WORKING SCIENTIFICALLY:

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Implementing and Assessing Open Investigation Work in Science

A resource book for teachers of primary and secondary science

Government of Western Australia
Department of Education and Training

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A resource book for teachers of primary and secondary science

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Foreword

This new edition of Working Scientifically reflects the changes that are evident in the Outcomes and Standards Framework as part of phase two of Curriculum Improvement Program (CIP). These changes, which include the introduction of standards and a revision of the language of the Student Outcome Statements, have been made in response to a department review of the CIP.

The Working Scientifically outcomes in the Curriculum Framework are process outcomes that include Investigating. This outcome has been selected for the standard for Science in Years 5, 7 and 9 as it is a process central to science. Investigations stimulate student interest in science and provide a vehicle through which conceptual understandings can be developed further. For students to improve their understanding of this process and their capacity to use it to test their own ideas and solve problems, they need to be provided with opportunities to plan and conduct their own investigations, process and analyse their data and reflect on their findings.

Teachers have now taken on the challenge of implementing investigation work with their students. Professor Mark Hackling, the author of this book, has worked with many teachers in researching effective ways of implementing this approach in the classroom.

This revised publication provides support for teachers in understanding the process of scientific investigation, implementing investigations with their students, monitoring students' progress, and planning for each student's improvement.

I am confident that this resource will make a very useful contribution in supporting teachers to implement the Outcomes and Standards Framework.

PJ Moss.

PAM MOSS

DIRECTOR, EARLY YEARS, K-10 ACADEMIC STANDARDS AND SUPPORT

August 2005

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The *Working Scientifically* approach to open investigation work in science

Why do we include practical work in science?

When teachers are asked why they include practical work in science, the answer given often varies between primary and secondary teachers. Reasons given usually include providing opportunities for:

- ➥language development;
- ➥learning to work cooperatively;
- ➥concrete experiences of natural phenomena;
- ➥stimulating curiosity and creativity;
- ➥motivation and enjoyment of science;
- ➥developing investigation and problem-solving skills;
- ➥developing techniques and manipulative skills associated with using scientific equipment;
- ➥experiencing and developing an understanding of the nature of science; and
- ➥conceptual development.

Primary teachers tend to place more emphasis on reasons in the first half of the list and secondary teachers to place more emphasis on reasons in the second half of the list.

There are many different forms of practical work: for example, demonstrations, practical exercises, fieldwork and open investigations. Each provides opportunities for different types of learning outcomes. It is therefore important to match the type of practical work to the intended learning outcome and to provide a wide range of practical experiences so that students have opportunities to develop a greater range of learning outcomes.

The degree of openness of practical activities can be assessed in terms of whether it is the teacher or student who decides the problem to be investigated, the equipment to be used, the procedure for setting up equipment and making observations and measurements, and the conclusions to be drawn. These criteria can be used to classify practical activities into categories as shown in Table 1.

Level	*Problem*	*Equipment*	*Procedure*	*Answer*	*Common name*
0	**Given**	**Given**	**Given**	**Given**	**Verification**
1	**Given**	**Given**	**Given**	**Open**	**Guided inquiry**
2a	**Given**	**Given**	**Open**	**Open**	**Open guided inquiry**
2b	**Given**	**Open**	**Open**	**Open**	**Open guided inquiry**
3	**Open**	**Open**	**Open**	**Open**	**Open inquiry**

Table 1. Levels of openness of inquiry in laboratory activities
(after Hegarty-Hazel, 1986)

At the lowest level of inquiry (Level 0), the problem to be investigated, the equipment to be used, the procedure and the answer to the problem are all given to the students by the teacher or by a worksheet. At the highest level of inquiry (Level 3), the students are required to determine all of these for themselves.

Many would now argue that the student should be involved in selecting the problem or variables to be investigated, and that the problem should be embedded in a context familiar to the student for the learning experience to be meaningful and represent authentic science (Woolnough, 1994). Student choice enhances ownership, motivation and persistence in the face of difficulties.

The majority of practical activities in the *Primary Investigations* curriculum are fairly closed because the curriculum was written for teachers who lacked confidence in teaching science and therefore was highly structured.

Similarly, lower secondary science is dominated by recipe-style, worksheet-based laboratory exercises (Staer, Goodrum & Hackling, 1998). This restricted diet of closed practical exercises provides students with few opportunities for practising skills of analysing a problem, formulating a researchable question or hypothesis, and planning and conducting their own experiments. Many science educators argue that students need the opportunity to do open investigation work if they are to develop the investigation and problem-solving skills that are at the heart of scientific literacy. These are included in the Overarching Statement, the Science Learning Area Statement (Curriculum Council, 1998), and the *Key Competencies* (Mayer, 1993).

The core skills of scientific reasoning entail the coordination of existing theories with new evidence bearing on them (Kuhn, Schauble & Garcia-Mila, 1992). Scientific theories stand in relation to actual or potential bodies of evidence against which they can be evaluated (Kuhn, 1989). Gott and Duggan (1996) have argued that understanding the nature of scientific evidence, which is based on competencies associated with experimental design, measurement and data handling, is central to scientific literacy.

In the US National Science Education Standards, a scientifically-literate person is defined as one who 'should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it' (National Academy of Sciences & National Research Council, 1996, p. 22).

In its definition and rationale for science education, the Western Australian Science Learning Area Statement also focuses on scientific evidence:

"Science has many methods of investigation, but all are based on the notion that evidence forms the basis for defensible conclusions . . . Science education empowers students to be questioning, reflective and critical thinkers. It does this by giving them particular ways of looking at the world and by emphasising the importance of evidence in forming conclusions."

Curriculum Council (1998) pp. 218–219

> **"** *Students investigate to answer questions about the natural and technological world, using reflection and analysis to prepare a plan; to collect, process and interpret data; to communicate conclusions; and to evaluate their plan, procedures and findings.* **"**
>
> Curriculum Council (1998) pp. 222

What are open investigations?

What does it mean to investigate scientifically?

Open investigations are activities in which students take the initiative in finding answers to problems (Jones, Simon, Fairbrother, Watson & Black, 1992). The problems require some kind of investigation in order to generate information that will give answers. Garnett, Garnett and Hackling (1995) describe a science investigation as 'a scientific problem which requires the student to plan a course of action, carry out the activity and collect the necessary data, organise and interpret the data, and reach a conclusion which is communicated in some form' (p. 27). The planning component and the problem-solving nature of the task distinguish investigations from other types of practical work.

The WA Science Learning Area Statement's major learning outcome for *Working Scientifically – Investigating* refers to Planning Investigations, Conducting Investigations, Processing Data and Evaluating Findings.

