

**A collaborative approach to developing science teaching
methods suitable for addressing diversity in classrooms**

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Session 1 Aims and Introduction

A collaborative approach to developing science teaching methods suitable for addressing diversity in classrooms

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References

Australian Academy of Science (2011a) *Effective Questioning: A stimulus for professional discussion*. Canberra: Australian Academy of Science from <http://www.science.org.au/sciencebydoing>

Australian Academy of Science (2011b) *Inquiry-based Teaching: A stimulus for professional discussion*. Canberra: Australian Academy of Science from <http://www.science.org.au/sciencebydoing>

Australian Academy of Science (2011c) *Student Learning: A stimulus for professional discussion*. Canberra: Australian Academy of Science from <http://www.science.org.au/sciencebydoing>

Definitions of Science Inquiry

Scientific inquiry involves posing questions; formulating testable hypotheses; planning, conducting and critiquing investigations; collecting, analysing and interpreting evidence; and communicating findings. **Science inquiry** is concerned with investigating ideas, evaluating claims, solving problems, drawing valid conclusions and developing evidence-based arguments. It also recognises that scientific explanations change as new or different evidence becomes available.

Australian Curriculum, Assessment and Reporting Authority. (2010). *Australian Curriculum Information Sheet: Science*. Retrieved 29 November 2011 from [http://www.acara.edu.au/verve/resources/AC SCIENCE INFO Senior Sec v1 FINAL.pdf](http://www.acara.edu.au/verve/resources/AC%20SCIENCE%20INFO%20Senior%20Sec%20v1%20FINAL.pdf)

Science inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyse, and interpret data; proposing answers, explanations, and predictions; and communicating the results. **Inquiry** requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations.

National Research Council. (1996). *National Science Education Standards*. Retrieved 8 December 2011 from http://www.nap.edu/openbook.php?record_id=4962

The position paper on the teaching of science – supported by a large body of research on science education – recommends a pedagogy that is hands-on and **inquiry-based**. While this is widely accepted at the idea level, practice in India has tended to be dominated by chalk and talk methods. To make in any progress in the desired direction, some changes have to be made at the level of the syllabus. In a hands-on way of learning science, we start with things that are directly related to the child's experience, and are therefore specific. From this we progress to the general. This means that 'topics' have to be reordered to reflect this. An example is the notion of electric current. If we think in an abstract way, current consists of charges in motion, so we may feel it should be treated at a late stage, only when the child is comfortable with 'charge'. But once we adopt a hands-on approach, we see that children can easily make simple electrical circuits, and study several aspects of 'current', while postponing making the connection with 'charge'.

National Council of Educational Research and Training. (2005). *Science Classes VI to VIII*. Retrieved 8 December 2011 from <http://www.ncert.nic.in/index.html>

Inquiry-based teaching

What is it?

Inquiry-based teaching is much more than giving students opportunities to develop inquiry skills, such as posing questions; planning. Conducting and critiquing investigations; collecting, analysing and interpreting evidence; and communicating findings. Inquiry-based teaching is a construction approach to learning in which students learn not only inquiry skills but actively construct an understanding of the science phenomena they are exploring. Students are involved in inquiry-based learning when they develop understanding of a science topic through seeking answers to questions, developing explanations based on evidence they collect, modifying explanations based on further investigation of information, communicating and justifying conclusions.

Students are involved in inquiry-based learning when they develop understanding of a science topic through seeking answers to questions, developing explanations based on evidence they collect, modifying explanations based on further investigation or information, communicating and justifying conclusions.

Types of inquiry

The type of inquiry you use depends on several things – the nature of the topic or question being investigated, the range of resources available to students, the time available, how well your students work with minimal teacher direction, how confident you feel teaching in this way. Some activities are more suited to open inquiry, some are too dangerous. On the continuum from open to closed inquiry activities, you must decide for each what will achieve the best learning outcomes for your class, considering all of the above.

Choose the type of inquiry in which you, the teacher, are not completely removed from your comfort zone and in which students are likely to achieve real learning and to have the necessary skills, before progressing along the continuum of activity types to further complexity in teaching and learning.

How ready are you and your students to adopt an inquiry-based approach?

You should consider your own experience and that of your students when you begin to use an inquiry-based approach to teaching and learning. Consider the skills you and your students have that equip you to benefit from teaching and learning in this manner. Choose the type of inquiry in which you, the teacher are not completely removed from your comfort zone and in which students are likely to achieve real learning and to hone the necessary skills, before progressing along the continuum of activity types to further complexity in teaching and learning.

Inquiry-based teaching

Inquiry-based teaching requires <u>less</u> emphasis on:	Inquiry-based teaching requires <u>more</u> emphasis on:
science being interesting for some students	science being interesting for all students
covering many science topics	studying a few fundamental concepts
theoretical, abstract topics	content that is meaningful to the student's experience and interest
presenting science by talk, text and demonstration	guiding students in active and text and demonstration extended student inquiry
asking for recitation of acquired knowledge	providing opportunities for discussion among students
individuals completing routine assignments	groups working cooperatively to investigate problems or issues
activities that demonstrate and verify science content	open-ended activities that investigate relevant science questions
memorising the name and definitions of scientific terms and facts	learning broader concepts that can be applied in new situations
learning science mainly from textbooks provided to students	learning science actively by seeking understanding from multiple sources of information, including books, Internet, media reports, discussion and hands-on investigations
assessing what is easily measures	assessing learning outcomes measured that are most valued
assessing recall of scientific terms and facts	assessing understanding and its application to new situations, and skills of investigation, data analysis and communication
end-of-topic multiple choice tests for grading and reporting	ongoing assessment of work and the provision of feedback that assists learning

The activity lesson:
teaching *skills*
associated with the
different phases

Some people believe that for student-centred inquiry the teacher has less of a role to play in student learning. The truth is that a skilled teacher remains the key to effective instruction and is the key element in any inquiry-based classroom.

An activity lesson usually has three phases; an introduction, the activity time and a conclusion. To perform effectively teachers must use different skills according to the focus and aim of each part of a lesson. These phases and the teaching skills required for each are outlined on the following page.

Discussing the activity



Introducing the activity



Student activity



Introducing the activity

The introductory phase is the initial part of the lesson where the scene is set for the day's activity. In this phase the teacher is the 'director' and 'organiser'. The teacher's role is to:

- Gain the interest of the students
- Elicit student prior learning
- Outline the problem or activity, and provide advanced organisation where appropriate
- Describe the arrangements for collection and use of equipment/materials
- Communicate time and outcome expectations

Communication with students in this phase should be simple, direct and concise to ensure that students receive the necessary information to carry out the task. Where possible, the introductory phase should be kept brief.

student activity

The bulk of the lesson is dedicated to student 'doing' and is referred to as the activity phase. In this phase the teacher is the 'helper' and 'facilitator', engaging students to:

- Assist with materials and activities
- Discuss ideas, challenging students to think more critically. During this phase the main method of communicating with students is via questioning.

Discussing the activity

An important, but often neglected and rushed part of the lesson is the conclusion phase. In this phase the teacher acts as coordinator, drawing together the students' ideas into a meaningful and coherent picture.

This is the most challenging phase of an activity lesson. The teacher:

- Encourages students to share their results from the activity
- Through discussion, helps students summarise the main ideas or concepts.

Again, questioning plays an important role in this phase to draw out students' ideas and assist them in refining their thoughts.



Inquiry classrooms are unstructured and chaotic

While inquiry classrooms frequently take on this appearance, a closer inspection usually reveals students who are engaged, enthusiastic and (very often) excited by their learning. In this state teenagers can appear a little unruly, but it is worth remembering that the correlation between student engagement and poor classroom behaviour is a negative one. It has been widely reported that students engaged

through inquiry rarely present behaviour management problems. So while the productive chatter and high energy levels in an inquiry classroom can present a challenge for the teacher who prefers quiet and order, the benefits far outweigh a bit of noise and rabble! Planning and organisation is the key to ensuring that the hustle and bustle results in productive learning experiences.



You can't assess inquiry-based learning

Inquiry-based learning can be assessed like any other concept or topic in science; learning is learning! There are some special features of inquiry-based learning, however, that make it particularly suited to particular methods of assessment. Inquiry learning can be thought of as a journey during which the body of knowledge and skill set grow. The use of diagnostic, formative and summative assessment activities effectively punctuate the journey to provide evidence as students move from the known to the unknown.



Inquiry is only good for high-achieving students

The ability to think creatively and critically is not solely for the high-achieving student. In fact, the *Science by Doing Pilot* revealed numerous cases where low-ability students embraced inquiry-based approaches much more readily than those more academically able. Many high-achieving students are proficient at 'working to the test' and feel uncomfortable with the 'unknown' that inquiry represents.



Doing hands-on science is the same as doing inquiry

Many science activities are highly structured despite being hands-on. Such tasks tell students what questions to answer, what materials to use, and how to go about solving questions and problems. Charts and tables to record data are often provided. This type of 'cookbook' activity provides a step-by-step approach to a solution. Although most inquiry-based activities are hands-on, not all hands-on activities are inquiry-oriented (Llewellyn 2002).



In inquiry-based teaching it is never okay to tell students the answers to their questions

It is not practical to assume that all knowledge can be gained through the inquiry method. There are always competing priorities for how students spend their time in class and decisions about how to respond to students' questions are made within this context. There will be times where it is not possible to have students design an investigation, or take the time to conduct research. Teacher explanation certainly still has a place in an inquiry-oriented classroom. However, it is through investigations that deep understanding and a greater transfer of knowledge is achieved.



All science subject matter should be taught through an inquiry-based approach

There is no one-size-fits-all, 'silver-bullet' solution for science education. Inquiry should be thought of, and used as, one of a variety of effective approaches and strategies. Relying on any one method, including inquiry, would be ineffective and likely to result in boredom for students. No-one knows your students and the context in which they learn better than you, therefore, you are best placed to make decisions about the variety and choice of approaches used in the classroom.



True inquiry occurs only when students generate and pursue their own questions

Students need practice at asking questions that are investigable. This takes time, guidance and many teacher-initiated investigations in the process. When time and student ability permit, however, every opportunity to allow students to pose and investigate their own questions should be seized upon. It is these experiences that promote advanced inquiry abilities and an understanding of how scientific knowledge is pursued.



It is impossible to cover everything in the curriculum using an inquiry-based approach

This statement holds true. It is not suggested that all science should be learned through inquiry. However, investigations are important ways to promote deep understanding of science content and the only way to help students to practise inquiry abilities. *Science by Doing* promotes more depth, less breadth, but appreciates that the issue of coverage vs. learning remains to be addressed.

What is inquiry-based teaching?

This is a simple question, but the answer is complex. The reason is that the nature of inquiry is itself complex and multifaceted. There are many different pictures of inquiry.

Perhaps to understand inquiry one needs to understand the nature of science. Science is a way of answering interesting questions about the natural and built world. The body of science understanding has been constructed upon questions and more questions. These questions arise from observations and the gathering of evidence.

Science inquiry

Science inquiry embraces the diverse ways in which scientists attempt to find answers to these questions. In education we refer to these ways as the science inquiry skills. Just as scientists seek answers, inquiry teaching refers to the ways in which students attempt to find answers to questions about science phenomena. Teachers or the students themselves may pose these questions.

While these two ideas, that is, science inquiry skills and science inquiry teaching, have similar features, they are also different. By understanding the similarities and differences, a teacher of science can more effectively implement successful inquiry teaching.

Science inquiry teaching

Science inquiry teaching is more than just teaching students science inquiry skills. It is about helping students find answers to their questions to do with science phenomena. It is about providing activities that provoke these questions and then creating opportunities by which students can gather and interrogate evidence and information. From this interrogation, understanding and genuine learning will occur. It is about structuring situations by which students can discuss their answers to questions with other students and the teacher. Through such discussion their ideas about science phenomena can be refined and developed in a way that leads to meaningful understanding. Within this discussion there continues to be an important place for teacher explanation.

Inquiry teaching is therefore associated with student activity and, commonly, student investigation. Within an activity lesson students may be given a task or problem or question to investigate. The teaching skills needed for inquiry lessons are varied, as illustrated by this professional learning resource.

What are the features of inquiry-based teaching?

As explained previously, inquiry-based teaching is focused on helping students find answers about science phenomena. There are some important features of such classroom lessons. These include:

- Students seek answers to science questions.
- Students develop answers and explanations based on evidence.
- Students refine their explanations in the light of new information or experiences.
- Students communicate and justify their explanations to others.

Answers and explanations are based on evidence

There are two dimensions to this feature. Firstly, the critical role of evidence. The evidence may come from the students' observations or from the data gathered by an investigation or from such sources as books, the Internet or people with relevant expertise.

The second dimension involves the development of explanations based on reason and logical deductions. Initially, explanations are tentative with respect to the available evidences and information. Teachers have a critical role in guiding the development of student explanations.

Seeking answers to questions

This feature emphasises the student-centred dimension of the learning. If students have little desire to actively seek answers, then there is little likelihood that learning will occur. For this reason it is important that questions are posed in a context that is meaningful and interesting to students. The context of the questions influences the motivation and interest of students.

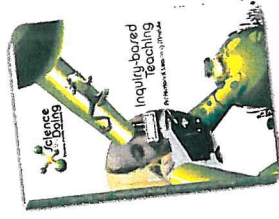
Sometimes students may pose the questions, but more commonly it is the teacher who presents them to students. Even if students suggest a question, teachers usually need to refine the question so it can be answered in a more manageable way. The art of good inquiry teaching lies in the art of developing interesting and relevant questions that can be successfully answered by students.

Explanations are refined

Tentative explanations need to be tested in new situations and with new information. For example, if students develop a classification system for certain objects, the value of the system is tested by introducing new objects.

Explanations are communicated

The process of refinement depends significantly on students communicating their ideas to others, including the teacher. Through sharing these explanations, students can review and clarify their ideas.



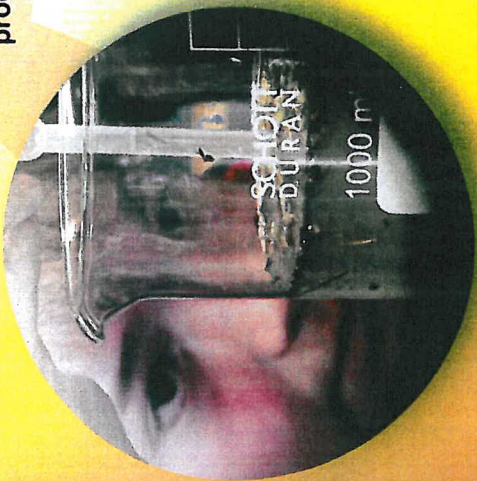
Forms of inquiry

Inquiry-based teaching is a complex, multifaceted way of teaching. One of the complexities relates to the fact that there is a variety of forms of inquiry-based teaching. While the most common form is guided-inquiry teaching, one can also present lessons that can be described as open inquiry or in other cases as closed inquiry. What factors influence the nature of these different forms?



One way of explaining the different forms is by deciding who is responsible for the different aspects of the inquiry process:

- 1 The posed question
- 2 The method by which the question is investigated
- 3 The answer or solution.



Forms of inquiry and responsibility for the different aspects of the inquiry process can be illustrated by the following table:

Question	student	teacher	teacher	teacher
Method	student	student	teacher	teacher
Answer	student	student	student	teacher
Type of inquiry	open inquiry	guided inquiry	guided inquiry	verification lesson
Examples (see page 12)	Hot cars	Sorting matter Rule of the seesaw	Pond investigation Using the Internet	Replicating Galileo

Open inquiry

For open inquiry the student is responsible for posing the question to be investigated, for determining how the question will be answered and for collecting the relevant evidence or information by which the question is answered. While open inquiry lessons tend to be time demanding, they are invaluable in helping students refine their inquiry skills.

Verification lesson

A verification lesson is one where the teacher is responsible for all the decisions associated with the question, method and answer. There are some situations where such lessons are appropriate.

Guided inquiry

The most common inquiry lesson is the guided inquiry lesson. In these lessons the teacher provides the question and/or the method by which the question is answered. There are also subtle variations in that students can make an input with the skillful guidance of a teacher.

"The confidence of students in my class has increased due to the collaborative and cooperative learning opportunities created through the inquiry method."

Science by Doing
Pilot teacher, NT

What do students bring to the learning experience?

- As research has shown, students come to any learning situation with established ideas formed from their direct experiences. These can be very powerful and in some cases, especially if they are misconceptions, can inhibit the learning of new concepts.
- It is important for a teacher to, firstly, be aware of students' prior knowledge and, secondly, be able to build on it. In some cases this may require confronting the misconception with experiences that will challenge and assist students to understand the scientific view.

Alternative conceptions

- Many empirical studies have shown that students hold pre-instructional conceptions about many phenomena and concepts that are substantially different from scientific concepts.
- View of learning
 - Sometimes students hold two inconsistent views at the same time – intuitive and formal
 - Students' alternative conceptions are often not recognised by the teacher
 - Research suggests that many students and teachers hold limited views of the nature of science
- Various terms have been used to describe these conceptions:
 - Alternative conceptions
 - Misconceptions
 - Naïve conceptions
 - Mistaken beliefs
 - Intuitive ideas
 - Children's science/mathematics
- Research tells us that:
 - Students come to class with a range of prior ideas or conceptions
 - Many of these conceptions differ in important ways from the views that have been constructed by scientists and mathematicians
 - Students from different cultures and countries have been found to hold similar ideas
 - Students' alternative conceptions can be a barrier to learning
 - These conceptions can be a starting point for the teacher to build upon

- Sources of alternative conceptions:
 - Sensory experiences (Piagetian)
 - Language experiences
 - Cultural background
 - Peer groups
 - Mass media
 - Science instruction
- Barriers to learning:
 - Alternative conceptions interfere with learning
 - Force is a property of an object associated with motion
 - Heat is a substance rather than a form of energy
 - Use of language for common and scientific concepts can differ e.g. energy, force, work, calculating
 - Students can do very well in tests and yet hold alternative conceptions.
- **What to do?** Students need to be challenged and supported to make major shifts in understanding

Examples of common misconceptions

- Force of gravity is greater on heavy objects than lighter objects, making them fall faster
- Objects moving at a constant velocity must have a force acting on them
- The sun is living
- Heat and temperature are the same
- Current is the same as voltage
- Seeds are non-living
- Plants get food through their roots

What is the 5Es model?

To assist curriculum developers and teachers plan inquiry-based lessons that capture the essence of what we know about student learning, a number of models have been developed. One that has a significant impact in Australia is the 5E model. It was formulated by a group of US science educators, including Rodger Bybee, Paul Kerbis and Susan Loucks-Horsley.

In the model there are five distinct but interconnected phases.

Engage

The teacher captures the interest of the student in a variety of ways. For this purpose context is important as the connection made to engage students will influence how students understand the science concepts that will be introduced. The teachers also wants to know information about the students' ideas and possible misconceptions.

Explore

In this phase students are normally involved with hands-on activities so that they have a common set of concrete experiences upon which the science concepts or skills can be built. In these explorations students are encouraged to use their own language to make connections and discuss ideas.

Explain

After a common set of experiences, the explanation which follows provides students with an opportunity to develop a better comprehension of the science concepts. This explanation may come from the teacher, students or third party sources like books, the Internet or films. It is at this point science terms and language are introduced to more clearly articulate and refine the science concepts.

Elaboration

This phase is often referred to as the application phase because students apply or extend their acquired learning to new situations. Such opportunities will also help students refine their ideas. During this phase students will use science language in their discussion.

Evaluation

Assessment is an important part of any learning process. Both students and the teacher need to know how much has been learnt and understood.

