **science knowledge** in the NCS. But the science knowledge is not the curriculum, and these notes are not a learning programme. The curriculum is about learners using the knowledge to produce outcomes. So these notes are just the basis for learning programmes that build the Assessment Standards for Learning Outcome NS1 ***Scientific Investigations*** and Learning Outcome NS3 ***Science Society and Environment***, as well as building the Assessment Standards of Learning Outcome NS2

9.1 The microscopic world of living things

Reasons for placing this in Grade 9

Grade 9 will be some learners' last opportunity to learn the science that affects their health and the health of the children they will have, and for this reason it is very important that they understand some key ideas about human life processes. One such key idea is that our state of health or disease is often determined by the existence and life processes of organisms that are much too small to see with the naked eye. We could not really teach these concepts any earlier than Grade 9 if we want outcomes at the level of explanation (for Learning Outcome NS3), interpretation and application of concepts (for Learning Outcome NS2).

Links to FET

In Grade 10 the learners will do

Main groupings of living organisms which are bacteria, protists, fungi, plants and animals.

Bacteria: simple single-celled organisms with no nucleus

Protists: Very diverse group including single-celled or simple multicellular organisms,

Fungi: Single-celled (e.g. yeasts) to multicellular organisms . . . .

In Grade 11,

Viruses, bacteria, protists and fungi . . . . Important role in maintaining balance in the environment / in web of life.

Roles in symbiotic relationships e.g. nitrogen-fixing bacteria in plants; E. coli in human intestines.

. . . . viruses – e.g. rabies, HIV/AIDS, influenza

bacteria – e.g. blight, cholera, tuberculosis, anthrax

protists- e.g. malaria

fungi – e.g. rusts, thrush, ringworm

Immunity

Immune response by plants or animals against infecting micro-organisms

Use of drugs e.g. antibiotics and response of infecting micro-organisms.

Concepts	Suggested elaboration
1 The existence of micro-organisms	There is a great variety of kinds and but are too small to see with the naked eye. Most micro-organisms reproduce very quickly and so they generally live in great numbers.
2 Micro-organisms have their own life processes	Micro-organisms have life processes, such as reproduction, respiration, etc., just as humans and other multi-cellular organisms have life processes.

3	Micro-organisms' role in the life of other organisms	The life processes of some micro-organisms are crucial to other processes of life on Earth, such as maintaining the fertility of the soil, the purification of water, or humans' digestion of food. Some micro-organisms may also be harmful to plants, animals and humans, and cause disease. Micro-organisms reproduce very much more quicky than larger organisms, and for that reason, person who is infected with a few germs (micro-organisms) may have billions of them within days, and become sick.
4	Micro-organisms can develop resistance to medicines.	Medical drugs can be used against some micro-organisms. But micro-organisms change randomly and very often (refer to the concepts of variation in topic ***8.2 Natural selection and adaptation***) and so some may escape the killing effect of the drug. These micro-organisms are resistant to the drug and they live and may reproduce more micro-organisms that are resistant in the same way. In other words, the drugs cause natural selection that favours the stronger, more resistant micro-organisms. Examples of drug-resistant micro-organisms that have appeared recently are drug-resistant HIV, MDR-TB and XDR-TB.

Research on learning and teaching this topic

The history of the germ theory of disease which took shape in the 1800s is a fascinating story which could stimulate learners to continue with science at FET level. Aspects of that history suggest some learning difficulties in the topic. The basic problem now, as it was in the 1800s, is that the organisms that are being discussed are invisibly small.

Refereed research on the problems of understanding this topic seems scarce, if one is looking for learners' understanding of microscope images and the nature of micro-organisms. The *Atlas of Science Literacy* (2006) cites Nagy (1953) who wrote *The representations of "germs" by children*. Much of the other literature refers to learners' understanding of the role of microbes in food safety.

However, we can easily see that there are some basic problems for a learner in understanding the existence and role of micro-organisms such as "germs" and cells. Firstly, they are too small to see and the learner is dependent on the teacher's say-so that they exist. Secondly, when the learner does accept that micro-organisms exist, he or she can only infer the micro-organisms' life processes from experiments, and cannot see them directly. Seeing small living things under a microscope or in a video, or in textbook photos, will not necessarily make learners aware of the roles of micro-organisms in the living world. Learners for example may find it hard to visualise micro-organisms in the air, or on hands that look clean, or in water that looks clear.

Dr Claire Flanagan, the director of the Johannesburg planetarium, conducts educational programmes for high schools. She often asks school groups "What is the smallest living thing that you know of?" She reports that the majority of learners in Grade 7 to 12 reply, "an ant" (Flanagan, 2009, pers. comm). These learners have been taught about micro-organisms but they have still not begun to "see" their environment as full of microscopic life.

Examples of activities to build concepts and language

Learners can

- collect spores and dust from the air by leaving a strip of clear sticky-tape hanging up for a few hours in an open environment. They can then examine it with a hand-lens
- calculate magnification of one specimen of a very small organism, working with images of the same specimen and going from slight magnifications to very large magnifications. (The magnifications could go to the level of the electron microscope.)

- calculate the number of micro-organisms, such as red blood cells, that would fit across a full-stop in their book.
- grow fungi or other micro-organisms on a dish of gelatine (the spores of the initial fungi or micro-organisms could come from water drawn from a river, or water that has run through soil, or from hands that have touched bathroom taps, or a cloth that has wiped a kitchen counter).
- play simulation games illustrating natural selection among micro-organisms
- take part in discussions or debates about whether patients with XDR-TB should be confined in special hospitals. This would involve debating patients' human rights, whether there are risks to other people's rights, why XDR-TB is different to ordinary TB – all good material for developing Learning Outcome NS3.

9.2 Cells as the basic units of life

Reasons for placing this in Grade 9

The progression for Senior Phase moves from the macroscopic, observable world, into the smaller and smaller microscopic world. Learners deal with bulk matter in Grade 7 and in Grade 8 begin to look for explanations of why matter behaves in certain ways, in terms of molecules and atoms. This trend continues in *Life and Living* Grade 9; the learners need to look for some explanations of how plants and animals grow, move, reproduce, and so on.