In practice, these processes may not take place in the strict order of, say, Planning – Conducting – Processing – Evaluating, because halfway through Conducting it may be realised that more planning is needed and therefore a more recursive model (see Figure 1) may more accurately represent the investigation process.

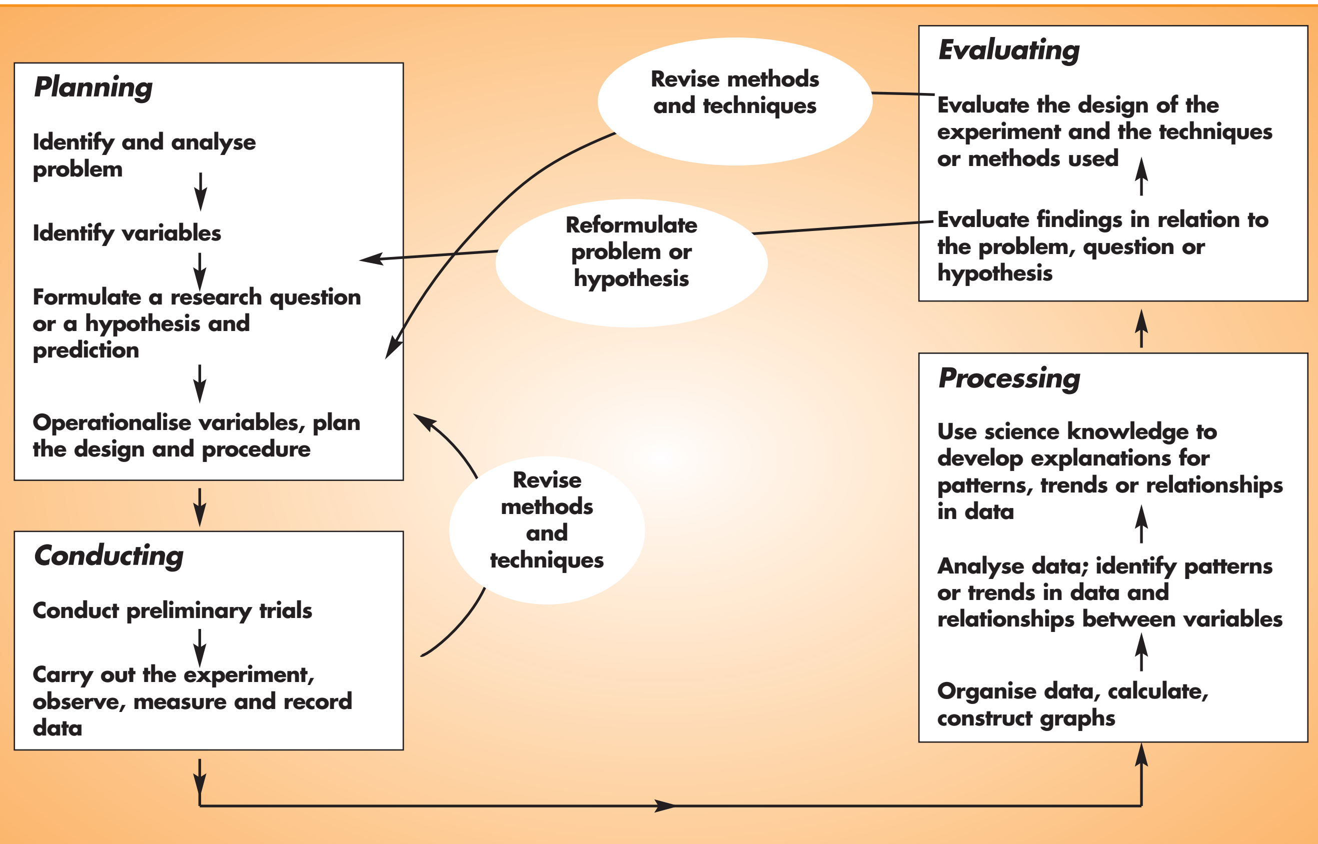


Figure 1. A model of science investigation processes **(Hackling & Fairbrother, 1996)**

How does investigation work open the door to conceptual learning?

Practical investigation work provides opportunities for students to practise and develop investigation skills and also gain concrete experiences of natural phenomena which provide a foundation for conceptual learning.

The investigation work of *Working Scientifically* provides an approach which can contribute to learning the understandings outlined in the conceptual strands Earth and Beyond, Energy and Change, Life and Living, and Natural and Processed Materials.

Although *Working Scientifically – Investigating* is a separate outcome in the Learning Area Statement, it is intended that investigations be integrated into the conceptual outcomes in the implemented curriculum. The conceptual outcomes provide the context for investigation work.

How does investigation work fit the 5Es model of instruction?

All forms of practical work should be integrated carefully into an instructional sequence so that meaningful links can be established between the practical and theoretical aspects of science. This linkage can be addressed at two levels: at the level of the individual activity using Gowin's V (Novak & Gowin, 1984), or at the level of a sequence of lessons, using the 5Es instructional model.

Gowin's V

For an individual practical activity, relationships between the practical and conceptual can be developed by using Gowin's V (Figure 2), which is a useful device for structuring the discussions that precede and follow the practical activity.

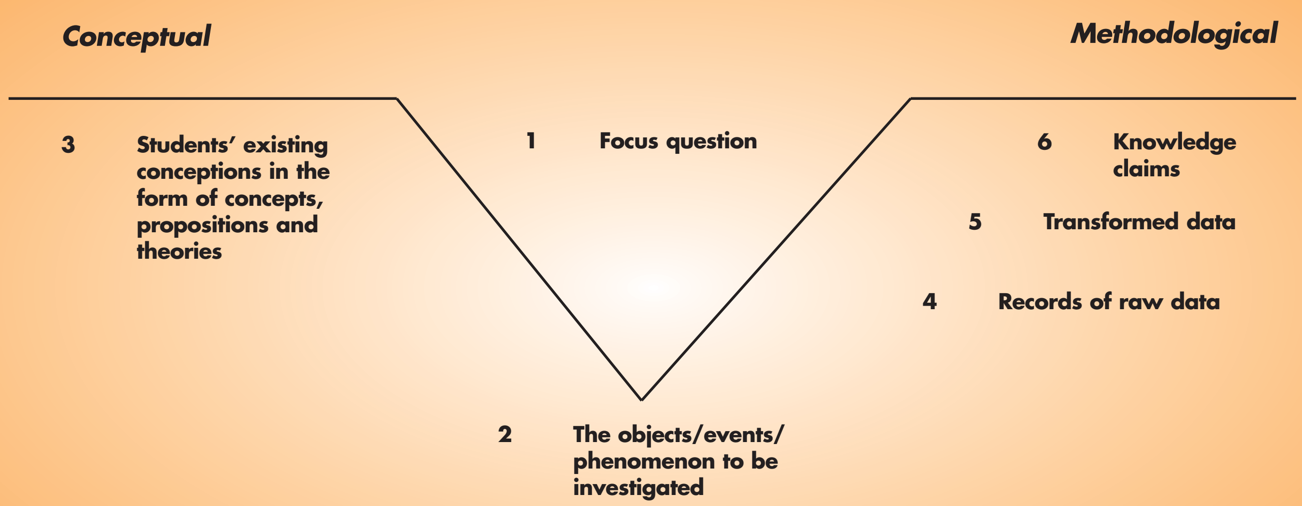


Figure 2. The structure of a V-map (Hackling, 1994)