An elaboration of the PrimaryConnections 5Es teaching and learning model

PHASE	PURPOSE	ROLE OF TEACHING AND LEARNING ACTIVITY
ENGAGE	Create interest and stimulate curiosity. Set learning within a meaningful context. Raise questions for inquiry. Reveal students' ideas and beliefs, compare students' ideas.	Activity or multi-modal text used to set context and establish topicality and relevance. Motivating/discrepant experience to create interest and raise questions. Open questions, individual student writing, drawing, acting out understandings, and discussion to reveal students' existing ideas and beliefs so that teachers are aware of current conceptions and can plan to extend and challenge as appropriate—a form of diagnostic assessment.
EXPLORE	Provide experience of the phenomenon or concept. Explore and inquire into students' questions and test their ideas. Investigate and solve problems.	Open investigations to experience the phenomenon, collect evidence through observation and measurement, test ideas and try to answer questions. Investigation of text-based materials (for example, newspaper articles, web-based articles) with consideration given to aspects of critical literacy, including making judgements about the reliability of the sources or the scientific claims made in the texts.
EXPLAIN	Introduce conceptual tools that can be used to interpret the evidence and construct explanations of the phenomenon. Construct multi-modal explanations and justify claims in terms of the evidence gathered. Compare explanations generated by different students/groups.	Student reading or teacher explanation to access concepts and terms that will be useful in interpreting evidence and explaining the phenomenon. Small group discussion to generate explanations, compare ideas and relate evidence to explanations. Individual writing, drawing and mapping to clarify ideas and explanations. Formative assessment to provide feedback to teacher and students about development of investigation skills and conceptual understanding.

An elaboration of the PrimaryConnections 5Es teaching and learning model

PHASE	PURPOSE	ROLE OF TEACHING AND LEARNING ACTIVITY
EXPLAIN (Continued)	Consider current scientific explanations.	Small group writing/design to generate a communication product (for example, poster, oral report, formal written report or PowerPoint presentation, cartoon strip, drama presentation, letter) with attention to form of argumentation, genre form/function and audience, and with integration of different modes for representing science ideas and findings.
ELABORATE	Use and apply concepts and explanations in new contexts to test their general applicability. Reconstruct and extend explanations and understanding using and integrating different modes, such as written language, diagrammatic and graphic modes, and mathematics.	Student-planned investigations, exercises, problems or design tasks to provide an opportunity to apply, clarify, extend and consolidate new conceptual understanding and skills. Further reading, individual and group writing may be used to introduce additional concepts and clarify meanings through writing. A communication product may be produced to re-represent ideas using and integrating diverse representational modes and genres consolidating and extending science understanding and literacy practices.
EVALUATE	Provide an opportunity for students to review and reflect on their own learning and new understanding and skills. Provide evidence for changes to students' understanding, beliefs and skills.	Discussion of open questions or writing and diagrammatic responses to open questions—may use same/similar questions to those used in <i>Engage</i> phase to generate additional evidence of the extent to which the learning outcomes have been achieved. Reflections on changes to explanations generated in <i>Engage</i> and <i>Evaluate</i> phases to help students be more metacognitively aware of their learning.

LINKING QUESTION

What is it about water that makes it such a unique chemical?

PART 2

PARTICULAR PROPERTIES OF WATER

Water is a liquid that displays a wide variety of interesting behaviours. It gurgles, bubbles, runs... How else would you describe water?



ACTIVITY 1

WATER DROPLETS

How is water different from other liquids? What physical properties can you observe?

What to use:

- a cup containing a little baby oil
- a cup containing a little water
- 2 pipettes or droppers
- food colouring
- 4 coloured toothpicks

Each student will need a hand lens (or magnifier), a sheet of graph paper and a sheet of wax paper to cover the graph paper.

What to do:

1. Work with a partner to observe and compare the characteristics of drops of water to oil. You may like to use a table like the one below to record your observations.

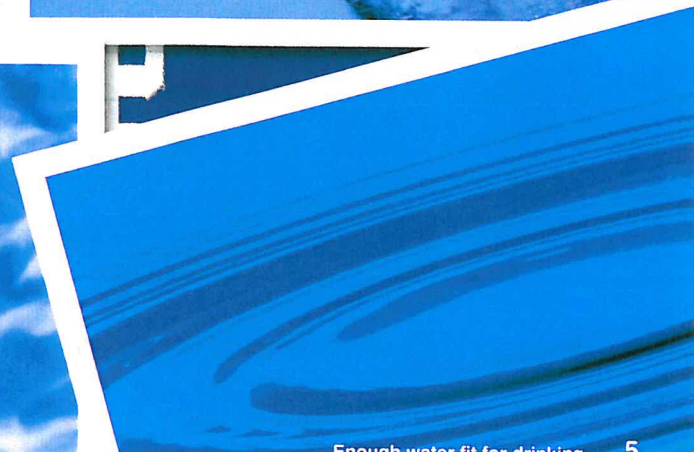
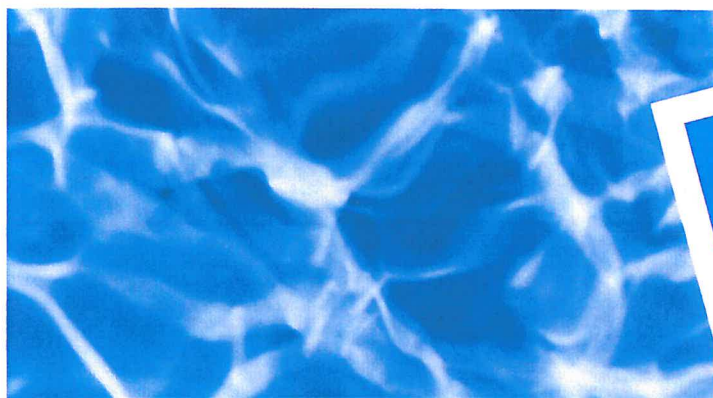
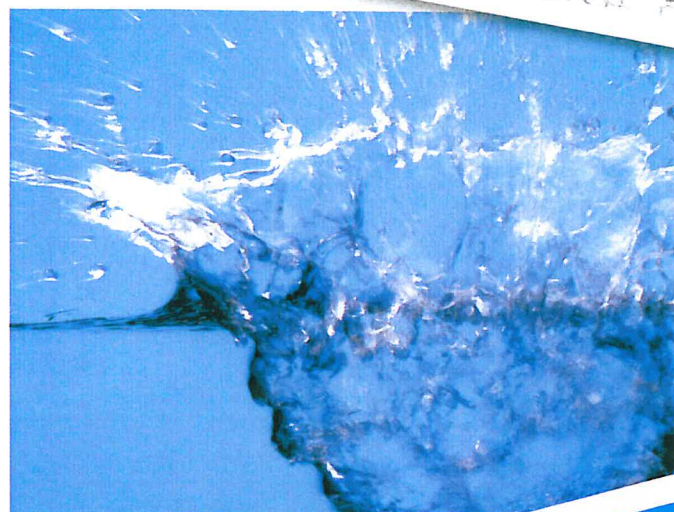
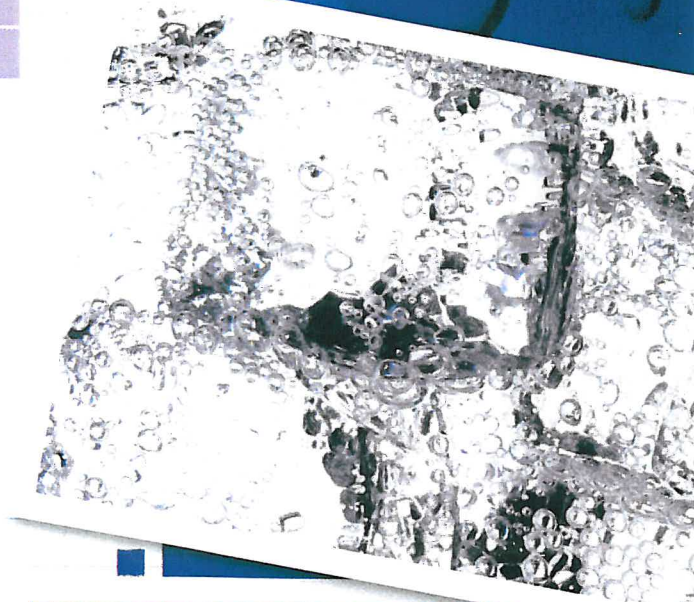
Draw and describe the	water	oil
bird's-eye view		
side view		
split drop		
joined drop		
coloured drop		

2. Prepare the work surface by placing the wax paper over the graph paper.
3. Practise making equal size drops of water using the graph paper as an approximate guide to size.
4. Decide who will use the water and who will use the oil.
5. Make a drop and examine it with the hand lens. Describe what you see from the top view and the side view.
6. Try to split the drop into smaller drops using a toothpick. Describe what happens.
7. Try to move the two drops together using a toothpick. What happens?
8. Dip the toothpick into a drop of food colouring and mix it into the new larger drop. Describe what happens.

Discussion:

Compare the behaviour of the water and oil drops:

- How were the drops alike?
- How were they different?



LINKING QUESTION

What is it about water that makes it such a unique chemical?

PART 2

PARTICULAR PROPERTIES OF WATER

ACTIVITY 2

GET TO KNOW THE WATER MOLECULE

Have you ever wondered what

H₂O

stands for?



Go to the digital resource **Get to know the water molecule.**

Home

Hints

Glossary

Find out more

Explore the water molecule

Enough Water Fit for Drinking

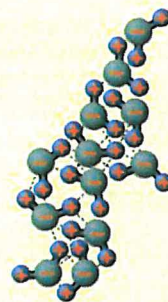
Get to know the water molecule

Peer into the submicroscopic world and get to know the water molecule.



Open the Water Molecule activity

Please only click once, object may take a minute to load.



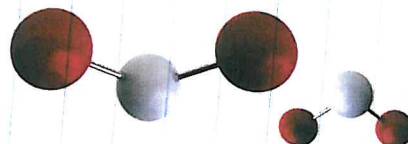
HYDROGEN

OXYGEN

HYDROGEN

Pure water is made up of the elements of hydrogen and oxygen. If you could peer into the submicroscopic world you would see that a single water molecule consists of three atoms – two of hydrogen and one of oxygen.

The behaviour of water molecules is often described as being similar to magnets.



LINKING QUESTION

What is it about water that makes it such a unique chemical?

PART 2

PARTICULAR PROPERTIES OF WATER

ACTIVITY 3A

INVESTIGATING COHESION

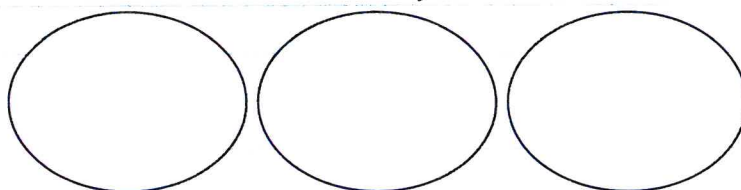
In pairs or small groups investigate cohesion further:

What to use:

five cent coin
cup partially filled with water
eye dropper or pipette

What to do:

1. Predict how many drops of water you will be able to place on the coin before it overflows.
2. How will you ensure it is a fair test? For example at what height will you drop the water from? Which side of the coin will be facing up? Should you carry out repeat trials? Place drops of water slowly on the coin and count and observe what happens.
3. Collect data by drawing a diagram showing the shape of the water on the coin after one drop, when the coin is half full and just after it overflows.



single
drop

half full
drops ____

near overflowing
drops ____

4. Record your data results. How many drops were you able to place on the surface of the coin before it overflowed?

Discussion:

- If the number of drops is very different from your prediction, explain what accounts for the difference.
- Explain your results in terms of cohesion.



You may have been warned not to touch the tent in the rain. Common tent materials are somewhat rainproof in that the surface tension of water will bridge the pores in the finely woven material. But if you touch the tent material with your finger, you break the surface tension and the rain will drip through.

Small insects like the water strider can walk on water because their weight is not enough to penetrate the surface.

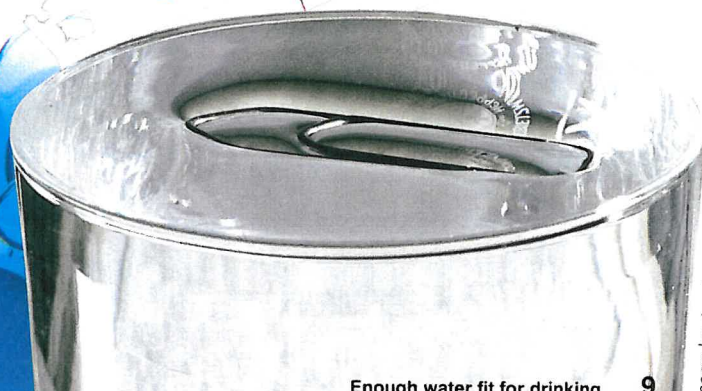
The scientific term for the skin that forms around the surface of water is

SURFACE Tension

Soaps and detergents help clean clothes by lowering the surface tension of the water so that it more readily soaks into pores and soiled areas.

The major reason for using hot water for washing is that its surface tension is lower and it is a better wetting agent. But if detergent lowers the surface tension, heating may be unnecessary.

? Could more paper clips be added without overflowing the water?



Session 3 Exploring Water

Materials

Activity 1 Water droplets, groups of 2, 15 groups

Per group

¼ cup baby oil

¼ cup water

2 pipettes/eye droppers

2 coloured toothpicks

Food colouring

1 A4 sheet graph paper

1 A4 sheet wax paper

Activity 3A Investigating cohesion, groups of 2, 15 groups

Per group

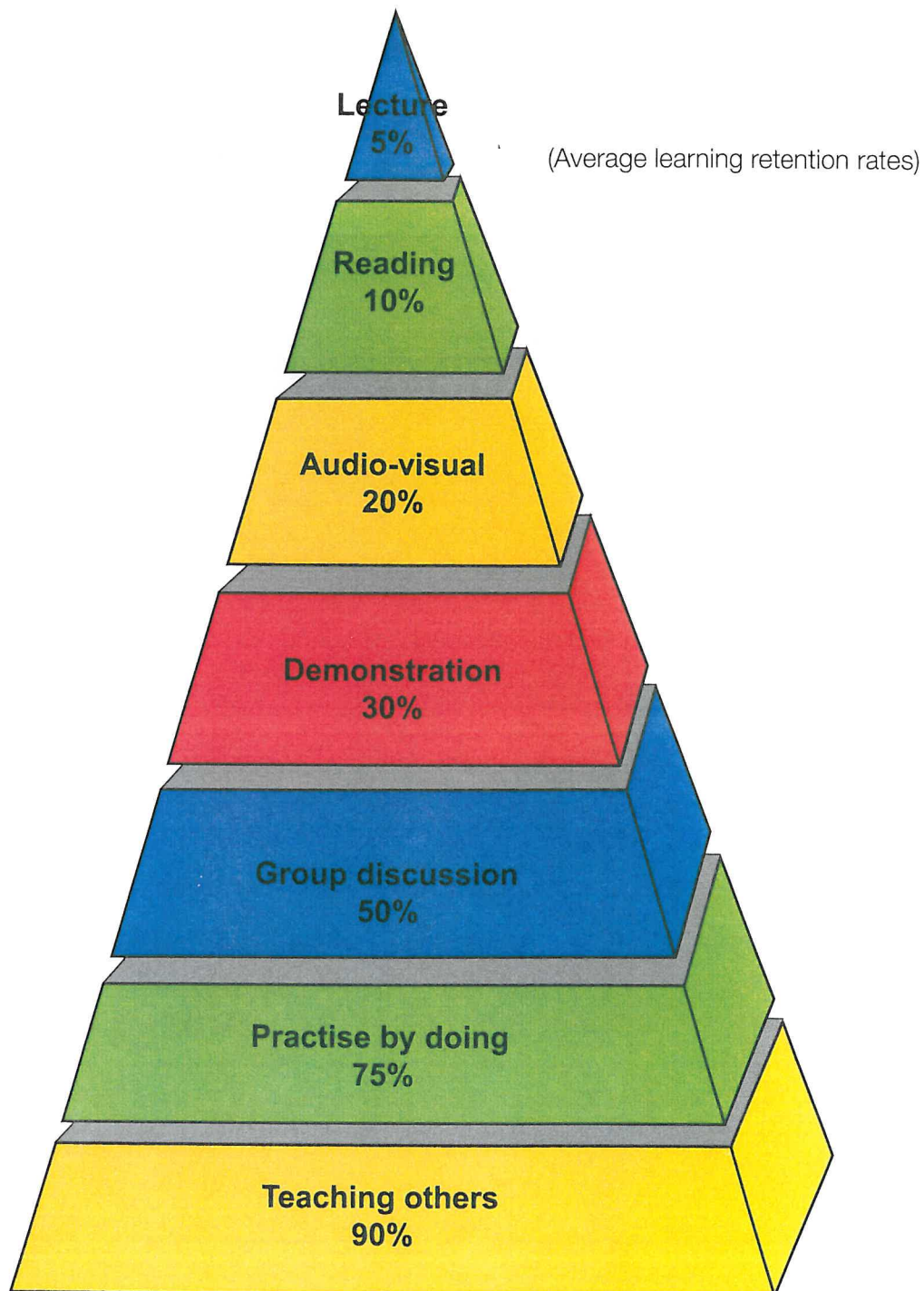
Five cent coin (or similar size)

Cup of water (from Activity 1)

1 pipette/eye dropper (from Activity 1)

Learning pyramid

The learning pyramid visually depicts approximate learning retention rates depending on the learning mode. It reflects learning theory which suggests that people learn best when they are actively involved in the learning process.



Reference

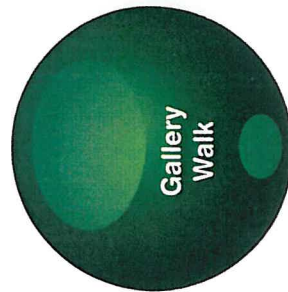
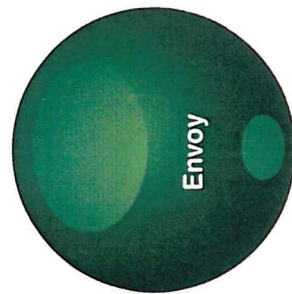
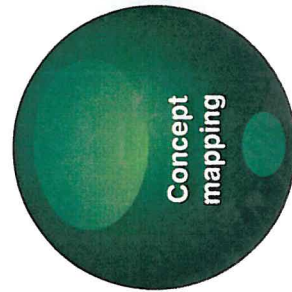
NTL Institute for Applied Behavioral Science,
300 N. Lee Street, Suite 300, Alexandria, VA 22314. 1-800-777-5227
<http://homepages.gold.ac.uk/polovina/learnpyramid/about.htm>

3 Inquiry-based teaching strategies



Adapted from: Goodrum, D (2004) 'Teaching Strategies for Science Classrooms' as found in Venville, G. and Dawson, V. (2004) *The Art of Teaching Science*. Allen & Unwin, Crows Nest, NSW.

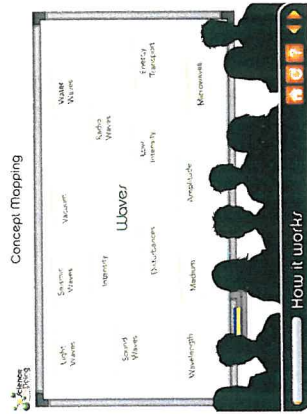
There is a range of different teaching strategies that supports the inquiry-based approach and includes collaborative and cooperative learning opportunities.



Six of these are outlined in the following three pages. Further information can be obtained from the Inquiry-based Strategies section of the CD-ROM which includes animations of these strategies in action.

Concept mapping

Concept maps allow students to represent diagrammatically what they know about the links and relationships between concepts. They allow students to access prior knowledge and provide teachers with feedback on what is known or unknown and/or what is misunderstood, either at a single point or over time. Concept maps are designed to increase the students' ability to organise and represent thoughts and help with reading comprehension.



How it works

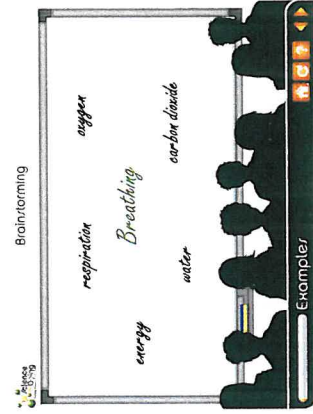
When concept maps are first introduced, model their use at the whole-class level. Brainstorm ideas as a class and ask students to assist jointly in grouping the words generated. Explain that each concept can be used only once. Link relationships with arrows or lines and talk aloud to model the cognitive processes involved. Ask students to assist in identifying and labelling the relationships between concepts.

Brainstorming

The purpose of brainstorming is to generate ideas quickly – it is a creative, problem-solving strategy.

How it works

Quantity is more important than quality; all ideas are accepted and not criticised. Hitchhiking (building from each other's ideas) is encouraged. Write exactly what is said – no paraphrasing.