Links to FET In Grade 10 the learners will do **Cells: the basic unit of life** Molecular make-up: Cells are mostly made of proteins, carbohydrates, lipids, nucleic acids and water	Cell structure and function: Introduce the idea of a cell as the smallest unit that has a complex organisation and carries out the properties of life e.g. Cell wall: support structure Cell membrane: boundaries and transport, etc.

Concepts	Suggested elaboration
1 Life processes of all living things depend on the molecular activity in cells	All living things (i.e. organisms) carry out their life processes such as growth and differentiation, repair, reproduction etc. by means of the activity in cells.
2 Plants and animals are made of sub-systems	Plants and animals are made of structures or organs ; these structures or organs are made of tissues, which are made of cells, which are made of molecules, which are made of atoms.
3 Cells are extremely small	Cells are extremely small; typically about 100 could be lined up between the mm marks on a ruler. However, cells are much bigger than atoms and molecules. Any cell is made up of hundreds of millions of molecules.
4 The basic structure of plant and animal cells	All cells have a membrane which allows some substances to pass through and blocks other substances from passing through. In this way the cell can absorb substances it needs and excrete waste products of the chemical reactions that happen inside the cell. Plant cells have a cellulose wall which makes the plant tissue stiff, while animal cells do not have this wall, and most animal tissues are more flexible.
5 Cells' own life processes	Cells carry out their own life processes of nutrition, respiration, growth, excretion, reproduction, repair. They die and are replaced. Both plant and animal cells respire, but cells of green plants contain chlorophyll that enables the cell to absorb the radiated energy of light. Plant cells use this energy in the photosynthesis reaction. In this reaction, waste products of water and oxygen are formed. In this way, plant cells make both food and oxygen that sustain life on Earth.
6 Cells are specialised to their functions in the organism	Cells are specialised to the functions they perform in the larger organism. So, for example, muscle cells are specialised to work in a particular way which is different to nerve cells that have a different function.

Research on learning and teaching this topic

In *Atlas of Science literacy* (2006) we have

> Preliminary research indicates that it may be easier for students to understand that the cell is the basic unit of **structure** (which they can observe) than that the cell is the basic unit of **function** (which has to be inferred from experiments) (Dreyfus & Jungwirth, 1989).

In other words, learners find it easier to form the concept of a cell as a thing with many parts in it, than to form the concept that life processes such as respiration or excretion occur because these are basic processes that take place in cells.

In SA, some high-school students hold the idea that "the cell" is a single structure in the body, and is located at about the position of the liver (M.Manqele, 1988, pers.comm).

Language concerns

The word "cell" has many meanings in English, and the teacher should list them and make sure the learners know which meaning is being used in any conversation. For example, "cell" can mean an electrical device that stores energy, or a basic living structure, or a room in a police station, or a block in a spreadsheet, or a small group of activists.

Examples of activities to build concepts and language

Learners can

- make models of plant and animal cells; these can be quite simple, representing only the cell membrane/wall, cytoplasm and nucleus, but they must be three-dimensional to get away from the idea that cells are flat, as they appear on the page of a book. Learners should several models and pack their model cells close together to emphasise that most cells are part of a tissue, and usually not separate. (Process skills are **interpreting** diagrams, then **communicating** their ideas through models)
- grow yeast cells in a dish to establish the concept that they respire, replicate and grow. (**Interpreting** instructions for growing the yeast, **observing**, **measuring**, **comparing**, **designing a fair test** of the idea that they respire)

9.3 Life processes and systems of humans

Reasons for placing this in Grade 9

As mentioned above, some learners will not study science again after leaving Grade 9 but they will need to make sense of health information for the rest of their lives. Therefore a conceptual base for understanding health information is essential for them. So do not see this topic as an introduction to physiology but as health education for all.

Grade 9 work schedules could begin with this topic, as most aspects of it are not conceptually difficult. It only appears as topic 9.3 because in Layer One, ***9.1 The microscopic world of living things*** lies on the same row in line with the unifying statement "The huge diversity of forms of life can be understood in terms of a history of change in environments and in characteristics of plants and animals throughout the world over millions of years."

Links to FET

In Grade 10 the learners will do respiration, balanced diets, human nutrition, digestion and gaseous exchange.

In Grade 11 they will do the human skeleton, joints and muscles, transport systems and the human circulatory system, excretion in humans and the urinary system.

Concepts	Suggested elaboration
1 Human life processes and body systems	This is health education rather than physiology. The emphasis must be on the functioning of the systems, and the learners' understanding of healthy living and care of themselves, rather than the detailed structure of the systems and organs. Structures of systems and organs can be taught as far as they are required to understand how the main aspects of the life processes are carried out.
1.1 Nutrition and digestion.	Relate these processes to the digestive system and to balanced diets. See concepts 3, 4 and 5 below.
1.2 Circulation	Circulation of blood and the transport of substances around the body. Relate to the circulatory system and the function of the heart. (**Not required**: The details of how the heart works in terms of the cycle of valves opening and closing.)
1.3 Movement and locomotion	Relate to the musculo-skeletal system and the nervous system. Also relate to nutrition and respiration as the processes that provide energy to the muscles.
1.4 Respiration.	Relate to the breathing system and circulatory system. Relate also to topic ***9.2 Cells as the basic units of life***, and chemical reactions with oxygen that release energy in cells. Link to topic ***9.7 Some important chemical reactions*** when possible.
1.5 Excretion	Relate to waste products of respiration, to circulation and the excretory system.
1.6 Sensing and response to stimuli.	Relate to the nervous system, and extend to mental functions like memory and locomotion in terms of sport. (Note that learners learned the structure of the eye in Grade 8 in order to do the topic ***8.8 Light, sight and radiation***)
1.7 Reproduction	Relate to reproductive system, to growth, cell specialisation and health of the unborn