Steps 1-3 are completed in the pre-practical discussion, Step 4 is completed as part of the practical work, and Steps 5 and 6 are the focus of the post-practical discussion.

In the pre-practical discussion, a large 'V' is drawn on the board. The teacher establishes the context and develops with the students a focus question for the investigation (Step 1).

In Step 2, the objects and events which will be the focus of the investigation are examined and written at the apex of the V.

In Step 3, the teacher elicits students' understandings relating to the phenomenon, so they are available to anticipate, monitor and comprehend the data to be collected; these are written on the conceptual side of the 'V'. Some of the students' beliefs may be unscientific and can be challenged in the post-practical discussion.

Following the practical activity, raw data collected by students are collated by the teacher on the lower right-hand side of the 'V' (Step 4).

At this stage, the teacher can facilitate the discussion of whether there is any need to transform the data into a table or graph to help identify any patterns in the data (Step 5). After this, the data can be interpreted in terms of the conceptual knowledge elicited in the pre-practical discussion. The data may be inconsistent with students' conceptions and this can lead to a discussion of the adequacy of the initial conceptions and the extent to which the data are subject to error or uncertainty.

An example of a completed V-map is illustrated in Figure 3. Such a map can be a useful way for students to record a summary of their work in their notes.

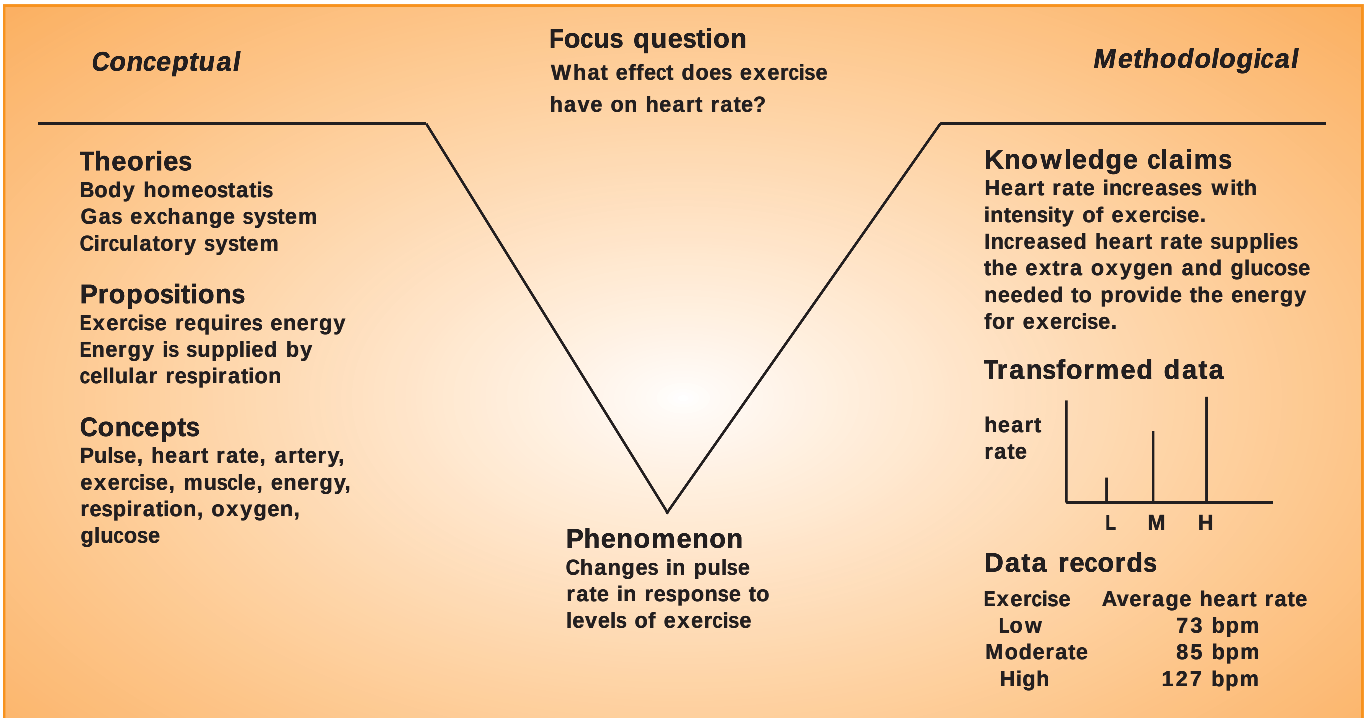


Figure 3. A completed V-map (Hackling, 1994)

The 5Es instructional model

Primary and lower secondary science curricula, such as *Primary Connections BSCS Middle School Science* and *Science Plus,* are structured around the '5Es' instructional model, which is derived from constructivist learning theory. Simply stated, constructivists argue that students use their own beliefs and understandings to interpret experiences and construct meaning for those experiences and their understandings of the world around them. The 5Es instructional model is based on the constructivist premise that students learn best when allowed to work out explanations for themselves over time through a variety of learning experiences structured by the teacher. To help students make the connections between what they already know and new experiences and information, modules of work are organised around the stages of the 5Es model (Figure 4).