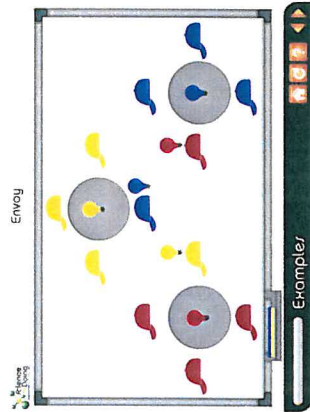


Envoy

This strategy encourages students to learn from each other and take responsibility for learning. It helps students to develop listening and oral skills and promotes skills in synthesising and summarising.

How it works

Students are formed into groups and are given a topic to discuss. One student from each group is selected to be the 'envoy'. When the group has completed its discussion of the topic the envoy reports to another group and outlines what was discussed. The envoy also listens to a report from the group they are visiting. The envoy then returns to their original group, which has also received a report from another group's envoy, and they exchange new ideas. Each group should now have input from two other groups.

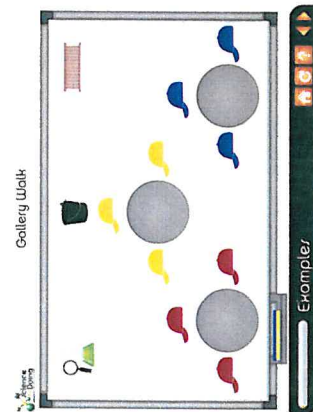


Gallery walk

Student or group work is placed around the room and students are given the opportunity to view other students' work and to 'show off' their own.

How it works

Student work is placed around the room and students are given time to circulate and view the display. Students can use the opportunity to read information prepared by others or consider the way the information is presented. They can collect information from the work of others or peer-assess using a prepared set of guidelines.

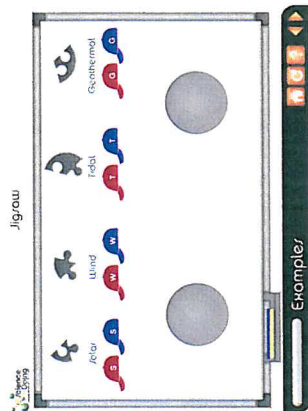


Jigsaw

This strategy provides a structure for group work and also allows students to cover a broad amount of information in a shorter period of time.

How it works

Students are formed into 'home' groups of about five or six. The topic is divided up into sections and each student in the home group is given a different aspect of the topic to research. The home groups split up and the students form into 'expert' groups so all members in one group are researching the same aspect of the topic. Students research their aspect of the topic in the expert groups and prepare to report to their home group. Students return to their home group and take turns to report as the expert on their aspect of the topic.

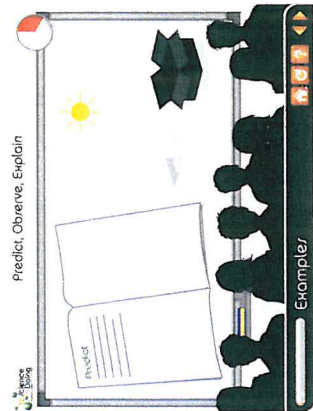


Predict-Observe-Explain (POE)

This strategy encourages students to think more carefully and critically about scientific phenomena by challenging them to examine events that surprise them.

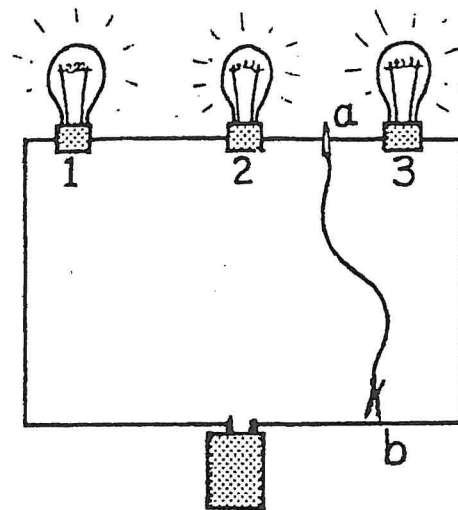
How it works

Students are given a situation and asked to predict what happens when something is done to change that situation. As the change is implemented the students make careful observations about what happens. By comparing their observations with their predictions they are encouraged to develop explanations of what is happening.



PREDICT OBSERVE EXPLAIN

The simple series circuit consists of three identical lamps powered by battery. When a wire is connected between points *a* and *b*,



- a) what happens to the brightness of lamp 3 ?
- b) does current in the circuit increase, decrease, or remain the same ?
- c) what happens to the brightness of lamps 1 and 2 ?
- d) does the voltage drop across lamps 1 and 2 increase, decrease, or remain the same ?

Session 4 POE Electric circuit activity

7 groups

Per group

3 light bulbs

1 battery of powerpack

Alligator clips or wires to connect bulbs, battery

INTRODUCTION

Science practical work can be used to help students achieve a number of learning outcomes, including: getting a feel for natural phenomena, developing investigation skills and processes, providing a platform of experiences on which conceptual understandings can be built, giving students a sense of the nature of science, and the excitement of inquiry and discovery. Different forms of practical work develop different learning outcomes so it is important to use a variety of practical experiences to develop the full range of outcomes.

Traditional recipe-style laboratory exercises in which students follow the teacher's instructions to answer the teacher's question provide little opportunity for student ownership, intellectual challenge or engagement, and even though students are hands-on they are often minds-off. Open investigations allow students to plan and conduct their own investigation within a context and boundaries set by the teacher. Investigations provide a more authentic experience of the nature of science and require students to be both hands-on and minds-on.

This chapter will address a number of questions related to practical work in science. What learning outcomes can be developed through practical work in science? What opportunities for learning are provided by different types of practical work? What processes are required to complete an investigation? How can student learning be scaffolded and facilitated?

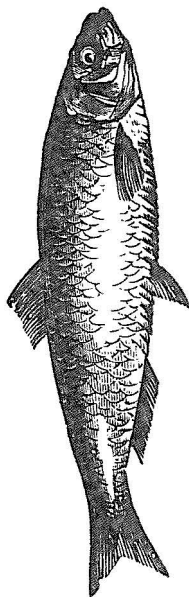
LEARNING FROM PRACTICAL WORK

There is an international consensus that the purpose of teaching and learning science in the compulsory years of schooling is the development of scientifically literate citizens. Scientifically literate citizens have the knowledge and skills of science that enable them to function effectively in society, helping them:

- to be interested in and understand the world around them;
- to engage in the discourses of and about science;
- to be sceptical and questioning of claims made by others about scientific matters;

CHAPTER SIX INVESTIGATING IN SCIENCE

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OUTCOMES

By the end of this chapter you will be able to:

- Distinguish between various forms of practical work in science and the learning outcomes that can be achieved through them
- Describe the processes of investigating the types of variables and how these relate to the research question or hypothesis and to the design of a controlled experiment
- Select appropriate scaffolds to support students' work through the phases of an investigation and describe a suitable instructional model to teach investigation skills

- to be able to identify questions, investigate and draw evidence-based conclusions; and
- to make informed decisions about the environment and their own health and wellbeing (Hacking *et al.*, 2001).

Practical work provides opportunities for students to develop learning outcomes that contribute to scientific literacy including the skills and understandings needed to conduct scientific investigations and to critically evaluate the claims made by others based on scientific evidence. Research indicates that many students are not yet developing these skills (Hacking & Garnett, 1995).

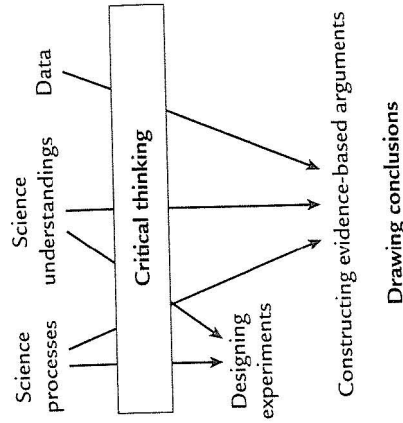
Practical work also helps students develop a sense of the nature of science. (See Chapter 1 for a more detailed consideration of the nature of science.) The nature of science refers to science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development (Lederman & Lederman, this volume). It is only when students practise as scientists, conducting their own investigations, that the nature of science becomes evident to them.

An important characteristic of scientific knowledge is that it is evidence based. To be scientifically literate, students need not only an understanding of the big ideas of science (e.g. nature of matter, evolution, energy) but also an understanding of the nature of scientific evidence (e.g. accuracy, uncertainty). Students need opportunities to develop the understandings and skills associated with the collection, validation, representation and interpretation of evidence (Gott & Duggan, 1996). Students who understand the nature of scientific evidence should be able to detect when:

- conclusions are not consistent with the data;
- fact and opinion are intermingled;
- graphs distort the appearance of data;
- averages mask variation in data; and
- high levels of precision are unwarranted (American Association for the Advancement of Science, 1989).

To plan and conduct investigations, think about, reason with and critically evaluate scientific ideas and evidence students need critical thinking skills. Critical thinking brings together scientific ideas, processes and often data, as illustrated in Figure 6.1.

FIGURE 6.1: The role of science process skills, science conceptual understandings and data in critical thinking



In summary, practical work provides opportunities for the development of aspects of scientific literacy, an understanding of the nature of science and, in particular, an understanding of scientific evidence and the development of critical thinking skills.

TYPES OF PRACTICAL WORK

There are many different forms of practical work including demonstrations, explorations, recipe-style exercises, investigations and projects. Practical work can be conducted in a range of contexts such as the school laboratory, the bush, the beach or at home.

Demonstrations are experiments performed by the teacher and observed by students that are used to model experimental methods and techniques or to perform experiments that would be unsafe for students to perform themselves (e.g. reaction of sodium and water). As the students play no part in manipulating the apparatus they are not able to develop manipulative skills.

Explorations are unstructured mini investigations where students have the opportunity to 'play' with materials and have concrete experiences of a phenomenon. Explorations are used to allow students to get a feel for phenomena such as magnetic attraction or crystallisation.

Most practical work conducted in secondary science takes the form of routine, recipe-style laboratory exercises in which students follow a procedure prescribed by the teacher to investigate a question set by the teacher (Staer *et al.*, 1998). Students follow the teacher's instructions to set up the prescribed equipment and make measurements and observations. Data interpretation is often structured by questions set by the teacher. Exercises provide opportunities for students to practise experimental techniques associated with data collection and process skills associated with data analysis and interpretation. There is no opportunity for students to develop skills associated with formulating a research question, identifying and manipulating variables or planning to control variables.

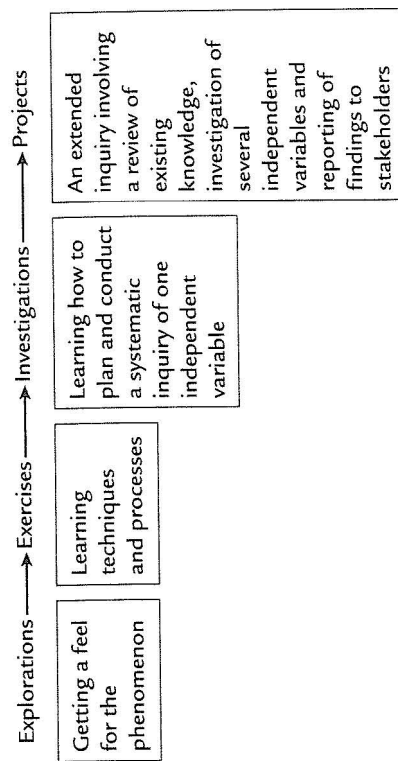
Investigations require students to plan and conduct an experiment within the context and boundaries set by the teacher. As students are required to make decisions about the experimental design, data presentation and interpretation there are opportunities for student ownership, engagement and intellectual challenge, and to practise critical thinking skills. Open investigations are more inquiry oriented than exercises and provide a more authentic experience of the nature of science compared to closed recipe-style laboratory exercises. Inquiry-oriented practical work has been shown to produce higher-order learning outcomes than traditional closed recipe-style laboratory exercises (Berg *et al.*, 2003).

Projects are a more extended form of inquiry often involving a review of existing knowledge, investigation of several independent variables and reporting of findings to stakeholders. Projects often extend over several weeks as they involve extensive fieldwork, observations or several experiments.

Teachers should use a range of types of practical work so that students have opportunities to learn a wide range of understandings and skills. Variety also helps cater for individual differences in students' learning styles. To improve the curriculum in secondary science, many of the laboratory exercises should be replaced with open investigations so that students can learn how to plan their own experiments. The easiest way to do this is simply to remove the detailed procedural instructions from some of the exercises to open them up and turn them into investigations.

Students need to build a foundation of skills, understandings and confidence before attempting more complex investigations and

FIGURE 6.2: A learning sequence that prepares students for more complex forms of practical work in science



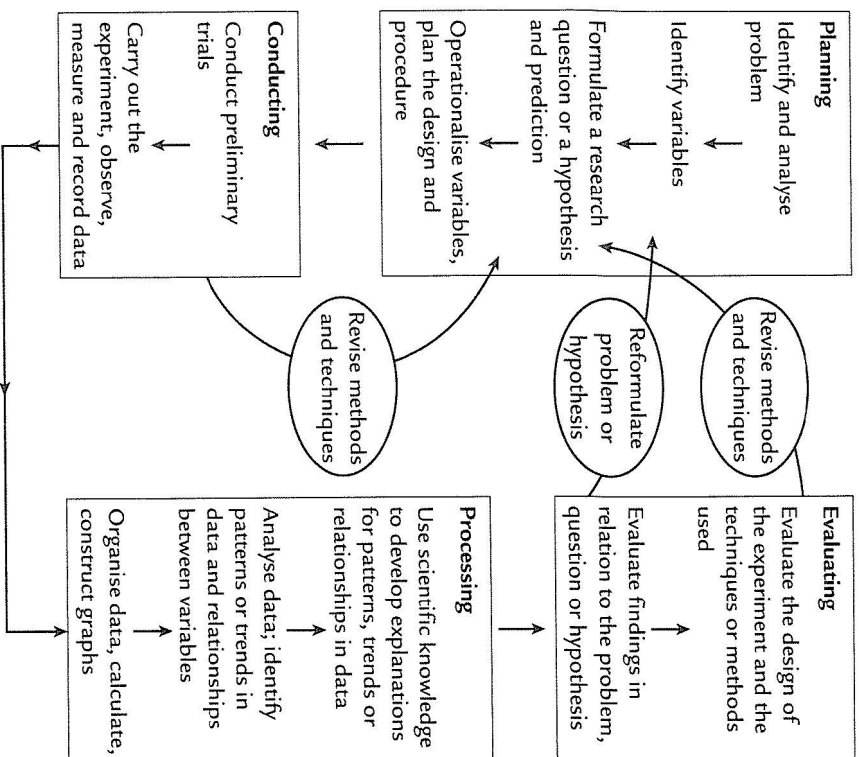
projects. Figure 6.2 illustrates an instructional sequence that prepares students for these more demanding tasks.

A MODEL OF INVESTIGATION PROCESSES

There is a wide range of types of investigations; however, most investigations require students to *plan* the experiment, *conduct* the experiment and collect data, *process* the data and communicate findings and finally reflect on their investigation, *evaluating* the quality of the findings and the investigation methods used. The evaluation phase focuses students on what they have learned from the investigation and this can be carried forward to improved planning of the next investigation. Figure 6.3 (p. 94) illustrates a model of the investigation processes. In practice, these processes may not take place in the strict order of planning–conducting–processing–evaluating, as part way through conducting the investigation students may realise that further planning is required to improve the measurement technique or design of the experiment.

In addition to these four phases of investigation there are opportunities for students to communicate their findings using posters, formal written reports and oral reports and thereby practise

FIGURE 6.3: A model of science investigation processes (Hacking & Fairbrother, 1996)



communicating using scientific genres of reporting. The findings from investigations may also guide students' decision making and actions in their own lives and develop outcomes associated with acting responsibly (e.g. an investigation of air temperatures inside cars parked in the sun should help students realise the dangers of leaving children and pets in cars on hot days).

IMPLEMENTING INVESTIGATION WORK IN SCIENCE

Many teachers who have not previously implemented open investigations with their students often raise concerns about doing this type of practical work. The most commonly cited concerns are listed below with a response to the concern.

- Investigations take longer to complete than laboratory exercises. Many investigations do take longer to complete than exercises as there is time needed for planning the experiment. Teachers should replace several exercises with a smaller number of investigations. In this way practical work can be contained within the available time.
- Students experience difficulty planning their own experiments. Students who have not previously completed investigations will not have had the opportunity to learn planning skills. Teacher modelling and coaching and explicit teaching of some skills will be required.
- Students will all want to do different experiments and it will be impossible to provide the equipment they require. Teachers can easily limit students to the same investigation or one or two independent variables for a given investigation or limit them to using only apparatus that is supplied. As confidence increases the teacher may open up the range of possibilities and allow students to place an order for equipment that will be brought to the next lesson.
- Students will have accidents. Teachers should require students to have their plan checked before they are permitted to carry out their investigation. It is also prudent to allow student access only to equipment and reagents that pose few safety concerns.

SCAFFOLDING AND FACILITATING STUDENT LEARNING

Open investigations are unstructured problem-solving tasks that require students to take the initiative to devise an appropriate approach to the problem, experimental design and techniques. Many students need considerable support if they are to engage successfully in these tasks. Support can be provided by breaking the task into a series of steps and by modelling some of the more difficult process skills.

Investigation planning and report sheets

Planning and report sheets guide students through a sequence of decision-making steps providing structure and scaffolding to support students while leaving the students responsible for the decision making. These scaffolds are structured by a sequence of questions and prompts. One scaffold, suitable for Year 6–10 students, is illustrated in Table 6.1 below.

TABLE 6.1: Questions used to scaffold investigations for lower secondary science students

Question or prompt	Instructional purpose of the question or prompt
What question or hypothesis are you going to investigate?	Students focus on the problem and formulate a question or hypothesis for investigation.
What do you think will happen? Explain why.	Students make a prediction and justify their prediction—this activates prior knowledge for the investigation.
Which variables are you going to: • change? • measure? • keep the same?	Students identify and operationalise the key variables.
How will you make it a fair test?	Students reflect on their plan and ensure that variables are controlled.
What equipment will you need?	Students think about the apparatus they will require to conduct the investigation.
Describe your experimental set-up using a labelled diagram and explain how you will collect your data.	The plan is set out in detail using a diagram and steps of their procedure.

Did you carry out any preliminary trials of your procedure to see if your planned method of data collection would work?

Were there any problems?

What changes did you make to fix the problems?

What happened? Describe your observations and record your results.

Can your results be presented as a graph?

What do your results tell you?

Are there any relationships, patterns or trends in your results?

Can you explain the relationships, patterns or trends in your results? Try to use some science ideas to help explain what happened.

What did you find out about the problem you investigated? Was the outcome different from your prediction? Explain.

What difficulties did you experience in doing this investigation?

How could you improve this investigation, e.g. fairness, accuracy?

These questions provide an opportunity for students to demonstrate that they conducted preliminary trials and have refined their procedure based on what they learned from the trials.

This prompts students to record their measurements and/or observations.

This prompts students to decide whether it would be worth graphing their data.

These questions prompt students to search for patterns in the data.

These questions prompt students to explain the patterns in their data by using scientific concepts.

These questions prompt students to summarise their findings as a conclusion and to compare their finding with their prediction. Discrepancies often occur between predictions and findings due to students' alternative frameworks. Such discrepancies may cause students to reflect on their beliefs.

This question prompts students to reflect on the processes used in the investigation and identify difficulties experienced.

This question helps students focus on what they have learned about improving their investigation processes.

Scaffolds such as the one illustrated in Table 6.1 lead students through the investigation process and elicit from them information about their thinking and doing at each stage of the investigation. Scaffolds therefore provide support to students and the written record of the investigation provides information needed by teachers to assess students' investigation work. A number of planning and report sheets suitable for scaffolding primary, lower secondary and upper secondary students' investigations can be downloaded in electronic form from Hackling (1998).

Operationalising variables

To understand the design of controlled experiments students need to understand the three types of variables and the relationships between them. This is best explained in the context of an investigation of the effect of drop height on the bounce height of a tennis ball. The height to which a ball bounces depends on the height from which it is dropped. The bounce height is therefore the *dependent variable* (DV) and the drop height is the *independent variable* (IV). There are a number of other variables that could also possibly influence the bounce height, for example the surface on which the ball bounces, the ball type and ball temperature. These other variables therefore need to be controlled (i.e. kept the same) so that we are sure that any change in bounce height is caused by the changes made to the drop height rather than changes in the surface or ball. These relationships are illustrated in Figure 6.4.