	child. Link with topic ***9.4 Pregnancy, birth, parenting and adult sexuality***
1.8 Growth and repair	Relate to cells' ability to replicate, and to proper nutrition. Link with topic ***9.2 Cells as the basic units of life***
2 Body systems are inter-dependent	The body's systems are interdependent and work together as one complex system. A change in any part of the complex system affects other parts of that system.
3 Balanced diet	Components of balanced diets, recognising cultural variety in food choices, and the long-term effects of diets. Integrate this with nutrition and digestion.
4 Basic health knowledge	How to recognise certain illness conditions e.g. dehydration in young children, diabetes. Basic first-aid e.g. cold water immersion for burns, not wrapping up a baby with a fever.
5 Life-style choices	Exercise, drugs, alcohol and other life-style choices that have a long-term affect on health. Integrate with nervous system, circulatory system, breathing system or other systems as appropriate.
6 Occupational health and safety	For example, preventing damage to hearing, lungs, spine, etc. by observing safety rules and wearing personal protective equipment.

Research on teaching and learning this topic

References to research in this area can be found in Brumby, Garrard & Auman, (1985), Moon, Wetton, & Williams (1985), Blum (1977), Merlde & Treagust (1987), Prout (1985) and Rice (1991).

Bear in mind that from a science point of view, "growth" means not only increase in size but also development and change in an organism.

We do know that learners have difficulty relating the intake of food to growth – that is, the difficulty lies in understanding that food substances are incorporated into cells and tissues of many different kinds. (For example, eating a yellow carrot does not result in small pieces of carrot entering the tissues or making the skin yellow.)

Learners also do not understand that the intestine is permeable and that molecules that have come from broken-down food substances can pass through the intestinal wall and into the bloodstream.

All learners need to visualise (make pictures in the mind) the internal structures of the body. Mathai and Ramadas (2009), focusing on the digestive system, found that learners in India were very good at verbal description of the structures but had much difficulty in drawing them or interpreting drawings of them. These authors point out that the ability to draw the structures is important because it enables the learners to show the teacher that they understand the processes that happen in those structures. Their claim is relevant to most of the sections on the human systems and life processes, and it is worth including this quotation from their paper:

> Visuals need to be understood and interpreted within a culture and context. In oral cultures exposure to pictures comes about through schooling. Liddell (1997) found that South African children interpreted less from pictures than their Western counterparts, who used pictures as a bridge to language development. They used pictures in a passive form; labelling and linking associated with picture interpretation progressively decreased through the school years. This is an area of pedagogy that needs attention.

Mathai and Ramadas (2009, page 455)

Examples of activities to build concepts and language

Learners can

- make models of the digestive system and describe what happens to a meal in each part of the system.
- Interpret nutritional information on food packages and plan balanced diets for people doing various kinds of work.
- Collect information about traditional diets and seasonal rotation of foods; compare with diets of people who live on supermarket food.
- compare the ways humans and plants obtain the food they need to grow.
- Measure and compare heart rates of athletes and sedentary people of the same size, or heart rates of adult smokers vs non-smokers.
- Plan and perform role plays and skits: for example, of sports coaches trying to work with teenagers who are overweight or don't like exercise
- Make models of the structure of the eye and link them with topic ***8.8 Light, sight and radiation***.
- Measure lung capacities of the class and relate the measurements to each person's height; plot the two variables on graph co-ordinates

9.4 Pregnancy, birth, parenting and adult sexuality

Reasons for placing this in Grade 9

This topic was included in Grade 7 to respond to the natural concerns and interests of children whose bodies are changing and maturing sexually, as well as because of much evidence that many children of that age are sexually active. Now it is picked up again in Grade 9 with added emphasis on using Grade 9 knowledge of human life processes in caring for children. This might seem premature for 15-year olds but in many schools 15-year olds are not only sexually active but have children of their own, or are heading households of younger children.

Of all that teenagers learn in school science, the knowledge in this topic might have the greatest positive consequences for their lives if they act upon it.

> **Links to FET**
>
> In Grade 12 they will do human reproductive systems, meiosis, DNA and genetics and genetic engineering.

Concepts

Concepts	Suggested elaboration
1 Physical and psychological changes in boys and girls at puberty.	Review and extend Grade 7 concepts dealing with puberty. Sexuality education deals not just with reproduction but also with the psychological aspects of establishing a satisfying identity that involves being male or female, and preparing mentally to be a caring partner and father / mother who can give a son or daughter a positive self-image. The approach is not simply to provide biological fact but to put it in a context of teens moving into adulthood in a positive way. The emphasis should be on relationships that need time to mature and that must not be pressured by expectations of sexual intercourse.
2 Menstrual cycle	Menstruation, fertile stages of the cycle. Myths about menstruation.
3 Conception	Sexual intercourse, conception. Twins.
4 Contraception	A few methods and their relative effectiveness or ineffectiveness.
5 Pregnancy	Pregnancy and factors in pregnancy, such as alcohol and other drugs, that affect the health of the baby. Harmful substances that can pass through the placenta. Foetal alcohol syndrome.
6 Birth process	Check-ups before the birth and signs that medical help may be needed.
7 Child-care	Application of Grade 9 life-processes knowledge to parenting and child-care, for example, nutrition and cognitive stimulation of babies and young children. Basic physical and psychological needs of babies and young children; responsibility of parents and care-givers for young children.
8 Myths about sex	Myths and misconceptions about having sex and avoiding pregnancy.
9 Sexually Transmitted Diseases	Link to topic ***9.1 Microscopic world of living things*** when discussing infections and treatment. Include HIV and the appearing of AIDS in an infected person.

Research on teaching and learning this topic

The ***Research*** section in Topic ***7.3 Changes that happen to young people in puberty***, and the comments about the complementary roles of Natural Sciences and Life Orientation, apply to this Grade 9 topic as well. Doidge, Radley and Lelliott (2008) report that Grade 7 teachers felt that the topic should be taught in the third term, giving the learners more time to mature mentally and more time to begin to trust their teacher. The advice is probably good for this Grade too.