Phase of instructional model	*Purpose*	*Role of reading, writing, practical work and discussion*
Engage	**Create interest and stimulate curiosity** **Raise questions** **Reveal student ideas and beliefs** **Compare students' ideas**	**Motivating/discrepant demonstrations to create interest and raise questions** **Open questions and individual writing to reveal students' beliefs**
Explore	**Experience the phenomenon or concept** **Explore questions and test students' ideas** **Investigate and solve problems**	**Open investigation work to experience the phenomenon, observe, test ideas and try to answer questions.**
Explain	**Compare ideas** **Introduce definitions and concept names** **Construct explanations and justify them in terms of observations and data**	**Small-group discussion to compare ideas and construct explanations** **Student text reading to access concept names and definitions** **Writing to clarify and document explanations**
Elaborate	**Use and apply concepts and explanations in new contexts** **Reconstruct and extend explanations to new contexts**	**Further practical activities or problems to provide opportunities to apply, extend, compare and clarify ideas**
Evaluate	**The teacher looks for evidence of changes in students' ideas, beliefs and skills** **Students review and evaluate their own learning**	**Write answers to open-ended questions to reveal conceptions** **Reflect on any changes to explanations**

Figure 4. Phases of the 5Es instructional model

The 5Es model provides a framework for structuring a sequence of lessons consistent with a constructivist approach.

The **Engage** lesson sets the context, raises questions and elicits students' existing beliefs.

The **Explore** lesson involves investigation work in which students gain first-hand (and, where possible, concrete) experience of the phenomenon of interest.

The **Explain** phase draws on students' beliefs from the Engage lesson, concepts introduced by the teacher or from text reading. These are used to construct explanations for the experiences of the Explore phase.

Further practical work provides more experiences of the phenomenon, this time in a different context, so that the **Elaborate** lesson can involve students applying conceptions developed in the Explain lesson to new contexts, thus extending and integrating their learning.

The **Evaluate** lesson provides an opportunity for students and the teacher to assess developed conceptions and compare them to their beliefs at the Engage phase.

In the *Primary Investigations* curriculum, some of the closed activities at the Explore phase can be replaced with open investigations to give students the opportunity to plan and conduct their own investigations and practise working scientifically.

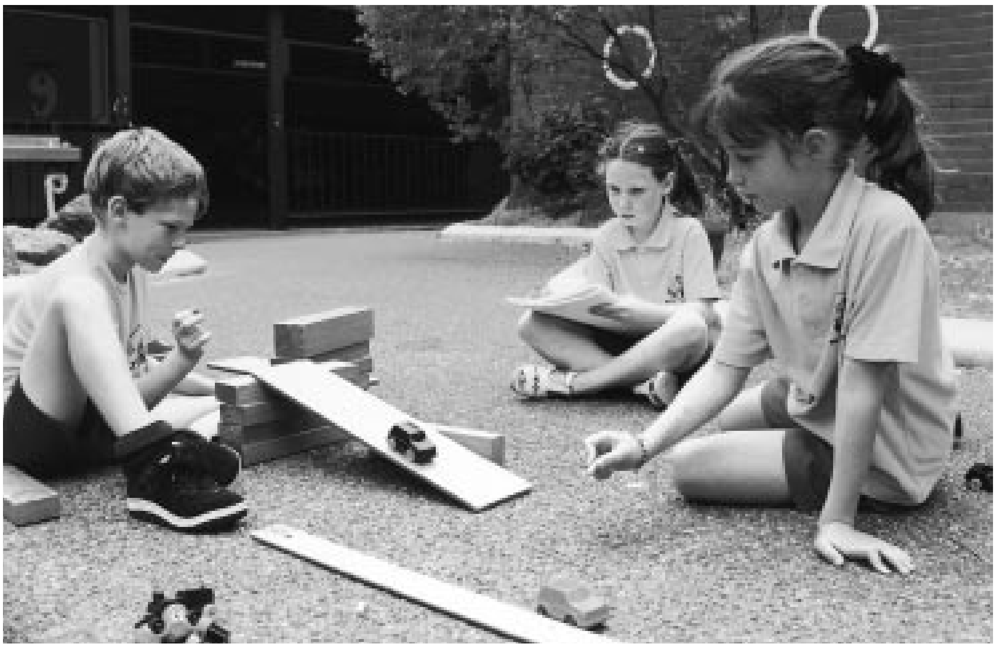
Similarly, in the secondary curriculum, open investigations need to replace some of the closed, recipe-style activities at appropriate places in the instructional sequence, which can be planned to follow the 5Es model.

The cognitive apprenticeship approach to teaching and learning of investigation processes

It is helpful to conceptualise the teacher and the student's 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 (Collins, Brown & Newman, 1989; 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.
- The teacher provides **scaffolding** to structure the work of the students.
- The teacher works alongside students, **coaching** them on specific skills and strategies.
- Students are encouraged to discuss and reflect on their decision making and strategies. **Articulation** of tacit knowledge helps make it explicit.
- As students gain competence, some of the scaffolding is **faded** away.



The variables structure of an investigation

Science experiments are designed to collect evidence to solve problems, answer questions or to test hypotheses. To have confidence in the collected data, we need to be sure the tests were fair and that sources of error were minimised. To do this we need to control variables and use repeat trials or replication. For example, if we were investigating the effect of the height from which a ball is dropped (the **independent variable**) on the height to which it bounces (the **dependent variable**), we would need to isolate and control variables to make sure it was a fair test. Variables such as the type of ball and the surface onto which it was dropped would need to be kept constant, or controlled (a **controlled variable**), so that we could be sure that it was the change in the drop height that was causing the effect on bounce height.

To get a fix on measurement error, we would **repeat trials** three times (e.g. drop the ball three times from 2m, then drop the ball three times from 1.5m, etc.) to see the extent of variation in results.

If the variation between the repeat trials was considered excessive, the measurement procedure would be modified to reduce the source of error. It is not always possible to repeat trials because trials may be destructive: for example, in testing the effect of temperature on seed germination – once a seed has been germinated it cannot be germinated again.

In these experiments, **replication** is used. This involves setting up two or three dishes of seeds at each temperature rather than just one. The extent of variation in results between replicates indicates measurement and sampling error: for example, to what extent were all the seeds viable?

Observations and measurements of variables can be either discrete or continuous. **Discrete data** are in categories, such as gender, type of animal, brand of paper towel or colour. **Continuous data** are associated with measurement involving a standard scale with equal intervals, such as height of plants in centimetres, the amount of fertiliser in grams or the length of time in seconds.

Types and examples of investigations

Not all investigations have the same structure and approach to data collection. Each type of investigation will provide opportunities to practise different approaches to the collection and analysis of data. A balanced science education program should not only include different types of practical work (such as demonstrations, closed exercises and open investigations), but also different types of investigations. Gott and Murphy (1987) classified investigations into three categories, in terms of the purpose of the problem posed to the students:

➥ Decide which ... problems

Example: Decide which brand of paper towel is best for absorbing spilt water.

➥ Find a way to ... problems

Example: Find a way of measuring the weight of a suitcase when existing equipment is not adequate.

➥ Find the effect of ... problems

Example: How does the depth of water in a container affect the rate at which water runs out of a hole in the bottom?