One way of helping students understand the relationships between variables in a controlled experiment is to use a variables table. An example of a variables table is illustrated in Figure 6.5.

Variables tables can be completed on the overhead projector using questioning to elicit the variables from students. In this way, the process of designing a controlled experiment can be modelled for students.

In summary, in a controlled experiment, the independent variable is changed to see what effect it has on the dependent variable while all other variables that could potentially affect the dependent variable are kept the same.

FIGURE 6.4: Relationships between independent, dependent and controlled variables

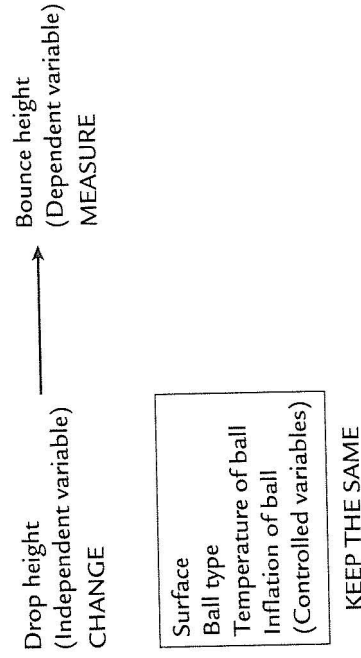


FIGURE 6.5: An example of a variables table
Research question: How does the amount of light affect the growth of seedlings?

What I will keep the same?	What I will change?	What I will measure?
Type of seeds Type of soil Amount of water Amount of fertiliser Size of container Planting depth of seeds	The amount of light: • dark • partial shade • full sun	The height of the seedlings
Controlled variables	Independent variable	Dependent variable

Writing research questions and hypotheses

Many students experience difficulty in writing testable research questions and hypotheses. Students need plenty of experience working with research questions before they are introduced to hypotheses.

Research questions are written in the form of a question about the possible relationship between an independent variable and a dependent variable. They can be written in a standard form that can be structured using the following algorithm:

What happens to _____ when we change _____?
(DV) (IV)

For example:

What happens to **the growth of wheat seedlings** when we change **the saltness of the water**?

Hypotheses are tentative declarative statements about the relationship between an independent variable and a dependent variable. They have a more complex structure than research questions. Hypotheses can be written in the following form:

This change to the independent variable
+ will cause this to happen to
+ the dependent variable

For example:

Increasing the salinity of water (IV) will reduce (relationship) the growth of wheat plants (DV).

As many secondary science students have a focus on 'getting the right answer' in their practical work, which comes from extensive experience of closed laboratory exercises, hypotheses cause problems for many students when their data do not support their hypotheses. Students will often fudge their data to match the hypothesis to give the appearance of getting the right answer. Students have been shown to commit this form of scientific fraud as they do not understand that the hypothesis may be wrong, that there may be error associated with their data due to measurement error, poor control of variables or small and unrepresentative samples. To write an hypothesis assumes that students have some knowledge about the phenomenon and the relationships between the associated variables. Hypotheses are therefore more suitable for older, more experienced and more able students. Most investigations can be successfully conducted using research questions.

The cognitive apprenticeship model of instruction

It is helpful to conceptualise the teacher's and the students' roles in learning the complex craft skills of science as being analogous to that of the tradesperson and apprentice. The cognitive apprenticeship model of instruction (Hennessy, 1993) has as its main elements modelling, scaffolding, coaching, articulation and fading:

- the teacher *models* strategies for the students making explicit their problem-solving processes (e.g. models the process of plotting a line graph);
- the teacher provides *scaffolding* to structure the work of the students (e.g. uses planning and report sheets to guide students through the steps of an investigation);
- the teacher works alongside students *coaching* them on specific skills and strategies (e.g. the teacher provides feedback and guidance on the measurement technique being used);
- students are encouraged to discuss and reflect on their decision making and strategies—*articulation* of tacit knowledge helps make it explicit (e.g. students work in small groups so they can discuss their methods of controlling variables); and
- as students gain competence some of the scaffolding is *faded* away (e.g. the planning and report sheets are withdrawn).

TYPES OF INVESTIGATIONS

Just as there are different types of practical work, so there are also different types of investigations. Each type has a different variable structure and provides different opportunities for learning. This is illustrated with the following examples in Table 6.2 (p. 102).

Type 1 investigations are very common in primary science as the independent variables are discrete (i.e. in categories) and data are presented using bar graphs. Type 2 investigations are common in secondary science as is the use of continuous independent variables (i.e. data are continuous on a measurement scale such as length or mass) and representing data by using line graphs. It is important to include a range of investigation types in the curriculum so that students are exposed to repeat trials, replication, discrete and continuous variables and bar and line graphing.

TABLE 6.2: Examples and features of various types of investigations

Type of investigation	Example	Features
1. Testing types of materials.	Which kind of paper towel holds most water?	Types or brands of materials are tested for absorbency, strength, stickiness, durability, etc. The independent variable is always discrete. Tests need to be repeated to give an indication of the extent of measurement and sampling error.
2. Investigating a relationship between two variables where repeat trials can be used.	Effect of the height from which a ball is released on the height to which it bounces.	Repeat trials and averaging are used because tests are non-destructive and the repeat trials give an indication of the extent of measurement error.
3. Investigating a relationship between two variables where replication can be used.	What effect does temperature have on germination?	Replication involves using several duplicate experiments set up at the same time. Replication is used because tests are destructive and can't be repeated and the material or population may be non-uniform hence replication gives an indication of the extent of sampling error.
4. Investigating the effect of several independent variables on one	How do the number of coils, length and thickness of wire, type of metal from	There is a need to test a number of independent variables separately or in combination on one

dependent variable often associated with a design problem. which wire is made and current affect the effectiveness of a heating element? How do you make a powerful heating element?

5. Survey-type research where populations are sampled to investigate the relationship between two variables. What is the relationship between height and arm span? The population being tested is non-uniform and samples are selected based on the parameters being investigated. Sampling is randomised to control for interfering variables.

SOURCES OF INTERESTING INVESTIGATIONS

One of the most useful sources of science investigation ideas is the CSIRO's CREativity in Science and Technology (CREST) website. The CSIRO has a program of awards that can be earned by students for completing science investigations. The CREST website offers a list of suggested investigations at three levels (bronze, silver and gold) which students may wish to do individually as projects. The school needs to register with CREST and individual students need also to register through their teacher before starting a project if they are to be awarded certificates for completing their investigations. Teachers searching for new ideas should look at the CREST projects section of the website (<www.csiro.gov.au/crest/>).

SUMMARY

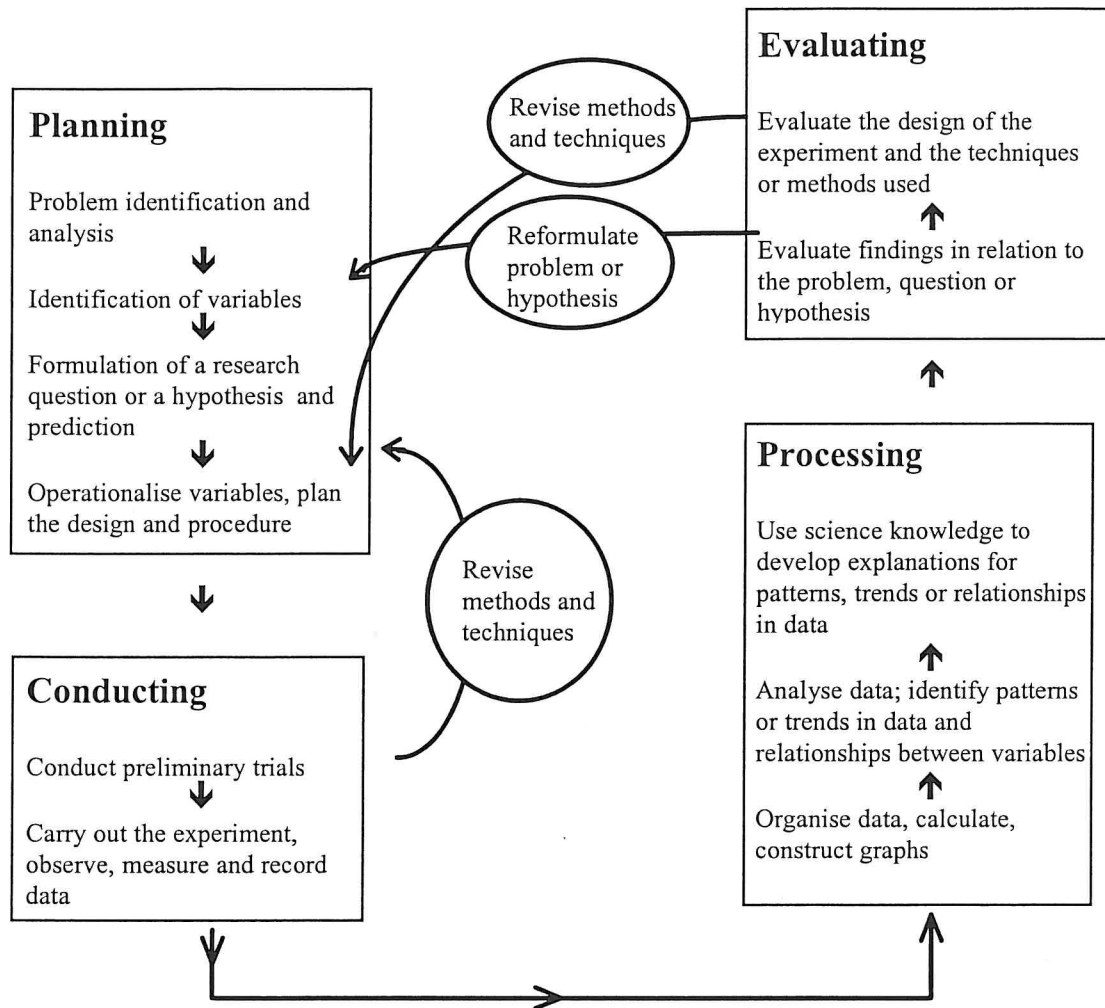
Practical work is an essential component of science programs for school students. It is through inquiry and investigation that scientists test ideas and generate new knowledge. By conducting investigations and practising as scientists, students can get a sense of the nature of science and learn skills and understandings at the heart of scientific

literacy. Inquiry-oriented and investigative science programs actively engage students in learning, increasing their interest in science and developing those critical thinking skills linked to reasoning with scientific processes, ideas and evidence.

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A model of science investigation processes



Hackling, M. W. & Fairbrother, R. W. (1996). Helping students to do open investigations in science. *Australian Science Teachers Journal*, 42(4), 26-33

Glossary of key terms

Variable: A factor that can be changed, kept the same or measured in an investigation.

Independent variable: The variable that is changed in an investigation to see what effect it has on the dependent variable.

Dependent variable: The variable that changes in response to changes in the independent variable. Often the variable that is measured in an investigation.

Controlled variable: A variable that is kept the same in all treatments to be sure that it is the change in the independent variable that is causing the change in the dependent variable.

Hypothesis: A tentative idea to be tested in an investigation stated as the relationship between the independent and dependent variables.

Preliminary trials: These represent a “dry run” of the procedure used to fine-tune the procedure and measurement techniques before doing the experiment and collecting the data.

Repeat trials: These are conducted to repeat data collections for a given trial to increase the sample space. Discrepancies between results for repeat trials provide information about the extent of measurement error.

Replication: In experiments such as germination tests it is useful to set up duplicate dishes of seeds for each set of conditions. This increases the sample space. Discrepancies in results for replicates gives information about the extent of control of variables and sampling error.

Rule: A generalised statement that summarises the pattern within a set of data as a relationship between variables (e.g. the longer the pendulum the slower the swing).

Discrete variables and data: Where data for a given variable is collected in categories eg hot and cold, tall and short, high and low, heavy and light.

Continuous variables and data: Where data for a given variable are collected using a continuous scale of measurement eg 10, 20, 30, 40 and 50 degrees Celsius; 10, 20, 30, 40 and 50 grams; 0, 30, 60, 90, 120, 150 and 180 seconds.

Mark W Hackling
Edith Cowan University

Investigation planner: Stages 2 and 3

Name: _____ Date: _____

Other members of your team: _____

Question for investigation		What do you think will happen? Explain why.
What things (variables) are you going to:		
Change	Measure/observe	Keep the same
How will you make it a fair test?		Draw the equipment you will use and show how it will be set up.
Write and draw about your observations in your science journal (and record your results in a table).		

Presenting results

Can you show your results in a graph?									

Explaining results

When you changed what happened to the?	
Why did this happen?	Did the results match your prediction? If not what was different?

Evaluating the investigation

What problems did you have in doing this investigation?	How could you improve this investigation (fairness, accuracy)?
---	--

Planning and Report Worksheet for Science Investigations

Student name _____

Other members of your group _____

Phase one: Planning

What is the problem you are investigating?

What do you know about this topic from personal experience and from science?

What variables may affect the phenomenon you are investigating?

Which of the variables are you going to investigate as your independent variable (this is the variable you will change to see what effect it has on the dependent variable)?

How will the independent variable be changed in the experiment?

What is the dependent variable (i.e. the variable that responds to changes in the independent variable)?

How will you measure the dependent variable?

What question are you investigating?

OR

What hypothesis are you testing? State your hypothesis as a relationship between the independent and dependent variables.

Predict what you think will happen. Explain why.

What variables are to be controlled (kept constant) to make it a fair test?

Describe your experimental set-up using a labelled diagram and explain how you will collect your data.

Are there any special safety precautions?

Phase two: Experimenting

Carry out some preliminary trials. Were there any problems?

How did you modify your experiment to fix the problems?

Collect and record the data you need to test your hypothesis. Draw your data table here.

Title of table:

How did you make sure your data were accurate?

Phase three: Data analysis

What is the best way to present your data? Is it appropriate to draw a graph? What type of graph is most suitable?

- Remember to plot the independent variable on the horizontal axis.
- Remember that the title of the graph should mention both the independent and dependent variables.

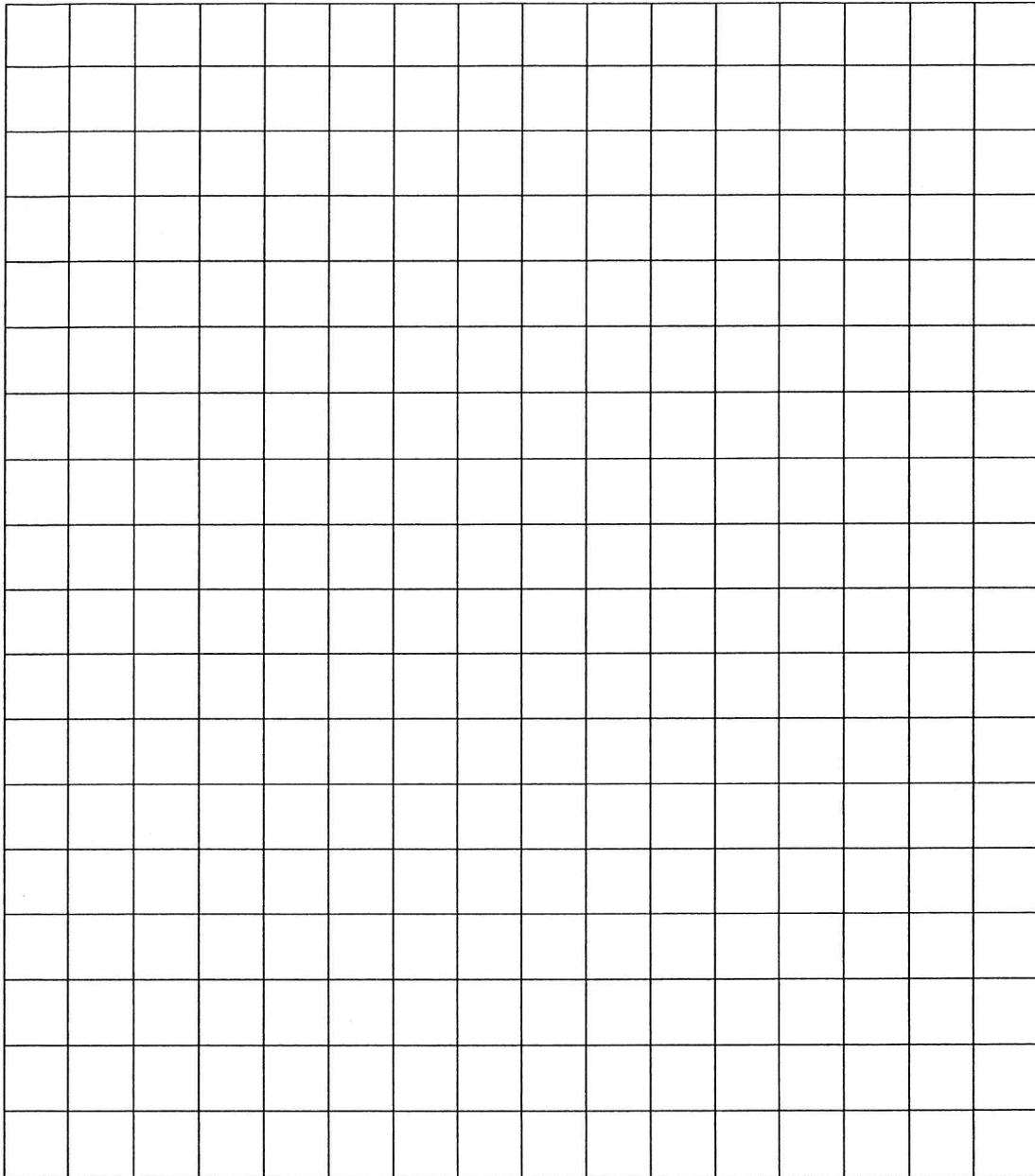
Use the graph paper on the next page.

Analyse your data. Are there any patterns or trends in your data? What is the relationship between the variables you have investigated? Is the hypothesis supported by the data?

Using science concepts explain the patterns, trends or relationships you have identified in your data. What is your conclusion?

Draw your graph on this page.

Title:



Phase four: Evaluation

What were the main sources of experimental error (sample size and selection, measurement error, poor control of variables)?

How confident are you with your conclusions? How much uncertainty/error is associated with your data?

How could the design of the experiment have been improved to reduce error?

What have you learned about the topic of your investigation? Was the outcome different from your prediction? Explain.

What have you learned about the methods of investigating in science?

Session 5 Investigating

Design and conduct an investigation to explore the bounce height of different balls on different surfaces

Four groups

Per group

Tape measure, stop watch, at least four different balls, (eg table tennis ball, golf ball, softball, soccer ball, basketball), at least four available surfaces (eg concrete, lino, carpet, grass)

Design and conduct an investigation to explore the effect of exercise on heart rate

Four groups

Per group

Stop watch, stethoscope, skipping rope

INTRODUCTION

The purpose of this chapter is to provide some simple and practical advice on how to improve the quality of teaching, which will result in better learning by your students. To understand the evolving development of teaching strategies you need to appreciate the influence of two significant forces that have emerged in recent years.

The first issue you need to consider is why science is taught in our schools. In previous years the prevailing view was that school science was necessary for the initial preparation of scientists or science-related positions. Notwithstanding the importance of this consideration, today we generally believe that the purpose of teaching science in our schools is to promote scientific literacy. In simple terms, scientific literacy refers to the extent to which people are able to use science in their daily lives. This shift in focus has had a profound impact on what we teach and how we teach.

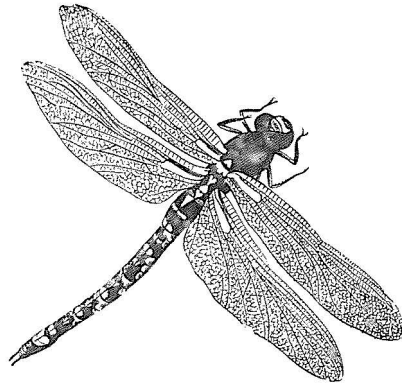
The second major influence on teaching approaches revolves around our understanding of how people learn science. Chapters 2 and 3 have explained in detail the current ideas on learning and the factors that affect learning. While there is much we still do not know about learning, the research of the past fifty years has shown the limitations of previous teaching practices. Our present views on learning provide some valuable insights into the types of teaching strategies we need to employ to provide opportunities that will result in more meaningful learning by students.