Learners in Grade 9 hold a number of worrying misconceptions about sex, how girls become pregnant, how HIV infection occurs, whether it is a real condition, whether it can be cured. Learners' own ideas are often much more sensible to them and they re-interpret what their teacher tells them to make the new information fit with what they already believe. We also know that teenagers claim that the education efforts in schools have greatly increased their knowledge of HIV infection but at the same time they report that they have not changed their risky sexual behaviour (Bodibe, 2007) . It is also the case that sexually active adolescents cause the distress of their grandmothers, who feel that authority roles in their communities are now greatly weakened. (Penn, Watermeyer and Macdonald, 2009)

Some teachers feel privileged to teach children this knowledge, other feel very anxious about it. In all cases, teachers do need good personal preparation so that they are aware of their own attitudes, and so that they can explain matters clearly, using correct science vocabulary. They should be able to see through the "street-wise" information that some learners have, and see the misconceptions and anxieties that teenagers have about sex. Teachers need to accept teen's curiosity or desire to shock them, but still maintain their own right to privacy and self-respect. Organisations like FAMSA, Family Life Centre, LoveLife, LifeLine, etc. offer this kind of teacher training.

This topic moves on from sex, conception and birth to applying the Grade 9 knowledge of human life processes to the care of children. Health researchers such as the Birth-to-Twenty Project at Wits University and health organisations have much to offer curriculum designers and teachers on factors that are important in raising young children.

Boys may be quite reluctant to learn about care of babies and young children – it helps if the teacher (especially if she is a woman) treats the boys and girls in the same way, sending an underlying message that both are responsible for children they bring into the world.

Examples of activities to build concepts and language

learners can

- interpret calendars showing a girl's menstrual cycle and identify fertile days
- interpret information on effectiveness of contraceptive methods
- debate myths about avoiding pregnancy, showing that they understand science reasons why these are myths
- class interview with a woman who has recently given birth – class discusses and prepares questions beforehand
- boys simulate caring for a baby (a doll or a bag of flour) 24 hours a day during a full week – discuss any changes in attitude – girls do the same.
- role-play e.g. a clinic sister giving science information to a couple thinking about starting a sexual relationship

9.5 Minerals and mining in South Africa

Reasons for placing this in Grade 9

This topic relates to a major industry and export-earner in South Africa, and is the focus of much empowerment legislation which is designed to bring previously disadvantaged people into the industry. It is also loaded with social justice issues because mining competes with other land uses and environmental conservation. The topic involves the process of mining (with its engineering, social and environmental meanings) and the process of producing metals from their ores (with its implications for understanding some of the chemistry). In these ways it relates also to learners' ideas of careers they might follow later, and possible reasons for continuing with Physical Science in FET.

Link to FET

Grade 11 has the topic

Exploiting the lithosphere/Earth's crust:

- Mining and mineral processing – gold, iron, phosphate, (South Africa's strengths); environmental impact of these activities;
- Energy resources and their use.

This topic is placed in the Grade 9 year when the learners have sufficient background knowledge to apply to the tasks we set them, and produce good evidence of progress in Learning Outcome 3. Placing it in earlier Grades would lose this potential for assessing how learners integrate previous learning.

In Grade 7 the learners have engaged with the concepts of the Earth as a rocky planet, with a hot core, atmosphere, seas and processes that lay down different kinds of rocks. By end Grade 8 and by mid-Grade 9, learners should have some grasp of atoms and molecules, elements and compounds, chemical reactions of synthesis by heating elements in oxygen, decomposition of elements by heating and electrolysis, reactions of ions of more reactive metals with less reactive metals, reactions of metals with oxygen, tests for the gases oxygen, hydrogen and carbon dioxide, non-contact forces like gravity and geomagnetism. This background knowledge can then be used in activities around extracting metals from ores (probably by simulated extractions).

Important note: The minerals and mines differ in different parts of South Africa and hopefully learners will be taught about the kind of mining that is relevant to their area. In the case of diamonds and coal, which do not need chemical processing to extract, teachers should add some lessons on these materials. For example, coal and diamond are made of the same element but the hardness of coal and diamond differ by a huge amount. Or teachers should add chemistry lessons on extracting a metal from its ore e.g. copper or gold. The extraction of salt from the sea or underground mines offers another opportunity for local curriculum development.

If we give mining enough room in the Grade 9 work schedule, Learning Outcome NS3 and the Critical Outcomes can come alive for learners almost anywhere in the country. The topic lends itself to extended projects that give us opportunities for authentic assessment.

This topic should not be treated in terms of defining the many new and unfamiliar ideas about mining; it is more important that learners should understand the processes which concentrate mineral resources, and processes involved in finding and extracting those minerals.

Concepts	Suggested elaboration
1 The structure of the Earth	The structure of the Earth with hot core, mantle and crust; movement in the crust and resulting magma (see detail in Grade 7)
2 Processes which create igneous and sedimentary rock.	Igneous rock forms from **magma** which cools and solidifies underground, or **lava** which is forced through the surface on land or from the sea-floor. Sedimentary rock is formed from sediments which are deposited, compacted and cemented together.
3 Volcanic action concentrates minerals.	Volcanoes and magma intrusions concentrate certain minerals in one place, as at Phalaborwa or in the Bushveld Igneous Complex for example.
4 Erosion and sedimentation concentrates minerals	The alluvial diamonds along the Orange River are in sediments eroded from ancient volcanic pipes in far away , e.g. the Kimberley area. The sedimentary rock of the Witwatersrand and Free State gold basin consists of gold-bearing sediments that were laid down in an ancient sea.
5 "Deep time" and the great age of some mineral deposits in South Africa	For example, the Witwatersrand and Free State gold deposits were laid down in sediments about 2 700 million years ago. Phalaborwa copper minerals were concentrated in an ancient volcano about 2 000 million years ago.
6 Origins of the coal and some mineral deposits in SA.	Origins of the coal deposits in SA; origins of diamonds; origins of minerals of the Bushveld Igneous Complex [5].
7 Ore and minerals	Minerals are compounds that miners want to extract. Rocks may contain several different minerals (= compounds). If the minerals are concentrated in certain layers or bodies of rock, those rocks are more valuable and they are called ore.
8 Renewable and non-renewable resources	Mining removes resources from the ground, and the resources are non-renewable. (Renewable *vs* non-renewable resources are first done in Grade 7)
9 Elements and compounds	Mining processes extract compounds (such as iron oxide) and process them further to extract elements (iron, in this example). The concept of elements *vs* compounds is first done in Grade 8.
10 Raw materials and processed products	Processing can be as simple as the removal of worthless rock from stockpiles of ore, through to the production of metals such as steel, vanadium, zinc, etc.
11 Reactions of metals	Revise oxides and reactions of metals with oxygen from topic 9.7 (which can be taught before topic 9.5) or use extraction as the context for teaching topic 9.7. Teach the reactivity series for metals.
12 Methods of extracting metals from ores	Learners should do at least one method, linked to topics 9.6 and 9.7. The methods will depend on the local mining option that is chosen and could then be electrolysis, heating with oxygen, displacement of less reactive metals, or simulating the cyanide process which extracts gold.