Another way of classifying investigation tasks is in terms of the methods of data collection and the ways in which error is reduced in the design of the experiment.

Types and examples

Type 1. Investigating a relationship between two variables where repeat trials can be used

Examples

How does the height from which a ball is released affect the height to which it bounces?
How does the amount of stretch in a rubber band affect the distance it travels when released?

Features

Repeat trials are conducted and averaged because tests are non-destructive and can be repeated to get a fix on measurement error.

Type 2. Investigating a relationship between two variables where replication can be used

Examples

What effect does temperature have on dissolving of jelly cubes/soluble aspirin tablets?
What effect does temperature have on germination?

Features

Replication is used because tests are destructive and cannot be repeated, and the material or population may be non-uniform. Hence, replication gives a fix on sampling error.

Type 3. Testing types of materials

Examples

Which kind of paper towel holds most water?
Which type of adhesive tape is the stickiest?

Features

Types or brands of materials are tested for absorbency, strength, stickiness, durability, etc. The independent variable is always discrete. Tests need to be repeated/replicated to get a fix on measurement and sampling error.

Type 4. Investigating the effect of several independent variables on one dependent variable – often associated with a design problem

Examples

How do the number of coils, length and thickness of wire, type of metal from which the wire is made and current affect the eficiency of a heating element?
How do you make a powerful heating element?
What effect does beam material, beam thickness and span width have on the strength of a bridge?
How do you build a strong bridge?

Features

There is a need to test a number of independent variables separately or in combinations on one dependent variable, and then develop a design brief.

# of investigations

Type 5. Survey research, where populations are sampled to investigate the relationships between variables

Examples

How do height and weight vary with age in boys and girls?

Features

The population being tested is non-uniform and samples are selected based on the parameters being investigated. Random sampling is used to control for interfering variables.

Type 6. Comparative or descriptive studies typical of field biology and the earth sciences

Examples

How do the animal communities differ in native bush and parkland? What factors are likely to have caused these differences?
Describe the moon as it changes through the lunar cycle and investigate its time of rising over a one-month period.

Features

A range of data types is collected to develop a description of a phenomenon or location. Random sampling may be used to control interfering variables. Comparisons may be made between sets of data relating to different locations or time. Such analyses of data attempt to identify possible causal relationships.

Type 7. Researching, analysing and explaining data collected and reported by other scientists

Examples

Search meteorological records and locate data for monthly rainfall in Perth over the past 50 years. Analyse the rainfall figures. Summarise the figures and present the information in a form that helps you identify patterns in the data. Using your knowledge of meteorology, develop explanations for any patterns you identify.

Features

The student must decide where the data can be located and how it can be retrieved. The data may be provided by the teacher. The data must be summarised and presented in a form that helps identify patterns (e.g. tables and graphs), and conceptual knowledge should be used to explain patterns in the data.

Type 8. Chemical analyses

Examples

Use qualitative chemical analysis to identify this unknown chemical.
Use quantitative chemical analysis to determine the percentage composition of ethanoic acid in vinegar.

Features

An extensive knowledge of solubility rules, tests for gases, reactions of acids, flame tests, indicators, gravimetric techniques or titration techniques are used to plan the analysis. With quantitative analysis, repetition of tests is used to get a fix on measurement error.

Implementing open investigations in science

Barriers to change

The primary science curriculum often has too little practical work and, at the lower-secondary level, practical work is dominated by closed, worksheet-based practical exercises. If more open investigations are to be introduced to the science curriculum, several barriers to change must be addressed. The following concerns of teachers represent impediments to the implementation of more open investigation work:

- The curriculum is too crowded with content to be covered and therefore there is not enough time to introduce investigations.
- Traditional assessments focus on mastery of content and do not reward teachers and students who spend time developing investigation skills.
- Difficulties associated with large numbers of students, equipment, safety and the diversity of experiments make classroom management difficult.
- Students cannot work without set procedures.

The replacement of syllabuses specified in terms of content statements and lists of objectives with a curriculum framework specified in terms of a small number of more global outcomes frees teachers to develop conceptual understandings in selected contexts, thus making space and time for the introduction of open investigations. With the inclusion of the *Working Scientifically – Investigating* outcome, students will be assessed and rewarded for developing investigation skills.

Students who are passive followers of teachers' instructions and worksheets on structured practical exercises will find it difficult to become autonomous decision-makers within open investigation tasks. Students will need scaffolding (Vygotsky, 1978) to provide a framework which supports them in making decisions about planning and conducting investigations.

Planning and report sheets developed in the Western Australian trial of the *Working Scientifically – Investigating* strand have been found useful by teachers in leading students through a sequence of decision-making steps as they plan and conduct their investigation, analyse their data and evaluate their investigation.

The support provided by the sheets reduces the students' dependence on teachers for instructions and thereby reduces the teachers' management problems.

The sheets also provide a mechanism for students to record their thinking and doing at the various phases of investigation and therefore to collect information needed by teachers for assessment purposes.

Scaffolding students' investigations, using planning and report sheets

Planning and report sheets have been developed for students at different levels of experience and competence with investigations. The first sheet (see Appendix 1) has been used by children with good language skills in the early and middle childhood years. This sheet is structured using the following statements and questions:

Question	Purpose of question
I am going to investigate ...	Students focus on the problem and formulate a question for investigation.
What I think will happen	Students make a prediction.
Why I think it will happen	Students justify their prediction using existing knowledge, beliefs and experiences. Prior knowledge is activated.
What I am going to do	Students plan the procedure.
What I will need	Students identify materials and equipment needed for their investigation.
How I will make it a fair test	Students refine their plan to ensure that tests are fair and variables are controlled.
What happened	Students record their observations and measurements.
Was this what I expected?	Students compare what happened with their prediction. It may force them to confront any discrepancies between their beliefs and their data.
Why it happened	Students construct an explanation for their data.
What was difficult for me?	Students reflect on what they did, how they did it, what was difficult and, perhaps, what was not done well.
How I could improve this investigation	Students identify weaknesses in their investigation and outline improvements that could be made.

Figure 5. Statements and questions from the early and middle childhood planning and report sheet

The second planning and report sheet (Appendix 2) is usually introduced early in the middle childhood phase of development and then used through this phase and that of early adolescence.