SCIENTIFIC LITERACY

There is widespread agreement within the education and broader community that the purpose of science education is to develop scientific literacy. The authors of the national review of Australian science teaching and learning (Goodrum *et al.*, 2001) have defined the attributes of a scientifically literate person as shown in Figure 4.1 (p. 56). These attributes inform the type of learning we expect from the compulsory years of schooling. For this learning it is important for a teacher to be able to relate learning to a real-world context that is meaningful for the student. Obviously students who seek occupations in science-related fields would pursue their interest in

CHAPTER FOUR TEACHING STRATEGIES FOR SCIENCE CLASSROOMS

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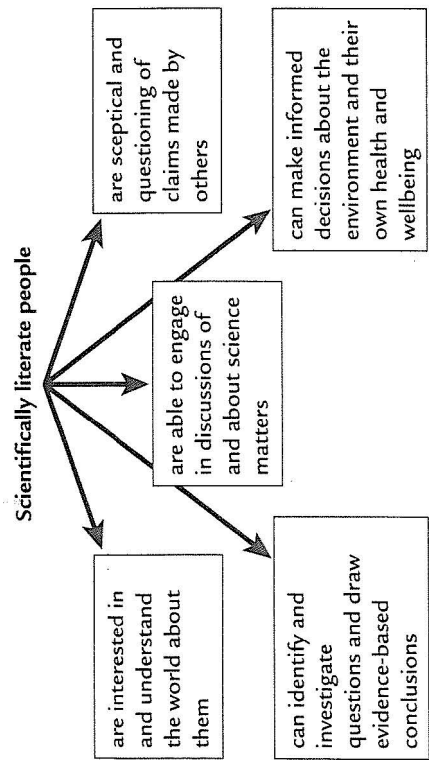


OUTCOMES

By the end of this chapter you will be able to:

- Understand the issues of scientific literacy and student learning theory and their impact on teaching strategies
- Understand how to develop a student-centred approach to teaching
- Understand the different student-centred models of teaching
- Understand how to structure lessons for meaningful learning
- Understand how to organise teams and develop specific strategies for meaningful learning

FIGURE 4.1: Attributes of scientifically literate people



post-compulsory studies. Students, however, have the right to a science education that enables them to feel confident and able to deal with the scientific issues that impact on their lives.

If you believe in a science education that promotes the development of scientific literacy then there are some expectations about the way the science is taught. Snapshot 4.1 attempts to outline some of the changes required to teaching when there is a commitment to teach for scientific literacy. In examining this snapshot, it would be wrong to suggest that one column contains only good teaching approaches and the other only poor approaches; rather, it is a question of emphasis. There is a need to do more of one and less of another, if you are to teach for scientific literacy. For example, there should be less emphasis on memorising the names of scientific terms and more emphasis on learning broad concepts that can be applied to new situations. But there will still be some scientific terms that are useful for a student to know and apply.

HOW DO STUDENTS LEARN?

Our understanding of how students learn affects the way in which we teach. In previous years the transmission model of learning influenced teaching. In this model it was believed that the mind of a

SNAPSHOT 4.1: Teaching for scientific literacy

Teaching for scientific literacy requires:

- | | |
|---|--|
| <p>less emphasis on</p> <ul style="list-style-type: none"> • science being interesting for only some students • covering many science topics • theoretical, abstract topics • presenting science by talk, text and demonstration • asking for recitation of acquired knowledge • individuals completing routine assignments • activities that demonstrate and verify science content • memorising the name and definitions of scientific terms • learning science mainly from textbooks provided to students • assessing what is easily measured • assessing recall of scientific terms and facts • end-of-topic multiple choice tests for grading and reporting | <p>more emphasis on</p> <ul style="list-style-type: none"> • science being interesting for all students • studying a few fundamental concepts • content that is meaningful to the student's experience and interest • guiding students in active and extended student inquiry • providing opportunities for scientific discussion among students • groups working cooperatively to investigate problems or issues • open-ended activities that investigate relevant science questions • learning broader concepts that can be applied in new situations • learning science actively by seeking understanding from multiple sources of information, including books, Internet, media reports, discussion and hands-on investigations • assessing learning outcomes that are most valued • assessing understanding and its application to new situations, and skills of investigation, data analysis and communication • ongoing assessment of work and the provision of feedback that assists learning |
|---|--|

student was empty and the role of the teacher was to fill it with scientific facts and principles. Teaching was acquainted with telling. This teacher-telling or didactic approach became entrenched in our school system with a related content-based testing regime. Even today some secondary schools are still influenced by the simplicity of this approach, despite all we know about how students learn.

The prevailing view of learning, explained in previous chapters, is that people construct meaning from what they previously know and the new experiences or information they encounter. Learning is an active process in which learners make sense of their world by developing meaningful constructions between what they know and the new experiences that change what they know. Learning is therefore a continual incremental process of comparing, testing and adapting. To learn new ideas and skills takes time and varies with individuals. With a better understanding of how students learn, we can suggest some important teaching principles that have a profound impact on the way teaching occurs.

Explanation follows experience

Unfortunately some teachers explain scientific ideas to students with no context or experiential base for the students. The impact of such explanations is minimal. For a scientific explanation to be effective, a teacher must first create or tap into experiences upon which the explanation is based. Such an approach has a stronger chance of providing meaning to the student. There are many ways teachers can provide experiences or help students relate to previous experiences. The most common approach is to provide concrete activities that allow students the opportunity to inquire and investigate. For example, if a person is to develop an understanding of floating as a concept they need to have experience with objects that float and objects that sink or with sinking objects that could be made to float. Through questioning, discussion and explanation the ideas associated with floating can be developed from direct hands-on experiences of the student.

Recognising prior experience

As we now know, all students come to any learning situation with some preconceived ideas. These ideas and experiences have an impact on

how and what students learn. A teacher needs not only to appreciate what ideas are held by students but to know how to build on this understanding.

There are a number of simple strategies a teacher can use to identify the ideas or experiences students have. One approach, at the beginning of a new topic, is to ask students to write a sentence or two (or draw a picture) to describe their initial understanding of the new concept. For example, in introducing a unit on energy students could be asked to write a simple sentence containing the word energy and then answer the question 'what is energy?'. Another approach is to pose a problem perhaps using a picture as a stimulus. Students could as a class or in small groups discuss possible solutions. For example, Allan said he got his energy from sleeping but John said he got his energy from food. Who is right?

As a general principle a teacher should always allow time to revise the previous lesson before starting a new lesson.

Student involvement

Students need to be interested and engaged if they are to learn. Good teachers continually attempt to spark curiosity by relating learning to current events or personal experiences. For example, a recent television show might provide the basis for raising an issue related to the given topic. Creative teachers are effective in using popular activities and events to illustrate teaching ideas.

Hands-on activities enhance student understanding. For example, to understand the ideas of electrical current or voltage teachers need to provide opportunities for students to play with batteries (dry cells) and light bulbs. The more personal the concrete involvement, the greater the potential for learning.

Student discussion

In previous years it was believed, by some, that the quietness of a teacher's class was a measure of teaching quality. Today we realise that quietness is not necessarily correlated with learning. This does not diminish the importance of classroom management skills but the significance of student discussion in facilitating learning is much more appreciated.

As students attempt to construct meaning and understanding they need to test and verify their thoughts by discussing them with their peers and their teacher. By chatting about their ideas in small groups or as a class, students can refine and adjust the conceptual pictures they create in their minds. Ideas need to be related to evidence and views need to be justified.

This does not mean teacher explanation is not important. It is, but it needs to be used judiciously for maximum impact. In an effective classroom, there is a balance between teacher explanation and student discussion.

The other important skill a teacher needs to develop is the skill of summarising the ideas generated from student discussion in a coherent manner. A whiteboard summary of these ideas is a good way to provide worthwhile notes for students. In developing this summary a teacher can challenge and refine possible alternative conceptions or inaccurate information.

Developing conceptual understanding

Intellectual rigour is an important issue in learning. Many science educators believe rigour is measured not by the amount of scientific facts that are memorised but by the depth of conceptual understanding. There is a difference between learning for memorisation and learning for understanding. If you understand a concept you can apply this understanding to a new situation. Many present-day curriculum documents outline learning outcomes in terms of developing levels of conceptual understanding rather than lists of science content to be covered.

Teaching for conceptual understanding is more challenging than the traditional view of teaching facts and principles. Despite the challenges, most teachers try to pursue the goal of more effective learning for their students.

While one can simplistically classify learning into two categories, learning for memorisation and learning for understanding, the fact is that there are many shades of grey between these two ideas. Learning for understanding will entail being able to remember some factual information relevant to the particular concept. It is a question of emphasis as explained earlier.

Questions and questioning

In traditional lessons the driving force of teaching is teacher explanation. In inquiry teaching the main engine for facilitating learning is the use of questions and discussion. Teachers need to develop an effective questioning technique to be successful.

To improve your questioning technique, use the following simple but powerful skills.

- *Ask a balance of broad and focused questions.* Broad questions like 'What do you observe about this flower?' and 'Why are the parts of a flower arranged as they are?' stimulate thinking among students. In traditional classes narrow or closed questions usually dominate and these are mainly used to challenge students to recall information. There are occasions, in a discussion, when there is value for the teacher to focus student thinking with a narrow question. Unfortunately many teachers only ask narrow questions. In inquiry lessons it is better to have a balance of questions that range between broad and narrow.
- *Allow for sufficient wait time.* Wait time is the time you, as a teacher, are willing to wait for students to answer a question. Research strongly indicates that if you allow three seconds or so students will learn better. This time provides the opportunity for student reflection and comparison. If a student answers quickly you should allow another three seconds. Hence students will be able to think further about the question. Remember you, the teacher, controls the wait time not the students.
- *Use 'evaluation-free' responses.* To develop a better inquiry atmosphere in a class it has been suggested that it is better to avoid comments like 'good boy', 'great answer' and 'well done'. Rather, responses are accepted or rejected on available evidence. By using an 'evaluation-free' style of responding to students a more normal discussion results. This approach encourages independent thought and inhibits the common classroom game called 'guessing what the teacher thinks'. In this game praise is bestowed on students who are successful in reading the teacher's mind rather than thinking for themselves.
- *Listen.* A good teacher is a good listener. By listening to a student response you attempt to understand the thinking behind the answer and as a result can ask more thoughtful and effective follow-up questions.

TEACHING MODELS

To help translate the ideas about learning into classroom action, various authors have devised teaching/learning models that suggest how teachers can effectively organise their science lessons. These models tend to emphasise aspects of the previously described principles. While there is a similarity about the models, the differences reflect the varying degrees of emphasis of the principles. The following three models have had an impact in Australia. Normally these models are applied to a science unit but can also be utilised within a lesson or for a series of lessons.

The 5E model

The 5E model is a simple model that is used in the primary science curriculum resource *Primary Investigations* (Australian Academy of Science, 1994) and is embedded in some secondary science programs. It consists of five distinct but interconnected phases.

- 1. Engage**
The interests of students are captured through a stimulating activity or question. Students have the opportunity to express what they know about the unit topic or concept so that they can make connections between what they know and the new ideas being introduced.
- 2. Explore**
Students explore problems or phenomena through hands-on activities, using their own language to discuss ideas. This exploration provides a common set of experiences which allow the new ideas to make sense.
- 3. Explain**
After the engage and explore experiences, explanations and scientific terms are provided to students to help them develop their ideas.
- 4. Elaborate**
Students apply what they have learnt to new situations. They have discussions using the newly acquired language to clarify their understanding.
- 5. Evaluate**
Students evaluate what they have learnt and learning is assessed.

The generative learning model

This model was developed by Roger Osborne and Peter Freyberg (1985). It proposes three distinct teaching phases.

- 1. Focus**
The teacher establishes a context by which the new concept can be explored. This context provides some motivation and interest for students. Within this phase the ideas of the student are clarified.
- 2. Challenge**
The ideas of the students are challenged and compared with the evidence from the scientist's view.
- 3. Application**
The new ideas are applied to new situations and problems through student discussion and analysis.

The interactive model

The interactive model revolves around the questions of students. The following description of the approach has been developed by Faire and Cosgrove (1988). It has been suggested that the teacher needs to be experienced to implement this model successfully.

- 1. Preparation**
The teacher and class select an agreed topic and seek background information.
- 2. Before views**
Students explain what they know about the topic prompted by the teacher.
- 3. Exploratory activities**
These activities provide the basis for further questions and stimulation.
- 4. Student questions**
This is the opportunity for students to ask formal questions about the topic.
- 5. Investigations**
From students' questions investigations are identified, selected and carried out.
- 6. After views**
Students complete individual or group statements about the topic. These are compared with 'before views'.
- 7. Reflections**
During this time students reflect on what has been verified and what still needs to be determined.

Structuring an activity lesson

One of the major ideas intrinsic to this chapter is that students learn more effectively from activity and experience rather than from listening to teacher explanation. These activities may involve hands-on inquiry, discussions and information research. Some teachers believe that in moving from teacher-centred to student-centred learning, the teacher has less of a role to play in the student activity. The opposite is true. The teacher in student-centred learning needs to help to structure situations by which students can learn more effectively through questions and relevant comments.

All activities proceed through three simple phases:

1. Introduction
2. Activity
3. Conclusion

Within any lesson this sequence may be repeated more than once.

1. Introduce the task or activity (brief)
 - Capture the interest of students by:
 - relating to personal experiences;
 - asking provocative questions;
 - relating to previous lesson;
 - giving engaging demonstration;
 - relating to TV, film, recent event.
 - Outline activity explaining any necessary advanced organisation.
 - Explain equipment arrangements.
 - Outline time and outcome expectations.
2. Student activity (main time allocation)
 - Assist groups or individuals with materials and their activity.
 - Discuss ideas with groups and individuals, challenging them to think more deeply about what they are doing.
3. Conclude activity with discussion (adequate time needs to be allowed)
 - Students share results of activity.
 - Through questioning help students summarise the main ideas.

COOPERATIVE LEARNING AND GROUP WORK

Working in a group or team enables students to share their experiences and to consider different points of view and solutions to a problem. Cooperative learning is an approach that encourages students to work together to help them learn better. Teams develop the social skills of sharing leadership, communicating, building trust and managing conflict. These skills take time to develop but the longer-term benefits are worth the effort.

The benefits of cooperative learning include:

- *More effective learning.* Students learn more effectively when they work cooperatively than when they work individually or competitively. They have a better attitude towards their schoolwork.
- *Improved self-confidence.* All students tend to be more successful when working in groups and this builds their self-confidence.
- *Better class management.* When students work in cooperative groups they take more responsibility for managing the equipment and their behaviour.
- *Teaching students how to work cooperatively.* Even though in most classes there is a balance between individual, team and class activity, students still need to work together regularly to develop effective team learning skills.

STRUCTURING COOPERATIVE LEARNING

Use the following ideas in planning cooperative learning with your class.

- Assign students to teams rather than allowing them to choose partners.
- Vary the composition of each team. Give students opportunities to work with others who might be of different ability level, sex or cultural background.
- Allow sufficient time for each team to learn to work together successfully.
- If the number of students in your class cannot be divided into teams of equal numbers, form groups of smaller rather than larger sizes. It is more difficult for students to work together effectively in larger groups.

- Some research suggests that for lower secondary students a group size of four with a gender balance provides a better basis for cooperative learning (Johnson & Johnson, 1994).
- Consider the use of specific team jobs to help students work together in a team.

Team jobs

For classes, even lower secondary classes, that have limited experience in working in groups there is value in considering the use of specific team jobs. Students are assigned jobs within their team. While each team member has a specific job they are accountable for the performance of the team and should be able to explain the team results and how they were obtained. It is important to rotate team jobs each time a team works together, to give all students an opportunity to perform different roles. It has been suggested that colour coding could be used to distinguish team jobs (e.g. coloured wool bracelets).

The possible team jobs are:

- *Manager (red)*. The manager is responsible for collecting and returning the team's equipment. The manager also tells the teacher if any equipment is damaged or broken. All team members are responsible for cleaning up after an activity and getting the equipment ready to return.
- *Speaker (blue)*. The speaker is responsible for asking the teacher or another team's speakers for help. If the team cannot decide how to follow a procedure, the speaker is the only person who may seek help. The speaker shares any information obtained with team members. The teacher may speak with all team members not just the speaker. The speaker is not the only person who reports to the class; each team member should be able to report on the team's results.
- *Director (green)*. The director is responsible for making sure that the team understands the team activity and helps team members to focus on each step to be completed. When the team has finished, the director helps team members to check that they have completed all aspects of the activity successfully. The director provides guidance but is not the team leader.
- *Reports coordinator (yellow)*. The reports coordinator is responsible for ensuring team members have completed all necessary reports,

data collections and relevant worksheets. The coordinator is not necessarily the team reporter or recorder. All team members can be called upon to report on behalf of the team. The coordinator ensures each member of the team has the necessary information so that they can report if required to the class.

Team skills

In addition to team roles that help teachers manage the work of small groups, it is important to help students develop skills that make teams more cohesive and improves the learning. Teachers need to assess their students' team skills and focus on each skill that would enhance their work. The choice of skills will depend on the skill level of the particular class. Teachers need to name the skill they wish to develop, explain to the class what is expected and how the skill will enhance students' group work and learning. In addition to this teachers need to give regular feedback on students' use of the selected skills. It is better to focus on one skill at a time.

Skills that improve group management

- Move into your groups quickly and quietly.
- Speak softly so only your team mates can hear you.
- Stay with your group.

Skills that help groups function as a team

- Use your team mates' names.
- Look at the person speaking to you.
- Listen to others without interrupting.
- Praise others.
- Treat others politely.

Skills that enhance learning

- Contribute ideas to the discussion.
- Encourage others to participate.
- Question the ideas of others, but disagree with the idea not the person.
- Modify your ideas when provided with new information.

Specific teaching strategies

Concept mapping

Concept maps allow students to represent diagrammatically what they know about the links and relationships between concepts. They allow students to access prior knowledge and provide teachers with feedback on what is known or unknown and/or what is misunderstood either at a single point or over time. Concept maps are designed to increase the student's ability to organise and represent thoughts and help with reading comprehension.

How it works. When concept maps are first introduced, model their use at the whole-class level. Brainstorm ideas as a class and ask students to assist jointly in grouping the words generated. Explain that each concept can be used only once. Link relationships with arrows or lines and talk aloud to model the cognitive processes involved. Ask students to assist in identifying and labelling the relationships between concepts.

Example. When introducing the topic of energy write the word 'energy' on the whiteboard with a box around it then ask, 'What other ideas are related to energy?'. Write these words on the whiteboard with each word in a box and a line connecting each word box. You may, for example, have the following words connected: energy-burning-wood-tree-plant-sun. The resulting diagram will look like an asymmetrical spider web with the word 'energy' at the centre of the web. Students who have experience with concept mapping could be asked to prepare a personal concept map of energy at the start of the unit. Then ask them to repeat the exercise at the end of the unit. Students could compare their before and after ideas as outlined in the interactive model described earlier in the chapter.

Brainstorming

The purpose of brainstorming is to generate ideas quickly—it is a creative, problem-solving strategy.

How it works. Quantity is more important than quality; all ideas are accepted and not criticised. Hitchhiking (building from each others' ideas) is encouraged. Write exactly what is said—no paraphrasing.

Example. At the start of any investigation there is value in reflecting on the factors or variables that could impact on the investigation.

Brainstorming could be used to do this. Write these ideas on the whiteboard as students call them out. Remember you should not assess the worth of any suggestion until you have written up all suggestions.

Envoy

This strategy encourages students to learn from each other and take responsibility for learning. It helps students to develop listening and oral skills and promotes skills in synthesising and summarising.

How it works. Students are formed into groups and are given a topic to discuss. One student from each group is selected to be the 'envoy'. When the group has completed its discussion of the topic the envoy reports to another group and outlines what was discussed. The envoy also listens to a report from the group they are visiting. The envoy then returns to their original group, which has also received a report from another group's envoy, and they exchange new ideas. Each group should now have input from two other groups.

Example. Divide the class into groups of, say, four students and ask them to develop an explanation for why there are no longer dinosaurs. After 15 minutes of discussion ask each group to select a person who will go to another group and describe the group's explanation. Use a circular approach for sending an envoy to the next group. In this way no group will miss out. The envoy will return to their original group with reactions to the explanation.