[5] Note that the topic is not intended as a review of factual information about minerals and the South African mining industry, but as an opportunity to develop Learning Outcomes NS1, NS2 and NS3 in terms of a few simple physical and chemical systems.

13	Indigenous technologies for extraction of metals	For example, evidence of iron smelting in northern Limpopo and on Witwatersrand. Link to chemistry in topic 9.7.
14	The economic effects of the mining industry	For example, the relationship between the international price of metals or other commodities from South Africa and job losses or job creation in the mining industry.
15	Some environmental impacts of mining	Impacts of open-cast and underground mining. Environmental impacts of mining include waste products and pollution of water resources. Mention laws that aim to control the environmental impacts of mining. Learners should debate decisions about using land for tourism, agriculture or mining. Study impacts on high-value tourist areas, wildlife and farming.

Research on learning and teaching this topic

There is not much research available on this topic yet. However, teachers should watch for learners who have difficulty visualising what an underground mine is like when shown a 3D diagram.

Some learners still have misconceptions about substances being "transformed" in chemical reactions as described in topic ***9.7 Some important chemical reactions***, so that they might imagine that processing changes one element into another, for example, copper ore might be transformed into gold.

Some learners believe that any rock can be treated to extract a metal or that the metal is always found in its pure form, hidden in the ore.

A potential source of research information on learning and teaching this topic is the website of the National Association of Geoscience Teachers in the USA publishes a journal called *Geoscience Education*. Research articles can be found at http://serc.carleton.edu/nagt/jge/abstracts/index.html

Examples of activities to build concepts and language

Learners can do activities that

- simulate the exploration of an area, collecting samples, testing them and deciding whether the mining company can cover its costs and make a profit from mining the mineral.
- simulate the crushing of an ore, dealing with the large percentage of waste, separate the compound by various methods, and use chemical reactions to decompose the remaining compound and extract the element
- do information-searches for studies of water pollution that results from coal-mining.
- Role-play community members meeting the executives of a mining company that plans to mine the community's land. Learners should read about and include the social impacts of mining, both positive and negative. Learners should also include reading about the effects of laws about environmental responsibility before, during and after mining.

9.6 Particle model of matter in chemical reactions

Reasons for placing this in Grade 9

The particle model of matter is first introduced in Grade 8, to explain changes of state (phase changes), the differences between solids, liquids and gases, dissolving, diffusion and heating by conduction, but we know that learners need time and repeated challenges before these concepts become meaningful to

> **Links to FET**
>
> In Grade 10 the learners will do Physical and Chemical Change
>
> • Microscopic interpretation of macroscopic changes (for example changes in conductivity and temperature)

them. For these reasons, the ideas appear again in Grade 9, and should challenge learners to explain more phenomena. This need not be treated as a separate topic, and it would make more sense to integrate it with the next topic, ***9.7 Some important chemical reactions***

Concepts		Suggested elaboration
1	The Model of Matter	All particle model of matter concepts done in Grade 8.
2	Molecules at microscopic level	Learners make models of molecules of common elements and compounds. They use large numbers of beads, beans, peas to represent the substances as solids, liquids or gases. (For example, a learner who makes a single O_2 molecule model does not show understanding of the macroscopic properties of oxygen gas. Learners must make many O_2 pairs of beads and place them at appropriate distances from each other.)
3	Chemical reactions at microscopic level.	Learners represent reactions of elements and compounds in bead models, drawings of atoms and in words to describe the macroscopic changes.
4	Balanced chemical equations	Learners must interpret the bead models of reactions and write the symbols that make up balanced chemical equations.

Research on teaching and learning this topic

This research section here is the same as for the Grade 8 topic ***8.5 The particle model of matter***.

Chemistry is difficult when learners are given the symbols with little opportunity to learn their meaning, and then assessment moves all too quickly after this to test their recall of the symbols. For example, what do these symbols mean to a learner who has not heated sodium hydrogen carbonate, collected the gas, identified it and then modelled the reaction?

$$2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$

Examples of activities to build concepts and language

Learners can

- use molecular stencils to draw atoms and molecules in reactions and physical changes, and write their formulae
- make bead models of some simple reactions like water forming from hydrogen and oxygen, or carbon being heated in oxygen or sulphur burning in oxygen. When the learners can make the models easily, they should begin to draw the atoms and molecules, freehand or using molecular stencils for accuracy.
- make models of molecules and atoms in reactions until the meaning of the subscripts in formulae and equations is clear e.g. they model Al_2O_3 making say twenty of these units, and laying them together in a model crystal. (This would be a flat, 2D model for convenience)
- model the atoms and molecules in reactions, using beans or beads in sufficient numbers to show that many atoms and molecules are involved in a reaction, that they react in constant proportions e.g.