This sheet incorporates a grid for graphing results and some additional and more demanding questions:

1. What are you going to investigate?
2. What do you think will happen? Explain why.
3. Which variables are you going to:
   - ➨ change?
   - ➨ measure?
   - ➨ keep the same?
4. How will you make it a fair test?
5. What equipment will you need?
6. What happened? Describe your observations and record your results.
7. Can your results be presented as a graph?
8. What do your results tell you? Are there any relationships, patterns or trends in your results?
9. Can you explain the relationships, patterns or trends in your results? Try to use some science ideas to help explain what happened.
10. What did you find out about the problem you investigated? Was the outcome different from your prediction? Explain.
11. What difficulties did you experience in doing this investigation?
12. How could you improve this investigation, e.g. fairness, accuracy?

Figure 6. Questions from the middle childhood and early adolescence planning and report sheet

A third planning and report sheet (Appendix 3) is generally suitable for students in middle and late adolescence, including secondary students who are preparing an entry for the Science Talent Search. This worksheet uses more formal language and incorporates more demanding questions than the earlier sheets.

1 What is the problem you are investigating?

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

3 What variables may affect the phenomenon you are investigating?

4 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)

5 How will the independent variable be changed in the experiment?

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

7 How will you measure the dependent variable?

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

9 Predict what you think will happen. Explain why.

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

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

12 Are there any special safety precautions?

13 Carry out some preliminary trials. Were there any problems?

14 How did you modify your experiment to fix the problems?

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

16 How did you make sure your data were accurate?

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

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

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

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

21 How confident are you of your conclusions?

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

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

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

Figure 7. Questions from the middle and late adolescence planning and report sheet

The Five Steps of Investigation

First

Write a short statement that makes clear what the problem is that you have to solve. Also write a research question or hypothesis, and then a prediction. Give a reason for your prediction.

Second

Write a plan which says what you intend doing. Say what you will do to make any tests fair. Explain what measurements are to be made and how they will be made. Draw a diagram to show how the equipment will be used to conduct your tests.

Third

Carry out your investigation and record all your observations and measurements. If you found that you needed to change your plan write down what changes were made and why they were necessary. Present your data in a way that helps show the patterns or trends in your results.

Fourth

Write a couple of paragraphs in response to these questions: What patterns or trends were present in the results? How do you explain the patterns? What did your results show you about the question or hypothesis that you were investigating?

Fifth

Write a paragraph that evaluates your investigation. Were your findings what you expected? To what extent did you reduce the errors associated with measurement, controlling variables and sampling?

Figure 8. A five-step scaffold for a student investigation.

Students who have had considerable experience in conducting their own investigations and have developed a schema for planning investigations may have the scaffolding reduced.

When assessing students' investigation skills, it may also be appropriate to present the task in a form that has less scaffolding. In these circumstances, the format shown in Figure 8 may be appropriate for presenting the task.

A photocopy master is provided as Appendix 4.

Other scaffolding tools

Students often need additional guidance and support to help them write a question for investigation or plan the design of the investigation so that tests are fair by controlling variables. Three additional scaffolding tools that address these problems are described here. Teachers need to model their purpose so that students can understand how to use them.

➥ The researchable-questions algorithm

The general structure of a researchable question is illustrated below, with two gaps to be filled.

What happens to ___*(DV)*___ when

we change ___*(IV)*___ ?

The gaps correspond to the dependent variable and the independent variable. This scaffold, without naming the types of variables with younger children, can be used to help children write their own questions.

For example: What happens to the growth of wheat when we change the salinity of the water?

From researchable questions students can learn to write hypotheses. Hypotheses are statements of tentative ideas to be tested which are expressed in the form of a relationship between an independent variable and a dependent variable. The general structure of an hypothesis is therefore:

(This change in the independent variable) + (will cause this to happen to) + (the dependent variable).

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

Researchable questions tend to be used with younger children, when the independent variable is discrete, and when there is little prior knowledge and experience of the phenomenon to guide the writing of an hypothesis. To write an hypothesis, the students must have sufficient observations, experience and knowledge of the phenomenon to state the expected relationship between the variables.

➥ 'Cows Moo Softly' is a useful scaffold to remind students how to plan a fair test

- **C**hange something
- **M**easure something

  and
- Keep everything else the **S**ame

➥ Variables tables

Variables tables are useful tools for helping students to plan controlled experiments and develop an understanding of the three types of variables that need to be considered in the planning phase.

Figure 9 shows a completed variables table for an experiment to investigate the question 'How does the amount of light affect the growth of seedlings?'

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**

***Figure 9. A completed variables table** (Hackling & Fairbrother, 1996)*

Cooperative learning strategies for effective investigation work

The effectiveness and success of all small-group work is dependent on students having a clear understanding of the task to be completed, sufficient prior knowledge and skill for the task, sufficient time and cooperative learning skills.

The *Primary Investigations* curriculum structures small-group work with groups of three using three roles:

- The equipment **manager,** who is responsible for collecting, checking and returning equipment;
- The **speaker,** who is the only group member who can ask the teacher or another group's speaker for help, and only after the group has formulated a clear question; and,
- The **director,** who is responsible for making sure that the team understands the task and steps to be followed.

In secondary schools where group sizes are often increased to four members, an additional role can be used:

- The **reporter,** who is responsible for reporting back to the class on the group's findings.

A photocopy master of these four group roles is provided as Appendix 5.

Basic skills for effective and cooperative group work include:

- moving into your groups quickly and quietly;
- speaking softly so that only your team-mates can hear you;
- staying with your group;
- using your team-mates' names;
- looking at the person speaking to you;
- letting others finish without interrupting;
- praising others; and
- treating others politely.

These expectations can be communicated to students through instructions, rules and modelling. It is useful for students to complete self-evaluation exercises to give feedback on their development of these cooperative learning skills.

Once these basic skills are established, more advanced skills can be introduced, including:

- encouraging others to participate;
- being sure that everyone understands;
- disagreeing with the idea not the person; and
- generating alternative ideas and explanations and choosing the explanation which best fits the data.

Assessing open investigations using Student Outcomes

Purposes of assessment

In the past, much of the energy and time devoted to assessment has been used for **summative** purposes: that is, to generate grades for reporting. Unfortunately, this assessment has not contributed to the improvement of learning because the data are commonly collected at the end of a unit of work after the learning has occurred. The assessment framework provided by the Student Outcomes provides a developmental continuum to structure **formative** assessment that is conducted during a unit of work and is used to provide feedback to teachers and learners about what has been achieved and what must be learned next. Because the Outcomes are criterion referenced and in levels, they provide standards that can also be used by the school and the system for **quality assurance** purposes.

Sources of assessment information

In early childhood classes, teachers' observations of children at work, students' drawings and oral questioning of children by the teacher are important sources of information. As children develop skills of written communication, written work samples become valuable. At various stages of investigation, groups may report back to the class on progress achieved. These oral reports also give the teacher insights into students' investigation skills. The relative importance of these different sources of information at different levels is illustrated in Figure 10.