Gallery walk

Student or group work is placed around the room and students are given the opportunity to view other students' work and to 'show off' their own.

How it works. Student work is placed around the room and students are given time to circulate and view the display. Students can use the opportunity to read information prepared by others or consider the way the information is presented. They can collect information from the work of others or peer assess using a prepared set of guidelines.

Example. Divide students into groups of three and ask them to design a device for using the sun to heat 200 mL of water. The students could draw their device on a large piece of paper. The drawings are then placed on tables and the class moves around examining the designs.

Jigsaw

This strategy provides a structure for group work and also allows students to cover a broad amount of information in a shorter period of time.

How it works. Students are formed into 'home' groups of about five or six. The topic is divided up into sections and each student in the home group is given a different aspect of the topic to research. The home groups split up and the students form into 'expert' groups such that all members in one group are researching the same aspect of the topic. Students research their aspect of the topic in the expert groups and prepare to report to their home group. Students return to their home group and take turns to report as the expert on their aspect of the topic.

Example. The class is divided into teams of five students who are asked to investigate types of energy. Each member of the team is assigned a type of energy to examine. Within the room there have been established energy centres on particular energy types like 'chemical energy' or 'solar energy'. After each student has received their energy type they go to the particular energy centre and find out as much as possible about that type by reading the available material and/or by chatting with the students at that centre. The students then return to their original team and each member makes a presentation to their team on their chosen topic. They could also prepare a short handout for each member of the team.

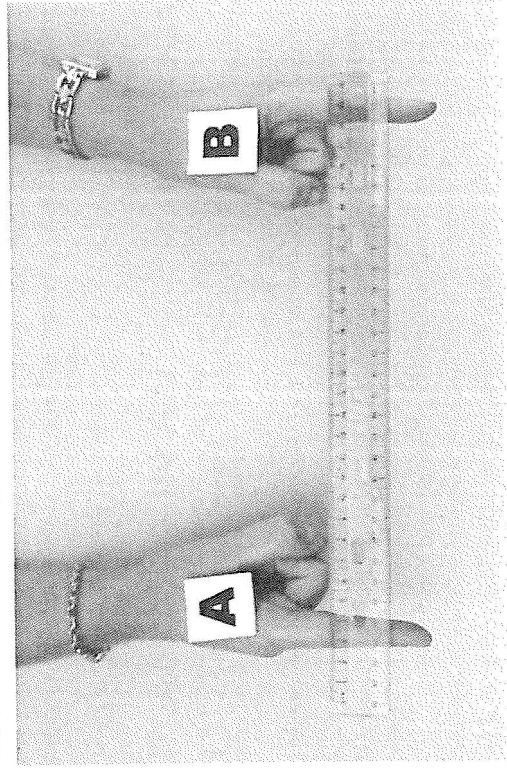
Predict—Observe—Explain (POE)

This strategy encourages students to think more carefully and critically about scientific phenomena by challenging them to examine events that surprise them.

How it works. Students are given a situation and asked to predict what happens when something is done to change that situation. As the change is implemented the students make careful observations about what happens. By comparing their observations with their predictions they are encouraged to develop explanations of what is happening.

Example. The teacher sets up a demonstration in front of the class as in Figure 4.2. A ruler is balanced between the fingers of a person's two hands. Students are asked to predict what will happen when one

FIGURE 4.2: A ruler being balanced on the fingers of two hands



hand (hand B) is moved towards the other hand which stays still (hand A). After students have discussed the various possibilities ask them to write down their personal prediction. Most students will suggest the ruler will fall on the left or right side of hand that does not move (hand A). In front of the class carry out the activity and ask students to observe closely. Discuss their observations. The ruler will move then stop then move again but will not fall. Ask the students to explain what is happening. Why does it sometimes move? Why does it sometimes not move? The explanation will introduce the ideas of friction and slipping and the factors that affect these ideas.

SUMMARY

This chapter begins with two questions that have a profound impact on teaching. Why do we teach science? How do we learn science effectively? These questions lead to the ideas of scientific literacy and constructivist learning. From these ideas a series of teaching principles are implied and described. These principles are embedded in various models that are examined. Using the principles a suggested



approach to planning lessons is outlined. This chapter also provides advice on how to develop cooperative learning using a team approach and concludes with a variety of specific strategies with relevant examples.

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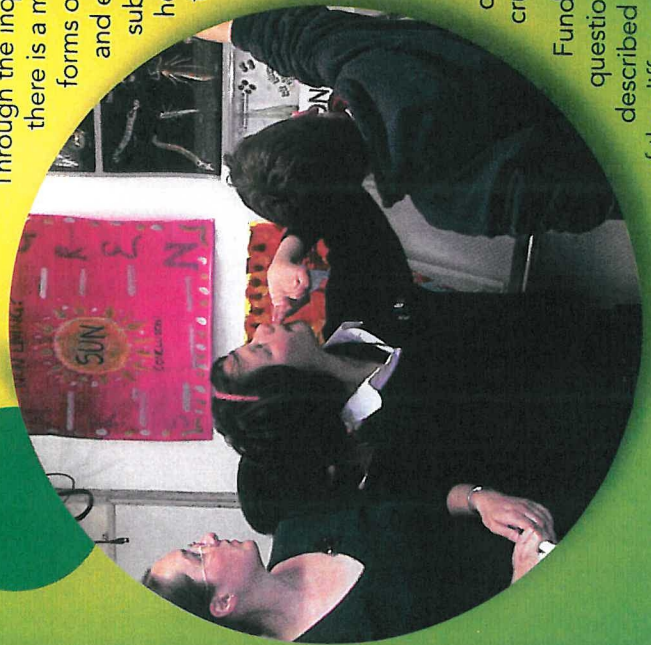
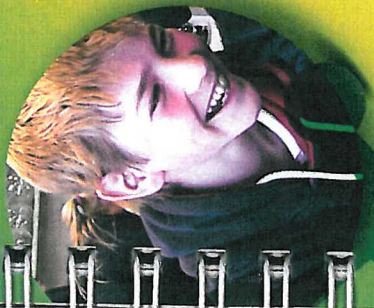
Questioning

Why is questioning so important when it comes to inquiry-based teaching?

The interaction between the teacher and students is a very important feature of any classroom, but takes on a special significance in an inquiry-based setting. In such a context current student knowledge provides the basis on which new learning and ideas are built. Effective questioning, therefore, becomes the tool by which teachers come to understand where student thinking is at any point in the learning journey.

Through the inquiry-based approach there is a move away from traditional forms of teaching, such as telling and explaining, to more subtle strategies which help students construct their own meaning of ideas. The ideal pattern of interaction is one where teachers are the agents and facilitators of thinking, rather than inquisitors in control of all knowledge. Questions, and the art of questioning, become crucial.

Fundamental to using questioning in the way described here is an understanding of the differences between closed and open questions.



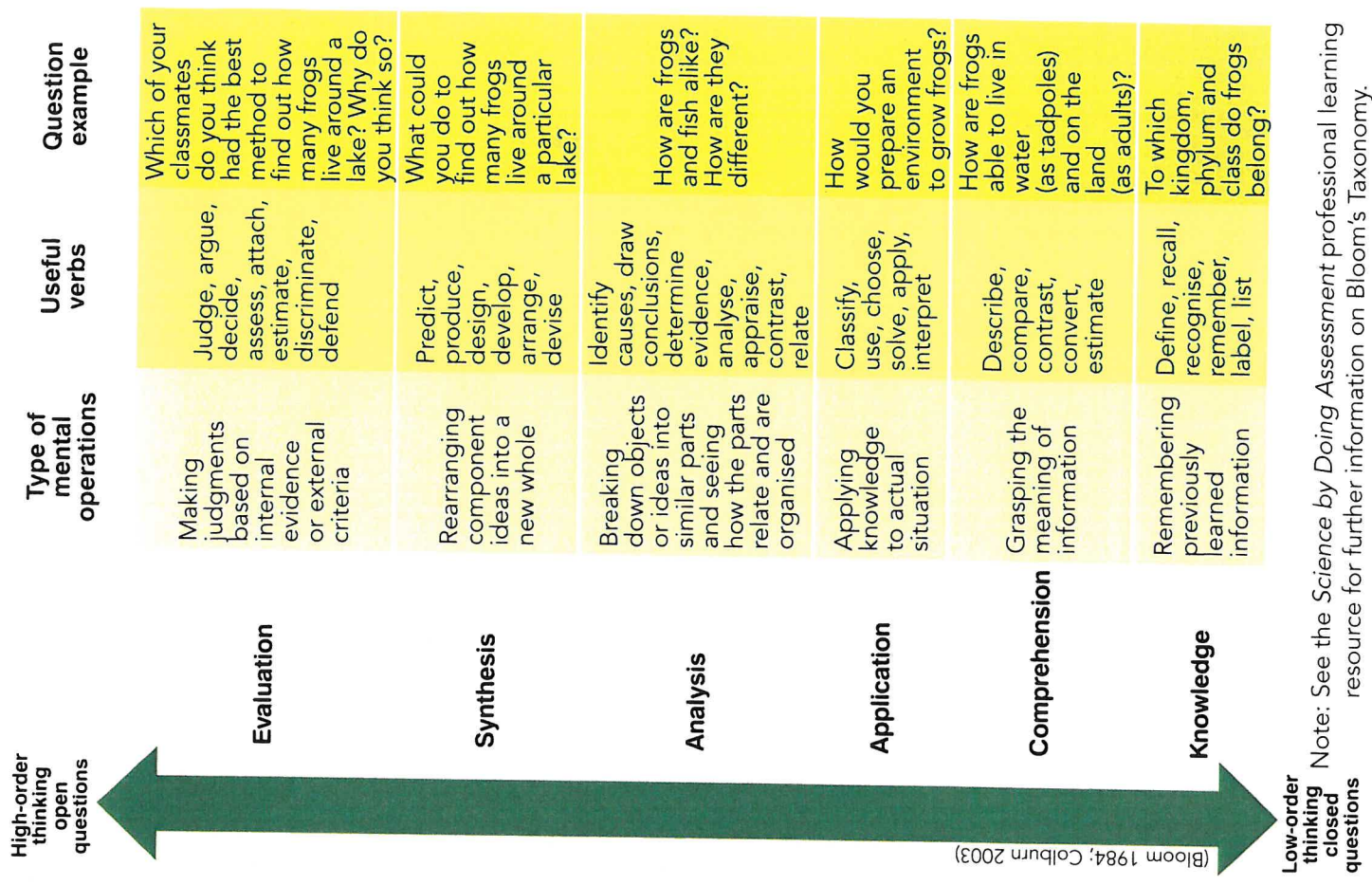
Closed questions have one clear answer and are useful when a quick check of knowledge is required.
For example:
Where are the kidneys located in the human body?

Open questions are more open-ended and allow students to give a variety of acceptable answers.
For example:
How are the kidneys structured to help them work effectively?

If we want our students to move beyond simple recall and memorisation of facts, then we need to foster the thinking skills required for reasoning, problem solving, evaluation and the formulation of hypotheses. The vehicle for doing this is through asking questions of an open nature.

What learning opportunities do open questions offer that closed questions do not?

This question is best answered by reflecting on the difference between low-order and high-order thinking. Although much reference is made to these different levels of thinking, it is useful to be reminded of the skills associated with each. Bloom's Taxonomy provides a useful framework for drawing a distinction between low- and high-order thinking.



While the act of questioning comes intuitively to most teachers, research suggests that most of the questions we ask of our students are closed (DfES 2024). That is, they only require the low-order-thinking skills of knowledge and comprehension to answer. To foster the development of higher-order thinking skills we need to ask more open questions that allow students to give a variety of possible answers. It is when students are thinking at this level that they are meaningfully drawn into the learning process, begin to take ownership of their learning, and construct their own meaning of ideas. For the teacher, listening to students' answers to open questions provides a most reliable indication of where current student thinking is at, the existence of any prevailing misconceptions, and how students are piecing together their acquired knowledge.

Science education is presented with a rather unique opportunity to enhance high-order thinking skills as the scientific method, by its very nature, requires the skills associated with analysis, synthesis and evaluation.

How can asking questions help students who are conducting an investigation?

In the inquiry context, when students are so often engaged in investigation, it is worthwhile giving consideration to the type of questions that may help them investigate more effectively. Typically, students ask numerous questions of the teacher during investigations. One of the most effective ways of responding to these questions is by posing another related, but different, question back to the student. In doing so the teacher acts to scaffold the process which enables students to answer their own questions.



The table below offers numerous questions to ask during the investigation process.

Student's target skill/need

Suggested question

Make a prediction

What would happen if...?

Make observations

What is this...?
How would you describe that...?
How does it do...?
How can you tell...?

Stay focused on the prediction/activity

How does your idea solve the challenge?
What do you need to answer the question?
What do you need to do next?

Answer his/her own questions

How can we find out the answer to that?
What do you think?
I'm not sure, but I do know that...

Learn from mistakes

What happened?
Why do you think this happened?
What did you learn when it did that?
How could you change...?

Problem solve or try another approach

Can you find a way to...?
Is there another way to look at this?
Why do you think this is happening?

Verify his/her thinking or conclusions

What led you to this idea/thinking?
How do you know this?
Where else could you check what you have discovered/found out?

Explain his/her thinking

How did you come up with this idea?
What do you want to have happen?
Tell me more about what you're thinking.

Make connections to the real world

What does this remind you of?
What are other examples of this occurring?

Share results

What did you find out?
Can you show me how this works?
How did you come up with that idea?

Assess what he/she has learned

What did you learn that you didn't know before?
If you could do this again, what would you change?

Experiment further

What other questions do you have?
What else would you like to know?

Consider and respond to implicit social or ethical issues

What would you do in response to...?
What could you do in response to...?
What actions would you take if...?

Waiting



What can happen when students are given adequate time to think?

In the late 1960s, the noted science educator Mary Budd Rowe recognised that some teachers used deliberate pauses during questioning sessions and classroom discussions. She noted that this practice had significant positive effects on student performance and so the concept of 'wait time' was developed.

It seems that when students are given adequate time to think in response to questions there is a ripple effect that leads to a more positive classroom environment, more quality teacher-student and student-student interactions, more higher-order thinking, an improvement in academic achievement and a decrease in behaviour problems (Rowe, 1996).

Wait time 1:
After the teacher
asks a question

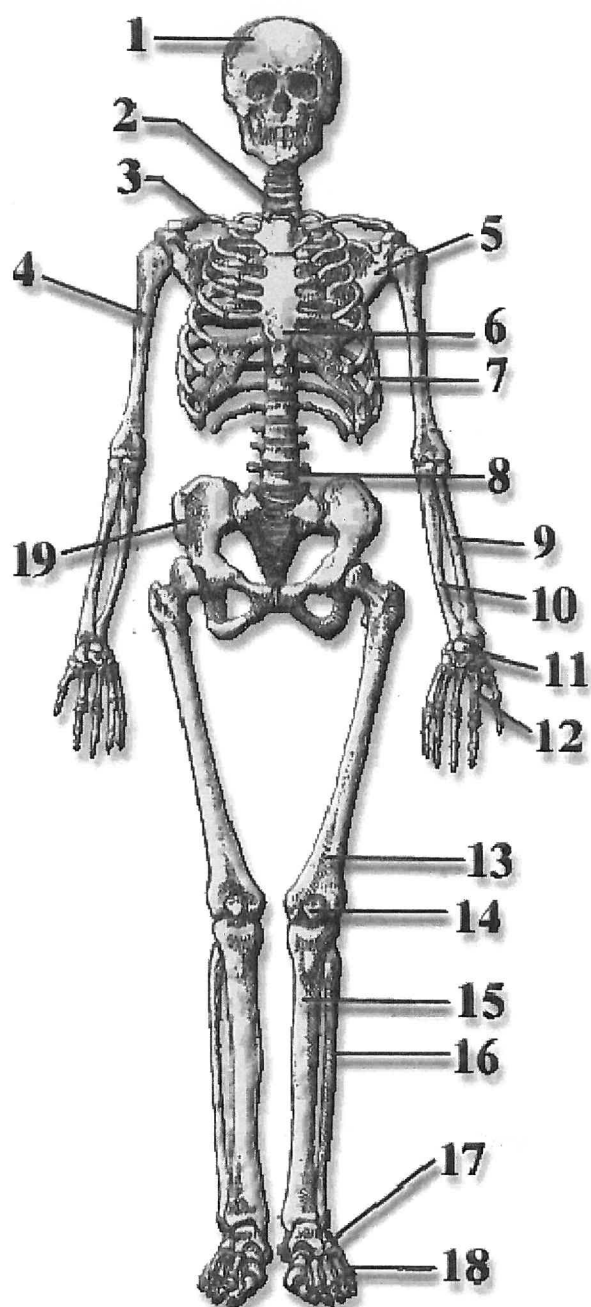
Wait time 2:
After a student
responds

The ideal length
for wait time 1 and
2 is three to five
seconds, longer is
even better!

Classroom changes with increased wait time

- 1 300-700% increase in the length of student responses
- 2 The number of unsolicited but appropriate responses increases
- 3 Failures to respond decrease
- 4 Confidence increases
- 5 Speculative responses increase
- 6 Teacher-centred show-and-tell decreases – student-to-student interaction increases
- 7 Teacher questions change in number and in kind
 - a. the number of open questions prompting higher-order thinking increases
 - b. there is more probing for clarification
- 8 Students make inferences and support these with data
- 9 Students ask more questions
- 10 Contributions by low-ability students increase
- 11 Disruptive behaviour decreases through more students being on-task
- 12 Achievement on logic tests improves

Adapted from Lipton, L. & Wellman, B. (2004) *Pathways to Understanding: patterns and practices in the learning-focused classroom*. MiraVia, Sherman CT



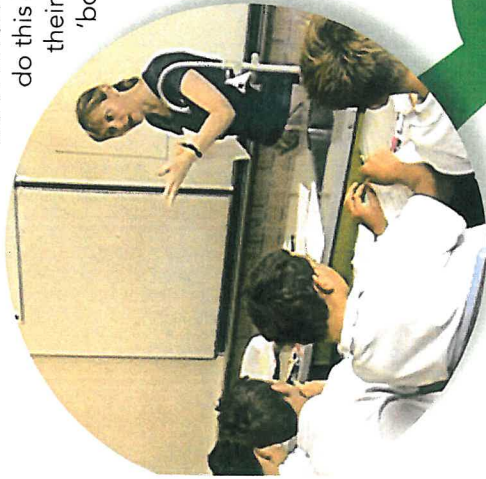
What is the role of diagnostic, formative and summative assessment?

Diagnostic assessment

Diagnostic assessment normally occurs at the start of a unit of study. In the medical field the idea of diagnosis is to examine a person so as to determine the nature of the disease or ailment that may be affecting the person. In education, diagnostic assessment is used to determine a student's understanding of a concept or topic.

If one accepts that learning is the process of constructing understanding from experience, then it is important to have a picture of the students' ideas. From science education research we have found that many students have strong and persistent ideas that have been acquired from their experiences. In some cases the act of teaching requires the teacher to confront these ideas before the student can develop a science view of the world. We often call these intuitive ideas 'misconceptions' or 'alternative conceptions'. Many of these misconceptions are based on the common language we use, for example 'cats see in the dark'.

Others are based on direct experience. For a student who observes the sun rising in the east and setting in the west it is not unreasonable to come to the conclusion that the Sun revolves around the Earth. In fact this view, which was proposed by Ptolemy, existed for hundreds of years up to the time of Galileo. If a teacher is to teach a unit on the solar system or seasons, it is important to determine to what degree students think the earth revolves around the sun. And you need to do this in a way that genuinely identifies their real understanding, not their 'book' understanding.



One of the difficulties of diagnostic assessment is that students will sometimes tell you what they think you want to know rather than what they really think. For this reason, diagnostic assessment should not be presented in the traditional, formal assessment manner. In fact, it should be unobtrusive, brief and even fun. It also should not have numbers associated with it. To give a diagnostic test, mark it and then tell a student they achieved 6/10 from the test defeats the purpose of the assessment.

Diagnostic assessment is mainly for the teacher, not necessarily for the student. It is to inform the teacher what students understand so the teaching sequence can be planned to meet their needs and help students develop a rich understanding. In the case of the earth/sun relationship, for a teacher to simply tell students that the earth revolves around the sun does not necessarily change their thinking. When Galileo actually gave the church that information there was strong resistance to the idea. A teacher, like Galileo, needs to provide the evidence by which students can deconstruct their understanding.