  $2Cu + O_2$ (heated)→ $2CuO$ is true but by using many more beads learners should realise that the equation $36\ Cu + 18\ O_2$ (heated)→ $36\ CuO$ is saying the same thing,

  and they should also realise that there may in fact be some Cu left over because there were not enough O_2 molecules.

9.7 Some important chemical reactions

Reasons for placing this in Grade 9

This topic could not be done any earlier because the learners first need an understanding of the particle model of matter, and the nature of compounds. To understand what is happening in the reactions we will do here, the learners must use the Grade 8 work on modelling reactions (the micro-level representation) before they write chemical equations (the symbolic representation).

We also try to build their understanding that there are patterns in reactions, and they do not have to memorise a large number of reactions. We include some reactions which are used in processing ore from mines – this builds the concept of chemical systems which is a major theme in FET.

Links to FET

In Grade 10 the learners will do

Physical and Chemical Change

- Microscopic interpretation of macroscopic changes (for example changes in conductivity and temperature)
- Separation of particles in decomposition and synthesis reactions
- Conservation of atoms and mass.
- Law of constant composition
- Conservation of energy
- Volume relationships in gaseous reactions.

Representing chemical change

- Balanced chemical equations.

Chemical systems

The impact of science on human development

The impact of science on the environment

In Grade 11, they go on to

Energy and chemical change:

- Energy changes in reactions related to bond energy changes;
- Exothermic and endothermic reactions;
- Activation energy.

Types of reaction:

- Acid-base and redox reactions;
- Substitution, addition and elimination.

Concepts	Suggested elaboration
1 Elements and compounds.	Review Grade 8 work. Learners must be able to give examples of classes of elements (solids *vs* liquids *vs* gases, metals *vs* non-metals). Solids *vs* liquids *vs* gases for compounds.
2 Models and symbolic representations of chemical change.	Revise Grade 8 work on modelling reactions using beads, beans, etc. to represent the atoms in correct proportions. Drawing the number of each of the atoms in correct proportions.
3 Acids, bases and neutral-isation. Indicators.	Examples of acids and bases from home and school science room, indicators such as beetroot and black tea.. **Patterns** in acids: sour-tasting foods are acidic; effects on an indicator. **Patterns** in soluble bases: soapy feel and effects on an indicator. Universal indicator. A pH scale represents a range from strongly acidic to strongly basic. Reactions of acids and bases. Neutralisation. Salts. **Pattern** in neutralisation reactions that produce a salt and water.
4 Chemical equations	Show how to represent neutralisation reactions **macroscopic** terms (bottles of reactants, dish of salt and water as products), in models showing what happens on **micro** level and in chemical **symbols** in equations. Writing chemical equations and balancing them. Model all the other reactions also.

5	Reactions of metals and non-metals with oxygen.	In general, metals react with oxygen to give alkaline oxides, and non-metals react with oxygen to give acidic oxides. Test the solutions with indicators. Model the formation of molecules (micro level) and write equations (symbolic level)
6	Exothermic and endothermic reactions	Some reactions require energy to start, after this, they are exothermic.
7	Reactions of acids with metal oxides.	In general, an acid + a metal oxide ➔ a salt + water. Metal oxides are bases because they neutralise acids. Model the formation of molecules (micro level) and write equations (symbolic level)
8	Reactions of acids with metal carbonates.	In general, an acid + a metal carbonate ➔ a salt + water + carbon dioxide. Metal carbonates are bases because they neutralise acids. Model the formation of product molecules (micro level) and write equations (symbolic level)
9	Reactions of acids with metals.	In general, an acid + a metal ➔ a salt + hydrogen. The reaction of some metals is much more vigorous than other metals. Model the formation of product molecules (micro level) and write equations (symbolic level)
10	Metals in a reactivity series.	Differences in the reactivity of metals. Some metals react with cold water, some react with hot water and others do not react with water. More reactive metals will displace a less reactive metal from a solution of its salt. Link with e.g. extraction of copper from copper sulphate solutions when processing copper ore.
11	Rust as one form of corrosion.	Rusting as a reaction of iron with oxygen in water. Prevention of rusting. High economic cost of rust corrosion.
12	Chemical reactions in mining .	At least one example of the process to extract a metal from its ore. Do the real macro reactions, model them and represent them in chemical equations. Also model one reaction that has environmental implications e.g. production of waste products SO_2 or $FeSO_4$ (Link to ***9.5 Mining and minerals***)

Research on learning and teaching this topic

Science education researchers in several countries have investigated learners' reasoning about chemical reactions. For example, Andersson (1986)) questioned Swedish Grade 7 to 9 students about the changes on copper water-pipes. He asked, *When a house was newly built, both the hot and the cold water pipes were shiny copper. Before long, the outside of these copper pipes became dull and had a thin dark coating on them. The outside of the hot water pipe had more of this coating than the cold water pipe. How did the coating form?*

Andersson found five kinds of thinking in the students; you may find the same ideas among your learners. The first idea is much closer to the scientific understanding of a reaction, but the other four, below, are not scientific understandings of chemical reactions.

1 A scientific conception of chemical reactions

Some learners were quite quick to form a scientific understanding of the chemical reaction: they said (correctly) that the black coating on the copper pipes is a substance which is formed when copper reacts with oxygen. The copper atoms are still copper atoms, but they have joined strongly with oxygen atoms from the air, and the black substance is made of copper oxide molecules.

2 ✗ The "It just happens like that" misconception

Some of your learners might feel that no explanation is needed. For them it is enough to say, "Some things just happen like that. Copper pipes just go dark-coloured."

3 ✗ The misconception that matter is displaced in a chemical change

Some other learners see a change like the dark substance appearing on the copper pipes as the dark substance coming out of the pipes. They reason, if you squeeze a sponge, then water comes out. Other examples would be, if smoke comes from burning wood, it means that the smoke is being driven out by the flame. If oxygen comes from heated mercuric oxide, then the heating is freeing oxygen which was trapped in the mercuric oxide.