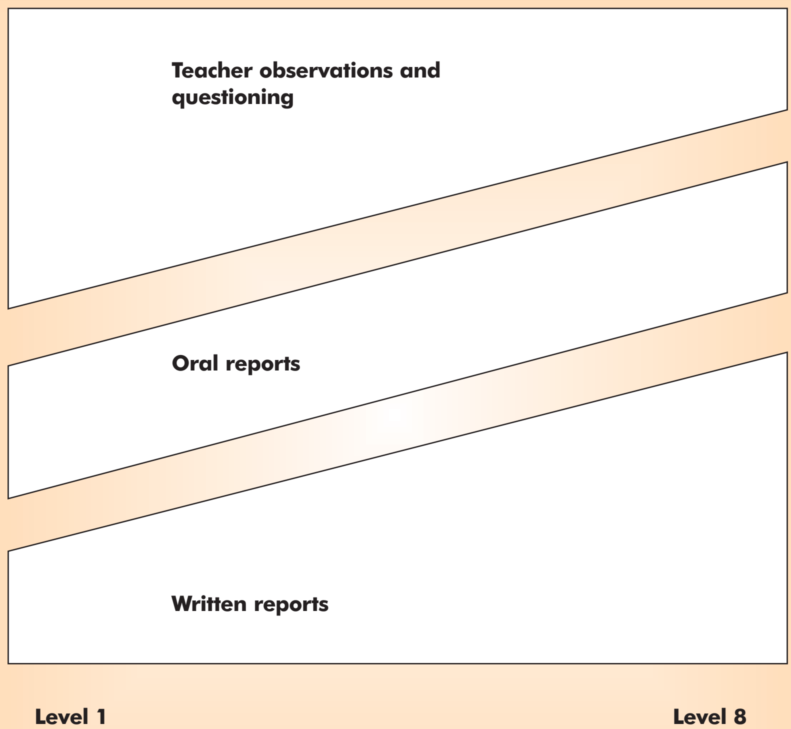


Figure 10. Sources of assessment data and their relative importance as children's skills develop

The collection of assessment information, in the form of written work samples, for making judgements about students' levels of work in *Investigating* is facilitated by using the planning and report sheets.

The questions on the sheets elicit from students information that is needed to make judgements using Outcome. The questions are linked to the assessment criteria in the Planning, Conducting, Processing and Evaluating aspects of *Investigating outcome.*

Observational data can be recorded as anecdotal records on adhesive tags, checklists or directly onto the students' planning and report sheets. Observations can be recorded on an opportunistic basis or may be pre-planned.

Collecting information and making judgements are progressive processes. A few early observations and work samples may be assessed informally to make tentative judgements, to guide teaching and learning, and to identify further information that must be collected to make a more considered and confident judgement that might be used for summative purposes.

It is efficient, initially, to collect as much information as possible in the form of written work samples and then to identify what further information is needed. Additional or missing information may be collected by returning the written report to the student with a request to document particular missing information or, where necessary, by observing subsequent investigations.

Following the investigation, when students have completed further reading and discussion of concepts related to the investigation, it would be useful to return their planning and report sheets and ask them to write, on a separate sheet of paper, one or two paragraphs interpreting their results in terms of the concepts discussed in class. This explanation will provide evidence about conceptual development and can be stapled to the back of the planning and report sheet.

Students' performance will be influenced by group membership, task and context variables. It is therefore necessary to collect several samples spanning different tasks and contexts and to make an 'on-balance' judgement of the level at which the student is working. Where there is a concern about collecting information about a particular student, that is not contaminated by the thinking of other group members, it may be necessary to implement the occasional investigation by following this procedure:

1 Set the context and introduce the problem to be investigated.
2 Students work individually to plan the investigation, recording their plans on planning and report sheets.
3 Collect the students' plans.
4 Discuss the various approaches devised by the students and, through whole-class discussion, select the best plan.
5 Students work in groups to carry out the experimental work and collect the data.
6 Students work individually using planning and report sheets to record their analysis of the data and their evaluation of the investigation.
7 Collect the planning and report sheets for assessment.

Using the Outcome to make judgements about students' achievement

The Outcome for the *Investigating* assessment framework is shown as Appendix 6.

The Foundation Outcome Statement (FOS) has been included for children with disabilities. Higher levels of investigating are described as a developmental continuum through Levels 1-8. These levels of achievement of *investigating* outcomes do not correspond with grade/year levels.

When the outcomes were first written in the *Curriculum Profile for Australian Schools* (Curriculum Corporation, 1994), there was an expectation that many year 3 students would be working at Level 2, many year 7 students would be working at Level 4 and many year 10 students would be working at Level 6.

Data obtained from research (Hackling & Garnett, 1995), trialing of outcome statements in Western Australian schools, and from the 1993 *Monitoring Standards in Education* tests (Education Department of Western Australia, 1994) indicate that these assumptions were a little ambitious, especially for years 7 and 10, and it appears that students will need the opportunity to practise these skills over several years to attain these levels of achievement.

Prior to the widespread implementation of open investigation work in schools, there has been insufficient opportunity for students to practise these skills.

The aspects are used for making judgements – for Planning, Conducting, Processing and Evaluating – which can identify strengths and weaknesses in students' investigation achievement.

The process of using the outcome to make judgementsabout the level of work demonstrated by a work sample is illustrated using an extract from a work sample provided by Tim, a year 6 student (Figure 12). Tim was investigating the effect of changing the weight of an empty ice-cream container, by adding sand, on the distance it could be propelled across the floor using an elastic band stretched between the legs of a chair.

This extract from Tim's work sample shows his planning for the investigation. Some of the variables to be considered have been identified – weight and distance. The sample is therefore at least at Level 2 for planning. In addition to this, there is evidence of some awareness of the need for fair testing '... using the same band and the same container'.

The sample also includes a prediction: 'I think the container with a bit of weight would go the furthest'. The sample therefore meets the requirements of Level 3.

What I am going to investigate I am going to investigate whether the weight of container affects how far it goes.

What I think will happen I think the conainer with a bit of weight would go the furthest.

Why I think it will happen I think it will happen because it is not too heavy nor too light

What I am going to measure I am going to measure how heavy the container is and how far it goes. (The weight and the distance)

What I will need sand, container, scales, elastic band, chair, desk.

How I will make it a fair test I will make it a fair test by doing more ~~to~~ than one test, using the same band and the same container.

What happened The container with nothing in it went the furthest. Results in table below.