Formative assessment

It was suggested that diagnostic assessment is mainly for the teacher. The reverse is the case for formative assessment. Formative assessment is primarily for the student. It is essentially the mechanism by which feedback is provided so as to inform and help the student learn. The idea behind formative assessment is that feedback will assist in the changes and construction of the student's final deep understanding. The term attempts to capture the sense that this assessment will provide information for the student's evolving concepts.

There is sufficient evidence that the more feedback a student receives the better the student will learn. While sometimes detailed feedback is important, students benefit from brief but continuous feedback.

While the emphasis of formative assessment is on the student, it is obvious that such information will also help the teacher adjust his/her teaching to what students need.

There is a simple axiom which is very true for students: "nothing succeeds like success". The phrase suggests that success breeds success. The true value of formative assessment is that learning can be broken down to small steps with an assessment dimension. Formative assessment helps the students move from one step to the next in a positive and successful manner.



Summative assessment

Summative assessment usually occurs at the end of a unit of study. Essentially, it is a summary of what and how well the student has learnt. The information from summative assessment is often converted into a grade measurement and this grade reported to parents and students.

Commonly, summative assessment is associated with end-of-unit pencil and paper tests. This does need not necessarily have to be the case. In the following pages there is a range of assessment techniques outlined. Some of these techniques lend themselves to summative assessment.

Perhaps the most used summative assessment technique in science is the multiple-choice item test. The attractiveness of this approach is that it is easy to administer and mark. Multiple-choice items are particularly useful for low level thinking activities like knowledge recall and definition of terms. They can be used for higher order thinking but require much effort in their preparation. Even despite this preparation the correct answer can be open to individual interpretation. One useful technique is to provide an opportunity for students to explain the reason for their answer selection.

There are a few important principles to consider when developing summative assessment. These principles also apply to the other forms of assessment.

1. One principle is the importance of quality. It is more important to have fewer quality assessment items that effectively determine and measure what the student understands rather than many items that are similar with a tendency to only measure a student's memory. In this case less can indeed measure more.
2. Another important principle is that of variety. There needs to be a variety of techniques so that you as a teacher can be confident the student has understood the science ideas. Some concepts lend themselves better to certain assessment approaches. That is why this module outlines a range of approaches.

Summary of assessment purposes				
		Diagnostic		Formative
Teacher	Student	planning	planning	reporting
			feedback	feedback

How can I help my students express their thinking?



There are many and varied approaches which provide a vehicle for students to express their thinking. Some are better suited to some phases of assessment (i.e. diagnostic, formative, and summative) than others. A few examples are presented here.

Interviews

Diagnostic Formative Summative



What: Teacher 'interviews' students on a particular concept or topic during an informal conversation.

How: Students usually work in small groups with the teacher circulating the room and interacting with each group. Student conversation is focused on a prompt such as a picture, graph, diagram, table of data, etc. Teacher uses effective questioning, for example, probing, paraphrasing and prompting to draw out, clarify and refine students' ideas.

Purpose: Interviews are best used to identify preconceived ideas or persistent misconceptions.

They provide a snapshot of current student thinking. This information can then be used to inform how a unit or learning sequence is progressed.



Finding out more: Refer to the *Exploring and Practising Assessment Techniques* CD-ROM.

Concept maps

Diagnostic Formative Summative



What: Concept maps allow students to represent diagrammatically what they know about the links and relationships between concepts.

How: Depending on the assessment phase, students can be provided with a set of related concepts/ideas/words, or the class could brainstorm a list, or students could work in pairs or individually to come up with a list. The list is then reorganised or rearranged by students to show the links and relationships.

Purpose: To determine how well students understand and make sense of the connections between isolated yet related concepts. Learning journeys and shifts in thinking can be mapped if concept maps are created at the beginning of a unit and built upon and amended as the unit progresses.

Finding out more: Refer to the *Modelling Assessment Techniques DVD, Exploring and Practising Assessment Techniques CD-ROM, Inquiry-based Teaching* professional learning resource.

Notebooking

Diagnostic Formative Summative



What: Science notebooks provide a record of student thinking and classroom experiences and are used much as a scientist would, before, during and after all investigations. They are a place where students formulate and record their questions, make predictions, record data, observations, illustrations, understandings, reflections and new concepts they have learned.

How: Notebooks can be electronic or hard copy. If hard copy, the notebook should be separate from the normal student workbook. Sentence starters, discussion starters and writing prompts can be used to assist students with making entries.

Purpose: Notebooks help students develop, practice and refine their science understandings. They provide a place where language, data and experience are brought together to form meaning for students. When used for diagnostic and formative assessment they provide evidence of student thinking and learning.

Finding out More: Refer to the *Student Learning* professional learning resource.

Rubrics

Diagnostic Formative Summative



What: A rubric is a feedback and assessment tool that lists the criteria for a piece of work. Unlike a checklist, there are several categories for each criterion which allows a more fine-tuned assessment to be given. Often, the categories relate to score points so that an overall grade can be awarded.

How: Using curriculum documents identify the critical knowledge and skill features of the task that will be assessed. Determine what each of these looks like at an accomplished level, and work back from that point to define gradations such as beginning and developing.

Purpose: The rubric clearly sets out for students what 'counts' in the assessment of their work. If provided to students at the outset of an assessment task it can provide direction for their efforts in completing the task. For the teacher, collated data from the application of a rubric provides an effective means of identifying whole-class strengths and weaknesses. Rubrics can also be useful to guide peer reviewing and student self assessment.

Finding out more: Refer to the *Modelling Assessment Techniques DVD, Exploring and Practising Assessment Techniques CD-ROM*, rubrics provided in the *Science by Doing* curriculum units.



Peer review

Diagnostic Formative Summative



What: Peer review involves students working in small groups, usually pairs, to act as a critical friend and review a fellow student's work.

How: Students look at one another's work and the reviewer gives feedback, including weaknesses or problems along with suggestions for improvement. This process is often most successful if students are guided by a checklist or rubric in their review.

Purpose: Peer reviewing reinforces that feedback need not only come from the teacher, and models the work of a scientist (most journals are peer reviewed). The reviewee benefits from having an opportunity to explain and answer questions about their work, and may receive suggestions about how their work may be improved. The reviewer benefits from viewing and applying assessment criteria which in turn informs the way that they look at their own work.

Self assessment

Diagnostic Formative Summative



What: Self assessment involves students standing back and making an objective assessment of the strengths and weaknesses of their work.

How: The process works best if students are provided with some guidelines when looking at their work. Checklists and rubrics are particularly useful.

Purpose: Students may use the information to identify what they need to do to improve the quality of their work (when used formatively), or may compare the information with the feedback received from the teacher (when used summatively) to identify similarities and differences in they way the work is perceived by both the teacher and student.



Portfolio

Diagnostic Formative Summative



What: A portfolio is a collection of work that demonstrates a student's skills, knowledge and/or development. It may also include, or be presented with, some type of commentary that explains how and why the evidence in the portfolios reflects the student's abilities.

How: Students compile a selection of work over an extended period of time that best demonstrates a learning journey and the abilities developed. Portfolios can be submitted for assessment or, even better, can be presented by the student in an interview context with teachers, parents, peers etc.

Purpose: Portfolios provide an effective means of assessing real or authentic tasks, such as designing and conducting experiments, project work or group work as they demonstrate growth over time.

Student Report

Diagnostic Formative Summative



What: A student (or students) prepares a written report on an investigation the student has carried out. The report outlines the question being investigated, methodology used, data gathered, analysis of data and final conclusion.

How: It takes time to develop experience in writing a science report. Initially, it is helpful if the teacher provides a template which outlines the various sections of the resource and what information belongs where.

Purpose: The student report can be used to determine aspects of the student's inquiry skills including the ability to present and analyse data.

Finding out more: Refer to the *Doing Science Investigations* curriculum unit.

How can we best plan *assessment* for a unit of work?



To support and extend the 'Plan Assessment for a Unit of Work' section of the Exploring and Practicing Assessment Techniques CD-ROM you may find it helpful to consider these 'before' and 'after' planning tools.

Before writing the unit...

Successful teaching requires teachers to design evaluation activities that provide acceptable evidence of students' learning, and to develop learning experiences that lead to success on those activities. By first considering what students are expected to learn and then determining how that can be measured, the design of strategies for teaching and learning can be tied closely to what students are expected to do to demonstrate their learning. This is referred to as 'backward design' or 'understanding by design' (*Wiggins & McTighe 2005*).

Step 1

Identify key intended learning outcomes

Step 2

Align assessment task/s with the intended learning outcomes

Step 3

Design student learning activities to provide opportunities for students to develop the full range of intended outcomes.



After writing the unit...

This check list can be used as a planning tool to take into account aspects of assessment when designing or modifying an existing unit of work.

Assessment check list for a unit of work

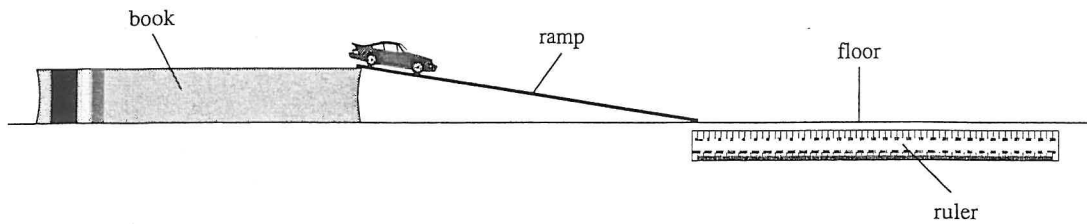


Have I considered this aspect?

- | | |
|--|--------------------------|
| Include tasks to uncover misconceptions and/or the student's current level of understanding or skill. | ☐ |
| Incorporate a number of assessment strategies (cartoon scenarios, rubric etc.) for diagnostic, formative and summative assessment. | ☐ |
| Include a variety of tasks so that the student has multiple opportunities to demonstrate understanding/skill. | ☐ |
| Include opportunities to assess both understanding of concepts and of process skills. | ☐ |
| Make assessment criteria explicit (e.g. supply a rubric before students begin task). | ☐ |
| Go beyond assessment of isolated science facts to consider higher-order thinking skills. | ☐ |
| Incorporate opportunities for frequent feedback on student work. | ☐ |
| Ensure that evidence of student learning will serve as a guide for the next appropriate step in learning. | ☐ |
| Provide students with opportunities to demonstrate the mastery of concepts and process skills by applying these to new contexts (ie demonstrate transfer of learning). | ☐ |
| Consider opportunities for student self assessment and/or peer assessment. | ☐ |
| Consider opportunities for working with colleagues to design the unit of work – including developing agreed assessment criteria to determine student progress. | ☐ |

Toy Cars

Sam rolled his toy car down a ramp like this.



Sam changed the number of books under the end of the ramp. The car travelled different distances. He measured these distances and recorded them in this table.

Number of books	Distance the car rolled (cm)
1	15
2	27
3	35

Q1. What question was Sam investigating?

Q2. Plot a graph to display Sam's results

[illegible]

Q3. What happened when Sam used more books? Explain why this happened.

Q4. How could Sam have improved his investigation?

Q5. Sam just let the car go at the top of the ramp. What forces are acting on the car and cause it to move and then stop?

Sam noticed that when the ramp was placed on the carpet or a polished wooden floor the car rolled different distances.

He measured how far the car went in each case and he wrote the numbers on a piece of paper.

31 cm
22 cm

Unfortunately he forgot to say which was which!

Q6. Write the numbers in the correct place in the table. Explain your choice on the lines below the table.

Surface	Distance the car rolled
Carpet	
Polished wooden floor	

Q7. Explain how Sam would need to conduct his investigation of the effect of floor type on distance travelled so that it would be a fair test?

Seeds

A class of Year 6 students were investigating a question about germination of seeds:

What happens to the number of seeds that germinate when the saltiness of the water is increased?

Q1. Name the two variables in this investigation.

Three groups of children placed soil in empty margarine containers, planted 20 seeds in each container, and the seeds were either watered with tap water or salty water. After two weeks, the number of seeds that had sprouted in each container was counted. Sally recorded the results on a scrap of paper.

Sally's group	tap water 15 sprouted, salty water 5 sprouted
Rob's group	tap water 17 sprouted, salty water 4 sprouted
Mary's group	tap water 13 sprouted, salty water 6 sprouted

Q2. Draw a table and display the results in the table.

Q3. Plot a graph to display these results.

[illegible]

Q4. What is your conclusion for this experiment?

Marking Scheme

Task 1: Toy cars

Q1

Score 1: What happens to the distance travelled by the car when the number of books is increased? (4 Planning)
or What effect does changing the number of books have on the distance travelled by the car? (4 Planning)

Q2

Score 3: Plots line graph, with 'Distance travelled' on vertical axis, and accurate plotting and title and axis labels (4 Processing)

Score 2: Plots line graph with either variables on wrong axes or some problems with accuracy of plotting or titles and labels

Score 1: Plots an accurate bar graph (3 Processing)

Q3.

Score 3: When he had more books it went further **because** has more (potential) energy and so it went faster by the end of the ramp and took more time to be stopped by frictional force (5 Conceptual)

Score 2: When he had more books it went further because it had more energy/started higher up (4 Conceptual)

Score 1: More books makes it go further (3 Conceptual)

Q4.

Score 2: Conducted repeat trails and calculated an average to get more reliable results (4 Conducting/ 5 Evaluating)

Score 1: Made more measurements (4 Evaluating)

Q5.

Score 2: gravity pulling down and friction slowing the car (5 Conceptual)

Score 1: gravity or friction (4 Conceptual)

Q6.

Surface	Distance the car rolled
Carpet	22cm
Polished wooden floor	31cm

Score 3: Correct placement and because the carpet has more frictional force opposing movement it stops faster and thus travels less distance (5 Conceptual)

Score 2: Correct placement and because the carpet has more friction (4 Conceptual)

Score 1: Correct placement and because the carpet stops it faster (3 Conceptual)

Q7.

Score 3: Use the same ramp, use the same car and use the same number of books for each floor type (5 Planning)

Score 2: Keeps two variables the same (4 Planning)

Score 1: Keeps one variable the same (4 Planning)

Task 2: Seeds

Q1.

Score 2: Saltiness of water; number of seeds that germinate (4 Planning)

Score 1: Names one correct variable from the question (3 Planning)

Q2.

Group	Number of seeds that sprouted	
	Tap water	Salty water
Sally	15	5
Rob	17	4
Mary	13	6
Average	15	5

Score 2: Structured table including average values (4 Processing)

Score 1: Structured table without averages (3 Processing)

Q3.

Score 2: Plots a bar graph of water type against number of seeds germinated showing only average values (4 Processing)

Score 1: Plots a bar graph showing results for each group (3 Processing)

Q4.

Score 3: On average 5 of 20 seeds germinate in salty water compared with 15 of 20 seeds in tap water. The presence of salt in water reduces the number of seeds that germinate. The salt may have a toxic affect on the seeds or may reduce the uptake of water by the seeds. (5 Processing)

Score 2: Any two of the three points above (4 processing)

Score 1: Less seeds germinated in the salty water (3 processing)

Question	Level 1	Level 2	Level 3	Level 4	Level 5
Task 1					
1				1 (I)	
2			2 (I)	3 (I)	
3			1 (C)	2 (C)	3 (C)
4				1 (I)	2 (I)
5				1 (C)	2 (C)
6			1 (C)	2 (C)	3 (C)
7				2 (I)	3 (I)
Task 2					
1			1 (I)	2 (I)	
2			1 (I)	2 (I)	
3			1 (I)	2 (I)	
4			1 (I)	2 (I)	3 (I)
Totals			8	20	16

The maximum possible score on this test is 26

Assumption: A person at a given Level would be expected to succeed on half of the items at that Level and on all items at lower levels.

Based on this:

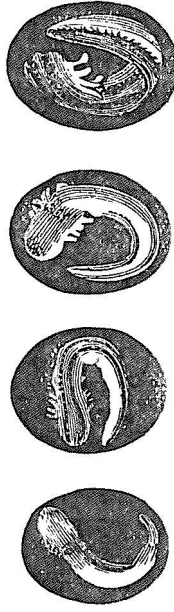
A person at Level 3 would be expected to score 4-8/26

A person at Level 4 would be expected to score 14-20/26

A person at level 5 would be expected to score 23-26/26

CHAPTER EIGHT ASSESSMENT IN SCIENCE

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OUTCOMES

By the end of this chapter you will be able to:

- Explain the relationships between teaching, learning and assessment
- Distinguish between diagnostic, formative and summative forms of assessment
- Describe the characteristics of quality assessment items and tasks

INTRODUCTION

Assessment is the process of gathering and interpreting information about the progress of students' learning. Assessment has a powerful influence over what is taught and learned in science as both teachers and students work towards assessments, especially tests at the end of topics. If assessments focus on recall of factual information teachers will rush through lots of content and students will attempt to memorise that content. This way of teaching and learning results in superficial surface-level learning. If assessments focus on applying conceptual understandings and skills to make sense of issues in the lives of students, teachers will focus on developing conceptual understandings within real-world contexts and students will attempt to learn for understanding, resulting in deeper learning.

Traditional assessment that focuses on mastery of factual information is the most powerful barrier to the reform of teaching so that it is more student centred, inquiry oriented and focused on developing scientific literacy. To reform teaching we first need to reform assessment so that it rewards teachers and students who work towards the learning outcomes that contribute to scientific literacy.

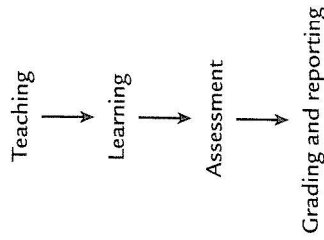
The national review of *The Status and Quality of Science Teaching and Learning in Australian Schools* (Goodrum *et al.*, 2001) noted two important concerns about current assessment practice in secondary science. First, the overemphasis on assessment of learning and the underutilisation of assessment to improve learning. Second, the widespread use of traditional testing that focuses on the extent to which students memorise and recall science facts; this focus hinders the development of meaningful understanding and the development of outcomes that contribute to scientific literacy.

This chapter will address a number of questions related to assessment. What are the relationships between teaching, learning and assessment? Why do we assess? What should be assessed? How should we assess? What are the characteristics of quality assessment items and tasks?

WHAT ARE THE RELATIONSHIPS BETWEEN TEACHING, LEARNING AND ASSESSMENT?

Those who hold views based on the behaviourist, transmission model about teaching and learning believe that the role of the teacher is the

FIGURE 8.1: A behaviourist view of the relationships between teaching, learning and assessment

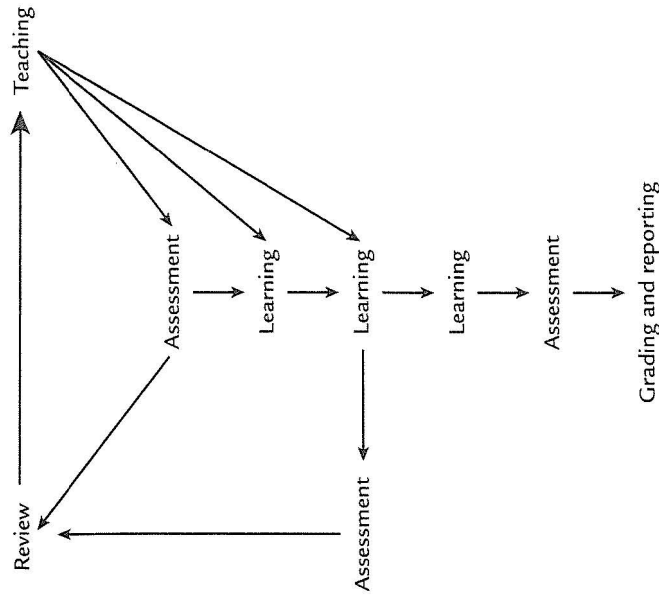


source of knowledge and that knowledge has to be transmitted to students through exposition and notes to be memorised. In this model the purpose of assessment is to ascertain the extent to which the transmitted knowledge has been remembered and this information is used to grade students and report to parents. This model is illustrated in Figure 8.1.