4 ✗ The misconception that matter is modified into another state in a chemical change

Some learners think that substances in a chemical reaction **take on a new state or form** but they **remain the same substance**. For example, they might say that you have shiny copper and dark copper; heat changes the form of the copper from shiny to dark. Or wood-ash is just wood in another form. For them this makes sense, because they remember that water changes into water vapour when you heat it, but it is still water.

5 ✗ The misconception that matter turns into other kinds of matter, or atoms turn into other kinds of atoms

Other learners might think that a chemical reaction changes a substance into a completely new substance. For example, they might say that the copper pipes have **changed into some other substance and are no longer copper**. A more familiar example is that when steel wool burns, it goes black. These learners may decide that the **steel has changed into carbon**. This misconception is not the chemist's idea of substances changing; it is more like the story of a witch who by magic turns a person into a frog.

The scientific view *is that the steel wool does not magically change into carbon. The iron (steel) is reacting with oxygen from the air and forming black iron oxide; the iron atoms do not change into carbon atoms.*

Examples of activities to build concepts and language

Learners can

- make models of molecules that form in a reaction when given the elements which begin the reaction
- predicting and identifying products of reactions. E.g reactions of acids with metal hydroxides . Predicting and identifying products of reactions, using models or other representations of the reactions. Apply particle model concepts to electrolysis and conduction in solutions when doing decompositions or extraction of metals from a compound.
- classify the oxides of metals and non-metals using an indicator
- make a collection of supermarket items such as cleaning liquids, bicarbonate of soda, vinegar, lemonade, tea, milk and use indicators to classify them as acids or alkalis
- neutralise sodium hydroxide with dilute hydrochloric acid using a medicine dropper, and collect the salt that forms.
- plan and carry out an investigation of the factors that make iron rust
- collect the copper from copper sulphate using iron to precipitate the copper.
- give examples of acids and bases from home and school science room, investigate indicators such as beetroot and black tea..

- identify patterns in acids: sour-tasting foods are acidic and change an indicator in the same way as well-known acids like “battery acid” and hydrochloric acid.
- identify patterns in soluble bases: they have a soapy feel and change an indicator in the same way as well-known alkalis such as caustic soda.
- classify substances as acidic or basic using indicators, order them on a pH scale using universal indicator

9.8 Electrical systems

Reasons for placing this topic in Grade 9

This topic builds on the Grade 7 topic ***Energy sources and transfers in systems*** and ***8.7 Cells and electrical circuits***. There is an important emphasis on the national electric supply and the systems that are needed for it. The section on electrostatics and lightning provides an opportunity for learners to discuss different explanations of lightning, and so it addresses the first assessment standard for Learning Outcome NS3 at Grade Level 9, ***Learner recognises differences in explanations offered by Natural Sciences and other systems of explanation***.

From here on, the emphasis in Grade 9 falls on circuits as systems, where a change in any part has effects on all the other parts. This means that learners need more than a qualitative understanding of voltage and current relationships, and so some measurement and calculation is needed.

This mathematical aspect has been left as late as possible in the GET to allow learners' mathematical skills to develop.

Another benefit of placing it in Grade 9 is that it gives necessary support to Technology in the Electronic Systems and Control strand.

Links to FET

In Grade 10, learners will do

Electrostatics:

•Two kinds of charge; • Force charges exert on each other (descriptive);

• Attraction between charged and uncharged objects (polarisation);

• Conductors and insulators

Electric circuits:

• Need for a closed circuit for charges to flow;

• Electrical potential difference (voltage) • Current • Resistance

• Principles and instruments of measurement of voltage (P.D.), current and resistance.

Concepts	Suggested elaboration
1 Electric forces and electrical systems.	Learners must do and discuss the usual enjoyable activities with electrostatic charges, and learn that like charges repel each other and unlike charges attract each other. They must develop the important understanding that when they have two charged objects attracting each other or repelling each other, they have created a system of two objects, and they have stored some potential energy in that system; the energy came from the learners because they did work on the system as they transferred some of their energy to the objects. (No definition like W = F x d is needed.) While doing this section, learners should learn how clouds separate huge quantities of charge and accumulate potential energy that is released in a lightning stroke. They should also explore beliefs about and explanations of lightning (refer to Learning Outcome NS3 ***Understanding science as a human endeavour in cultural contexts***).
2 Mechanical systems that transfer energy to electrical systems	van der Graaff generator (this apparatus models a storm-cloud building up charge; a hand-powered version of this apparatus is better for understanding the energy transfers). Dynamos on bicycles and wind-up torches. Discuss dynamos in ESKOM power stations. By doing some physical work to turn a dynamo to light a bulb, learners should understand that the bulb glows because energy is being transferred at some other place in the system. Energy from energy sources such as burning coal, falling water, wind, sunlight or nuclear reactions, is transferred to systems that turn electrical generators. Power as the rate of supplying energy to a system, using the units of joules, seconds and watts. Also power to electrical systems as voltage x current , using units of volts, amperes and watt. P = V x I

3	The national electricity grid	How power stations feed energy onto the grid, high voltages carried on powerlines, voltage stepped down for local distributors and consumers. What happens when the grid is overloaded. How private electricity producers could earn income from selling energy onto the grid.
4	Costs of energy from electrical systems.	Consumers pay for energy, not power or current. Energy is costed in kWh. The quantities of energy consumers pay for depend on the total kW of all the appliances and on how many hours they are used. Comparisons of appliances' energy consumption and cost, e.g. incandescent *vs.* compact fluorescent lamps. Alternatives to electricity, such as solar heating.
5	Cells as chemical systems and sources of energy.	Learners should make a cell or connect several home-made cells until they light an LED. They must understand that a cell is a store of substances that can react if an external circuit is connected across the terminals. Chemical reactions in the cell separate positive and negative charges which can then flow through the external circuit.
6	Series and parallel direct-current circuits.	Series and parallel circuits using cells/batteries. Voltage and current relationships in series and parallel circuits. Learners must know that in a simple parallel circuit, all the parallel resistors have the same voltage across them. In a simple series circuit, the resistors split up the voltage of the battery, with the higher resistors having the higher voltage. In a parallel circuit, the total current from the battery increases with each parallel resistor that is added in series, while in a series circuit the total current from the battery decreases with each resistor that is added in series.
7	Resistance and resistors	All conductors, even very good conductors, heat up to some extent when a current flows through them. This means that some energy is given away in every kind of conductor, and we say that every kind of conductor has resistance. A resistor is a conductor that we select, to control the quantity of current, or to give us a useful energy transfer. Resistors are manufactured to have accurate resistances such as 100 ohms, or 470 ohms, for example. Other examples of resistors are bulbs, rheostats, motors, light-sensitive diodes. (Link to Technology - Electronic systems and control)
8	Factors that affect resistance	Type of material, diameter (or thickness), length, temperature. (Link to Technology - Electronic systems and control)
9	Wiring in homes, cars, toys.	Learners should be able to identify series and parallel circuits, fuses, circuit-breakers, earthing and earth-leakage systems.
10	Safety with electricity.	Safety practices, explained with reasons. Examples of parallel connection causing overload of mains circuits. Reasons for using circuit-breakers. Illegal connections to ESKOM mains supply, in terms of dangers and in terms of energy theft.