Contemporary constructivist learning theory (explained further in Chapters 2 and 3) helps us understand the powerful influence that existing conceptions, particularly alternative conceptions, have on students' construction of meaning and their learning from classroom activities (Osborne & Wittrock, 1983). Consequently, assessment strategies that reveal students' existing conceptions early in the instructional sequence have been included in a number of constructivist-based teaching-learning models (Cosgrove & Osborne, 1985; Driver & Oldham, 1986). Assessment before and during the instructional sequence can provide information to teachers and students that can be used to improve teaching and learning. The relationships between teaching, learning and assessment are more complex and interactive in a constructivist model compared to those in a behaviourist model.

This constructivist model shows how teaching, learning and assessment have interactive relationships (see Figure 8.2) and there are roles for assessment *for* learning in addition to assessment *of* learning.

FIGURE 8.2: A constructivist view of the relationships between teaching, learning and assessment



WHY DO WE ASSESS?

The purposes of assessment can be defined in terms of the use to which the assessment information is put (William, 2000). The four main purposes for which assessment is conducted are:

- *Evaluative*—for evaluating curricula or for accountability purposes, for example benchmarking the performance of teachers, schools or systems against each other or against defined standards of performance.
- *Summative*—for determining the extent to which students have achieved learning outcomes and/or for certifying achievement and/or for selecting those students who will progress to the next level of education.

- *Formative*—for providing feedback to teachers and learners so that teaching and learning are improved.
- *Diagnostic*—to identify students' prior knowledge and alternative conceptions, so that instruction can be planned to build on existing knowledge and to address students' alternative conceptions.

Of these four roles for assessment, classroom teachers are only directly involved in diagnostic, formative and summative assessment.

Diagnostic assessment

Diagnostic assessment is conducted at the beginning of a module or the beginning of a lesson. It is used to determine students' existing knowledge about the topic to be taught, and to identify students' alternative frameworks so that lessons can be planned to build on the prior knowledge and to challenge the alternative conceptions.

Good diagnostic assessment involves the use of probing, open questions that elicit students' understandings of the topic or concept of interest. In its simplest and most common form, teachers open their lessons with a number of open questions to generate a whole-class discussion that reveals students' existing ideas and beliefs. Once the teacher has ascertained students' existing ideas the teacher leads the class into an exploration of the new concepts, taking an approach that fits with students' existing level of knowledge.

A number of researchers have developed diagnostic assessment items that have been designed to elicit common misconceptions. Robin Millar and Vicky Hames (2003) have developed a set of items for a range of physical science topics that can be downloaded from the Internet. Brenda Keogh and Stuart Naylor (2001) have developed a series of concept cartoons that use a cartoon to set a context and pose a question about a natural phenomenon and three or four children give their explanation about what is happening in the cartoon. Some of the views expressed provide alternative conceptions while others a scientific explanation. The cartoons are used to stimulate discussion between students by asking them 'What do *you* think?'

Diagnostic items (e.g. Snapshot 8.1) can be used on the overhead projector to stimulate a whole-class discussion or printed out and used to stimulate small-group discussions. Disclosure of conceptions in these discussions makes both teacher and students aware of

SNAPSHOT 8.1: An example of how to write diagnostic test items

One simple way of writing diagnostic items is to add an open question, as a follow-up to a multiple-choice item, that asks students to explain the reason for their choice of answer. This example is based on the research conducted by Osborne and Cosgrove (1983) into students' ideas about the change of state of matter. The explanation provided to the follow-up question reveals students' beliefs about the composition of the bubbles.

When water boils large bubbles are formed.

Q1. What do you think is in the bubbles?

- (a) air
- (b) steam
- (c) heat
- (d) oxygen or hydrogen

Q2. Explain the reason for your answer.

the range of conceptions existing in the class, and this can lead to investigations to test the various views held by the students.

Formative assessment

Formative assessment is used to provide feedback to teachers and learners so that teaching and learning are improved. Wiliam (1998) argues that five conditions must be met for assessment to be truly formative:

1. a mechanism must exist for determining students' current level of achievement;
2. a desired level of achievement, above the current level, is identified;
3. the two levels are compared so that a gap is identified;
4. the teacher provides prompts, scaffolding or support that informs students about *how* to close the gap; and
5. the learner uses the information to close the gap.

Formative assessment can be structured around profiles of learning in outcomes that are set out in levels and describe a progression in learning as illustrated in Snapshot 8.2.

SNAPSHOT 8.2: An analysis of the conducting investigations substrand in the Western Australian Curriculum Framework progress map (Curriculum Council of Western Australia, 2003) reveals the following continuum in measurement skills

- Level 1: Observes and describes.
- Level 2: Measures using non-standard units, for example counts number of blocks or hand spans.
- Level 3: Measures using standard units, for example cm.
- Level 4: Makes repeated measurements.
- Level 5: Uses preliminary trials to improve the measurement technique.

When a student has been located at one level, it is then possible, knowing what needs to be done differently or in addition to what the child is doing at that level, to work out what intervention is needed to facilitate the student's development to the next level.

For example, a student is investigating how far an empty icecream tub travels over different floor surfaces when propelled by an elastic band stretched between the legs of a chair. The student makes one measurement on each surface then moves on to the next surface, that is, level 3. Knowing that to move to level 4 the student must recognise and understand the need to make repeat measurements on each surface, it is possible for the teacher to devise appropriate questions to scaffold the student's thinking through this developmental step. The following dialogue may result:

Teacher: Would the tub go the same distance if you shot it along the same surface again?

Student: Yes. It would probably go almost exactly the same distance.

Teacher: Try it and find out. (The difference is usually much larger than the student anticipates.)

Teacher: Why do you think the tub did not go as far this time?

Student: Oh, the tub might have hit a bump in the carpet, or I might have let it go differently, or the band might have lost its stretch.

Teacher: Do you think one measurement is enough per surface or would it be better to do three?

Student: It would be better to do three. If you only did one measurement it might have been affected by a bump in the carpet; three measurements are more likely to give you a result you can rely on.

For students to be metacognitively in control of their learning and production of quality academic work, they must have an understanding of the standard being aimed for, compare their current level of performance with the standard and engage in appropriate action which leads to closure of the gap. Teachers therefore need to make information about standards explicit to students. Levels of performance can be communicated to students through descriptive statements, rubrics and/or exemplars.

One of the most effective ways of helping students understand the outcomes they are working towards is to involve them in self- and peer-assessment. Students working in pairs using a rubric and commenting on each other's work can help them objectively compare their work to the standards described in the rubric and develop an understanding of the expected standards and what aspects of their work needs to be improved.

Research has shown that formative assessment is one of the most effective strategies for improving learning (Black & Wiliam, 1998). However, the key to its effectiveness is the quality of feedback given by teachers to students about their learning. Research by Ruth Butler (1987, 1988) demonstrates that feedback must be task-involving rather than ego-involving, that is, directs attention to the task rather than to the self or ego. Students given comments only improved their achievement significantly and *all* students had high interest in the work. Students given grades only showed no improvement in achievement, and those students who obtained high grades had high interest, whereas those receiving low grades had low interest in the work. Giving grades and comments had no effect on achievement as students attend to the grades to the exclusion of the comments, and interest correlated with the grades received. The addition of praise with grades increased ego involvement. To maximise achievement gains, feedback should therefore be limited to comments that describe what the student is doing well and what needs to be improved and give some guidance on how to improve the work.

Summative assessment

Summative assessment is used towards the end of a module, term, semester or year to determine the extent to which students have achieved the learning outcomes. Teachers use the information for grading or determining the level of achievement and reporting to parents. Teachers typically use a range of evidence on which they will determine the students' grades for the semester. Sources of evidence usually include pencil and paper tests, quizzes or examinations, assignments, projects, reports of investigations and experiments, oral reports, work samples assembled into a portfolio and teacher observations of students' performance.

Cumulative approaches to collecting this evidence over a semester reduce the reliance on tests at the end of the semester, which create considerable stress and anxiety for students. Such tests only assess a sample of the important learning outcomes and advantage those students who can perform best under test conditions. Using a range of varied sources of evidence provides a more valid, reliable and equitable assessment of students' achievement in science.

WHAT SHOULD BE ASSESSED?

Assessment should focus on the learning outcomes that are of the greatest value to students so that teaching and learning address these outcomes. In the compulsory years of secondary schooling, there is universal agreement that science should focus on the development of scientific literacy. (See Chapter 4 for more information about scientific literacy.) Scientifically literate citizens question, investigate, gather and analyse information, and make evidence-based decisions about themselves and their world (Goodrum *et al.*, 2001). Being scientifically literate is more about being a critical thinker than about acquiring a body of knowledge. Teaching, learning and assessment should therefore focus on those learning outcomes that contribute to scientific literacy.

It is also helpful to consider learning outcomes in terms of cognitive, psychomotor and affective domains. The cognitive domain includes knowledge and conceptual understandings and intellectual skills such as the process skills of science. These cognitive outcomes can be assessed at different levels, for example simple

recall, comprehension, application to new contexts, synthesis or evaluation. Most science assessments address cognitive learning outcomes. The psychomotor domain includes science hand skills and apparatus skills, for example skills of making accurate measurements. Psychomotor skills need to be assessed in a situation where the student performs the skill and the assessment is made by observing the performance or by checking the accuracy of results, such as measurements made. The affective domain includes attitudes towards science (e.g. like-dislike, trust-distrust) and scientific attitudes (e.g. objectivity in evaluating evidence). It is useful to survey students' attitudes towards science to gain feedback on students' views so that instruction and classroom climate can be modified to increase students' enjoyment and engagement with science.

HOW SHOULD WE ASSESS?

It is important to recognise that not all assessments need to be highly formalised. Diagnostic and formative assessments used for improving learning are usually informal and often spontaneous, occurring as the teacher interacts with students while observing their work and asking questions. These assessments require the teacher to have a rich knowledge of student learning and the developmental continuum leading to key learning outcomes, so that the teacher can recognise where the student is on their learning journey and respond with appropriate prompts or questions that will help the student move forward. When highly reliable assessments are required for important decisions such as university admission, more formalised test-based assessment procedures are required to ensure reliability and to authenticate that the work has been produced by the student rather than some other person.

There are a variety of ways of collecting evidence about students' learning. These include observation, closed objective questions, open questions, exercises, projects and investigations, library and web-based research assignments and portfolios.

Observation and conferencing

Observation and conferencing are powerful and commonly used assessment procedures in primary school situations where the

teacher works with the same class of students for extended periods of time. In secondary schools, observations and informal conversations with individuals are useful for collecting evidence from students with limited literacy skills who have difficulty in providing evidence in written form. Observations are also useful to note students who are able to perform certain skills during investigations, for example controlling variables. These observations can be recorded directly by the teacher on the student's written work so that they are available when the student's work is collected for assessment. Evidence is most efficiently collected from secondary students through written work. Analysis of evidence collected this way will reveal gaps that can be filled by observation and conferencing.

Closed objective questions

Teachers will often include closed objective questions such as true-false, fill the gap and multiple-choice items on quizzes and tests as they are quick and easy to mark. These types of items are useful for assessing students' mastery of basic content and facts; however, they are relatively ineffective in assessing higher-order cognitive outcomes.

Open questions

To assess whether a student really understands science concepts it is important to use open questions that require students to explain using their own words, and to set the question in a different context from that in which the concept was taught. This ensures the student is required to apply the learning from the old context to a new context, using their own words rather than simply recalling the words used by the teaching without any real understanding. It must be recognised that the new context should be relatively similar to the old context and be familiar to the students or the difficulty of the assessment will be increased considerably.

Exercises

Exercises such as analysing and interpreting second-hand data or conducting routine laboratory exercises and writing a report can be useful for gathering evidence about students' use of science process skills such as constructing data tables and graphing.

Projects and investigations

Projects and investigations in which students plan and conduct their own investigations and collect and analyse their data are valuable approaches for collecting evidence about science critical thinking skills. (See Chapter 6 for more information about investigations.) These skills require the student to bring together conceptual understandings, science process skills and data for interpreting data, drawing conclusions and planning or critiquing the design of investigations.

Library and web-based research assignments

Not all research requires the collection of new data. Scientifically literate citizens should also be able to search for and select relevant existing information about a question, and synthesise that information into a coherent report that can be communicated to others. Library and web-based research assignments are valuable tools for collecting evidence about these abilities.

Portfolios

Portfolios can be used to assemble a range of work samples to illustrate the growth in skills and understandings and to provide evidence of the current level of achievement. The major benefit of portfolios is that students can be actively involved in selecting work samples for inclusion that will illustrate their achievements. This raises their ownership over the work, increases their understanding of the learning outcomes to be achieved and enhances their metacognitive awareness of their learning progress.

Once evidence has been collected, teachers must interpret and make judgements about the evidence. Marking schemes and rubrics are required to guide those judgements to enhance their accuracy and consistency.

Marking schemes

Marking schemes are usually devised by teachers for the use of teachers in marking students' work and awarding scores, which are then used to award grades in norm-referenced assessment schemes. Norm-referenced assessment schemes involve marks, percentages and grades, which are interpreted by comparing the performance of

one student with their peers. Detailed marking keys are particularly important to ensure consistency of marking of open-ended tasks and items. A sample task and marking key are shown in Snapshot 8.3 to illustrate one style of marking key.

SNAPSHOT 8.3: An example of a marking key

Detailed marking keys are particularly important to ensure consistency in the marking of open-ended tasks and items. A sample task and marking key are shown here to illustrate one style:

Task

In about 175 years, readily available supplies of fossil fuels will be used up. Write a short newspaper article, no more than one page long, about this issue. In your story explain the history of energy use and how future generations will meet their energy needs. Make sure you include a catchy headline for your story.

Marking key

Award any valid points mentioned up to a maximum of 10 marks:

- Suitable headline encapsulating the issue discussed in the article. (1)
- Clarity and accuracy of communication in standard English. (up to 2 marks)
- Wood was an important fuel for fires used for cooking and keeping warm (1) and was later supplemented by other fossil fuels such as coal. (1)
- Industrial Revolution saw a huge increase in the use of fossil fuels such as coal and gas. (1)
- The development of road and rail transport, which use petroleum-based fuels, led to a huge increase in oil consumption. (1)
- Great efforts made to increase the efficiency of energy use as costs of energy rise e.g. more efficient engines and greater use of insulation. (1)
- With concerns about the greenhouse effect (1) and increasing costs of fossil fuels, greater use made of nuclear energy (1) and renewable energy sources such as solar, wind and hydro. (1)
- As technologies improved some use made of fuel cell technologies (1) and fusion. (1)

Rubrics

Rubrics are devised by teachers, sometimes with students' involvement, and are used by students and by teachers working in standards-based assessment schemes. Rubrics help students understand the learning outcomes they are striving to achieve and the standards or steps along that learning journey. Students can use rubrics for self-assessment exercises. Rubrics help teachers be clear about standards or levels of achievement and can provide a framework to guide both formative and summative assessment. Table 8.1 (p. 140) illustrates a rubric used to guide the assessment of data handling skills including measurement, data recording and graphing.

WHAT ARE THE CHARACTERISTICS OF QUALITY ASSESSMENT?

Quality assessments should be valid, reliable, authentic, fair, comparable and educative. Each of these characteristics is considered in the following paragraphs.

Validity

Validity asks whether the assessment actually assesses what you intended to assess.

There are a number of aspects or types of validity. For teacher assessments the two most important are content validity and construct validity. Content validity refers to the extent to which the assessments match the content and learning outcomes of the unit of work. This can be assured by preparing an assessment specifications grid in which you list the outcomes and content on one side of the grid and the assessment tasks and items on the other side. By putting ticks in the boxes you can check the extent to which the assessment tasks match the outcomes. Construct validity refers to the extent to which the assessments really require students to use the understandings or skills intended to be assessed. Construct validity is checked by working through the tasks to determine the steps and reasoning required to complete each task. One of the most common threats to construct validity is the reading difficulty of the tasks. If reading

TABLE 8.1: An example of an assessment rubric

Data handling skills		Level 3	Level 4	Level 5
Measurement		Uses measurement when required and uses standard units of measurement, e.g. cm, kg	Makes repeated measurements or uses replicates	Trials the measurement procedure to improve its accuracy and uses apparatus that enhance accuracy, e.g. uses appropriate size measuring cylinder
Recording data		Data are recorded using an appropriate form, e.g. lists, tables or diagrams	Data recording is comprehensive, e.g. all trials are recorded	Data recording uses an appropriate form, is comprehensive and uses appropriate conventions, e.g. tables have titles, column headings and units, independent variable recorded in left column and dependent variable in right column
Graphing		Constructs bar graphs	Plots bar and line graphs appropriate to the data type, i.e. line graphs when data for both variables are continuous	When plotting line graphs, plots averages for repeated measurements, places the dependent variable on the vertical axis and uses appropriate scales with regular intervals

difficulty prevents some students from understanding what they need to do, the task is placing more weight on the assessment of reading comprehension than the science.

Reliability

If students were given the same assessment task on two different occasions separated by a few days, and the results on the two occasions were the same, this would indicate that the assessment was highly reliable. Reliable assessments would produce the same student rankings on repeated administrations. Without reliability, a teacher cannot have any confidence in the results from assessments. With important assessments such as university entrance examinations, the assessments need to be highly reliable.

The reality is that assessments of learning tend to be somewhat unreliable due to transient influences such as students' motivation, fatigue, guessing and practice effects. Guessing can be reduced by making all task and item instructions unambiguous and writing at a reading comprehension level below that possessed by the students. There is a degree of error or uncertainty associated with all assessments. Such errors can be reduced by using a number of smaller assessments rather than a single high-stakes assessment.

Authenticity

Some school assessments are decontextualised and involve contrived tasks that bear no relationship to the ways in which students will be expected to use the understandings and skills in their adult lives; such tasks lack authenticity. Authentic assessments are meaningful, contextualised in real-life situations and require the application of skills and understandings that have long-lasting value in the person's life. Authentic assessments are often naturally integrated into the teaching-learning process. Authentic tasks assess things of value and because they are meaningful to students they are motivated to engage with them. Authenticity may require students to work in teams on certain tasks, which will require clearly established ways of sharing credit for the work between the participants.

Fairness and equity

The research literature (Parker & Rennie, 1998) indicates that student performance on assessments is strongly influenced by the test-taking situation, the response format of assessment tasks and by the context within which the assessment tasks are set. These influences are also differential influences in that they favour one sex over another or students with one learning style over another. Formal, timed, competitive external examinations tend to favour males whereas cumulative school-based assessments tend to favour females. Differences in test anxiety, social and communication skills are factors that have been used to explain these differences in performance. Multiple-choice items tend to favour boys whereas extended-response items tend to favour girls. The extent of contextualisation of test items and the nature of the context can also selectively advantage some students over others. The greater the contextualisation of the task or question, the greater the demand for reading and graphical comprehension skills required to understand the question. Familiarity of context influences item difficulty, therefore if the context is more familiar to one sex, socioeconomic, geographical or ethnic group it will be advantaged over other groups.

Assessment practices must allow all learners the opportunity to demonstrate what they know, understand and can do. Gardner (1992) has shown that students have a range of intelligences that give them different strengths in learning and showing what they have learned. Diversity in assessment practice allows all students the opportunity to demonstrate their learning accomplishments.

Comparability

Assessments made by different teachers and across different schools should be comparable in standards. The same work completed in different classes and assessed by different teachers should be assessed against the same outcomes and standards and receive similar grades or levels of achievement. Comparability is enhanced when teams of teachers collaboratively prepare assessment tasks and marking schemes, some common assessment tasks are completed by all students, and teams of teachers mark samples of students' work and compare and modify their assessments until they reach a consistent standard in applying the marking scheme.

Educative

All assessments should in themselves be a learning experience so that students practise the application of valuable knowledge and skills in completing the tasks and receive feedback that guides future learning.

SUMMARY

Assessment has a powerful influence over what is taught and learned, provides evidence for making decisions about students' educational futures and consumes a large proportion of teachers' time. Teachers should therefore think very carefully about why they assess, what they assess, how they assess and the quality of their assessments. As the primary purpose of schooling is to improve learning, assessment must focus strongly on providing feedback to teachers and students that is used for improving teaching and learning. To do this assessment must be embedded within the teaching-learning process, rather than tacked on the end of the learning sequence merely to measure the extent of learning. The fundamental purpose of science education in the compulsory years of schooling is to develop scientifically literate citizens. Science assessments should therefore focus on those learning outcomes that contribute to scientific literacy.

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