Research on teaching and learning this topic

In this Grade the learners must deal with the concept of voltage as the unit of energy transfer in circuits. From Grade 6 onwards, the learners have been exposed to the idea of voltage in the simple form that the higher the voltage of a cell, battery or ESKOM installation, the greater the quantity of energy that it can transfer, and the higher the voltage, the more danger involved for the learner.

> This section should be read together with the corresponding sections in Grade 6, 7 and 8, on pages 63, 84 and 111. Children's understanding of electric circuits has been researched extensively, both in SA and other countries. References are, for example, the working papers of the Learning in Science Project in New Zealand (1980), Bradley and Stanton (1986), Cohen, Eylon and Ganiel (1982), Moodie (1988) and Shipstone (1985). Shipstone lists many other useful references.

While this understanding of voltage is too simple [6], it puts the emphasis in the right place: in the mind of the learner voltage must be connected to the energy which the source can supply. The current concept then can take its proper place – current is a **result** of the voltage across the circuit.

There is much evidence that learners have great difficulty in distinguishing between voltage and current (Shipstone, 1985, p.44). Many learners see voltage as part of the current, and that the current is the cause of the voltage. (In fact the truth is exactly the opposite – it is the voltage that causes the current to flow.)

If learners do not get the distinction between voltage and current clear, they will not be able to predict the voltages across different resistors in series nor understand why the voltage drop across a good conductor is near zero nor why the voltage across the ends of an open circuit (no current flowing) is not zero but the same as the voltage of the battery.

> This statement, that voltage is the measure of energy transfer to a resistor, is a first approximation to a full definition of voltage – in Grade 10 they will deal with it in a more precise form, where the term will be "potential difference" and it will be defined as the amount of energy per unit charge that can be transferred from the energy source to a resistor. However, at Grade 9 level we would gain nothing by insisting on this definition; the most important thing is create a strong connection between the term "voltage" and the energy concept.

As a summary, there are five main misconceptions to bear in mind when writing learning programmes at Grade 9 level:

✗ the current causes a voltage; a misconception. In fact, the voltage causes the current.

✗ part of the current is used up in each of the resistors **-** a misconception. In fact the energy, not the current, is less after passing through a resistor.

✗ the current comes out of one end of the battery and reaches the resistors one after the other; this is a misconception. In fact all the charges everywhere in the circuit begin move instantly.

✗ electricity in wire travels very fast, because the light comes on as soon as you press the switch; this a misconception. In fact, the charges drift quite slowly, at a speed of only millimetres per second. However, **all** the charges, everywhere in the circuit, begin to drift as soon as a person presses the switch. This includes the charges in the bulb filament also, and so the filament heats up immediately.

✗ a resistor has resistance but gets tired and cannot resist the current after some time; this is a misconception. Resistance is not used up.

Language concerns in this topic

When teachers switch between English and African languages they should be careful of using terms like *amandla* and *ugesi / igezi* which connote power (or energy, or force or electricity) but do not have the specific meanings that science concepts require.

The other language issues and the named misconceptions in the Grade 8 research section are still relevant in this Grade 9 section.

[6] For example, an arc welder working at say 20 volts but high current, obviously transfers enough energy to melt steel.

Examples of activities to build concepts and language

- Learners use a system such as a dynamo mounted on a bicycle and wired to bulbs, to transfer energy from their bodies to the rest of the system and light up the bulbs or provide energy to a beeper. They experience physical tiredness as they transfer energy to the dynamo and the bulbs, and feel the effect of connecting and lighting up more bulbs in parallel.
- Learners make series circuits and measure voltages across the resistors. They should find that the voltages across resistors in series add up to the voltage of the battery (when the battery is producing a current).

  They should also find that the parts of the circuit with the highest resistance have the largest voltage across them. This will include the fact that when a switch is open, the resistance across the contacts is nearly infinite and so the voltage across the contacts is equal to the voltage of the battery. Further, they should use this understanding to explain why the resistance across a good conductor like a copper strip is nearly zero. (A voltmeter with a needle will show a zero voltage drop across a copper strip but a digital meter will usually show a small voltage drop of a few millivolts.)

  The underlying conceptual development must be that the energy of the battery is being transferred to the resistors; the resistor with the greatest resistance gives off the most energy (to be accurate, it gives off the most energy per second, but this level of understanding is not the essence of the concept). For this reason, learners should work with resistors of different resistance. For example, they should use two bulbs of different power ratings, measure voltages across them and note which one feels the hottest and looks the brightest. (Torch bulbs are made with white, green and blue beads inside the glass to support the filaments; the colour of the bead is code for the resistance of the filament.)
- Learners make parallel circuits and measure voltages across the resistors in parallel; they should find that all the resistors have the **same voltage** across them and it does not matter whether the resistance of each is high or low. However, the amount of **current** flowing through each parallel resistor **does** depend on whether its resistance is high or low.

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