	Test 1	Test 2	Test 3	Ave.
0gms	178cm	245cm	220cm	214.3'cm
100gms	75cm	74cm	60cm	69.6'cm
200gms	22cm	65cm	70cm	52.3'
300gms	25cm	60cm	50cm	45cm
400gms	38cm	20cm	30cm	29.3'cm

Why it happened The light one went the furthest becaus there is no weight pulling it back.

How I could improve this investigation I could have improved this investigation by being more organised and getting my measurements excact

The sample also meets the expectations of Level 4, in that the student identifies the variable to be changed (weight), the variable to be measured (distance) and at least one variable to be controlled (same band and container).

The sample does not show evidence of formulating a question or hypothesis and there is no evidence that the key variable of how far the band was stretched back was being controlled.

It would appear that, from the available evidence, the work sample represents planning at Level 4. Tim may have controlled the distance that the band was pulled back, but simply not recorded it on the planning and report sheet.

For this reason, written work samples do need to be supplemented with observational data.

Using formative assessment to inform teaching and learning

The continuum of outcomes in the assessment framework is a basis for providing appropriate formative assessment feedback to students: for example, a student who is investigating the effect of the height from which a ball is dropped on the height to which it bounces may only be taking one measurement or conducting one trial at each drop height. The failure to make repeat trials at each drop height may be the only thing preventing the student from achieving Level 4 for *Conducting Investigations*.

An effective way to help the student understand the need for repeat trials is to ask if he or she thinks that if the ball was dropped from the same height several times, it would bounce to the same height each time. If the student predicts that the ball will bounce to the same height each time, ask for the repeat trials to be performed to illustrate the variation in the heights that occurs.

A discussion of the sources of error will then help the student to understand the variations that occur due to measurement error and lack of control over variables and the need for repeat trials and averaging. Locating a student on the continuum and identifying which skills are preventing movement to the next level informs the teacher about the experiences that need to be provided for the student to develop the skills required to move to the next level.

Using portfolios for assessment of open investigation work

Portfolios provide a useful approach to involving students in collecting evidence to demonstrate their learning in the *Investigating Scientifically* outcome.

Judgements about a student's level of competence need to be based on a collection of work samples because performance is influenced by task and context variables. A reliable judgement, therefore, should be made as an 'on-balance' judgement across, say, four or five investigation work samples.

The involvement of students in selecting which samples are included in the portfolio requires them to consider the features of a good investigation – what criteria distinguish poor, average, good or outstanding investigation work?

The provision of clearly expressed outcomes may encourage dialogue which will help students to understand the requirements for improved performance.

Appendix 7 shows how outcomes can be written in a form accessible to students, and provides a self-evaluation worksheet that can be used by students to evaluate their own work—identifying their strengths, weaknesses and what they need to do better.

Once students have conducted their self-evaluation, the teacher can go through the same process.

The completed evaluation sheet enclosed with the portfolio provides useful information to parents and would provide a focus for a parent-teacher interview.

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Working Scientifically

Appendix

1: Early and middle childhood planning and report sheet

2: Middle childhood and early adolescence planning and report sheet

3: Early and late adolescence planning and report sheet

4: The five steps of investigation

5: Roles for cooperative group work

6: *Investigating Outcome*

7: Science investigations self-evaluation checklist

Planning and Report Worksheet for Science Investigations

Student name ____

Other members of your group ____

I am going to investigate:

What I think will happen:

Why I think it will happen:

What I am going to do:

What I will need:

How I will make it a fair test:

What happened:

Was this what I expected?

Why it happened:

What was difficult for me?

How I could improve this investigation:

Planning and Report Worksheet for Science Investigations

Student name ____ Class ____________________

Other members of your group____

What are you going to investigate?

What do you think will happen? Explain why.

Which variables are you going to:

- change?

- measure?

- keep the same?

How will you make it a fair test?

What equipment will you need?

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, for example, 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?

The Five Steps of Investigation

First

Write a short statement that makes clear what the problem is that you have to solve. Also write a research question or hypothesis, and then a prediction. Give a reason for your prediction.

Second

Write a plan which says what you intend doing. Say what you will do to make any tests fair. Explain what measurements are to be made and how they will be made. Draw a diagram to show how the equipment will be used to conduct your tests.

Third

Carry out your investigation and record all your observations and measurements. If you found that you needed to change your plan, write down what changes were made and why they were necessary. Present your data in a way that helps show the patterns or trends in your results.

Fourth

Write a couple of paragraphs in response to these questions: What patterns or trends were present in the results? How do you explain the patterns? What did your results show you about the question or hypothesis that you were investigating?

Fifth

Write a paragraph that evaluates your investigation. Were your findings what you expected? To what extent did you reduce the errors associated with measurements, controlling variables and sampling?

Roles for Cooperative Group Work

Manager

The equipment manager is responsible for collecting, checking and returning equipment.

Speaker

The speaker is the only group member who can ask the teacher or another group's speaker for help, and only after the group has formulated a clear question.

Director

The director is responsible for making sure that the team understands the task and steps to be followed.

Reporter

The reporter is responsible for reporting back to class on the group's findings.

Investigating	FOUNDATION	LEVEL 1	LEVEL 2	LEVEL 3
Students investigate to answer questions about the natural and technological world, using reflection and analysis to prepare a plan: to collect, process and interpret data: to communicate conclusions: and to evaluate their plan, procedures and findings.	I F **The student:** Explores, uses and responds to changes to objects and events, and indicates preferences based on experiences.	I 1 **The student:** Focuses on a problem, responds to teacher's suggestions to carry out simple activities requiring observation and sharing of observations.	I 2 **The student:** When given a focus question and a familiar situation, contributes elementary ideas about variables and procedures, collects and makes limited records of data and can say whether what happened was expected.	YEAR 7 I 3 **The student:** Shows some awareness of the need for fair testing and makes simple predictions; collects and organises numerical data and descriptive information using simple tables, diagrams and graphs: and identifies main features, patterns and difficulties in the investigation.
Planning Students plan investigations to test ideas about the natural and technological world.	I F.1 Recognises, identifies and explores familiar objects and events in the environment.	I 1.1 Focuses on problems and responds to teacher's suggestions and questions.	I 2.1 Identifies, given a focus question in a familiar context, some of the variables to be considered.	YEAR 5 I 3.1 Plans for investigations, showing some awareness of the need for fair testing; and makes simple predictions (not guesses) based on personal experience.
Conducting Students collect and record a variety of information relevant to their investigations.	I F.2 Explores the environment using the senses.	I 1.2 Carries out activities involving a small number of steps; and observes and describes.	I 2.2 Observes, classifies, describes and makes simple non-standard measurements and limited records of data; and uses independent variables that are usually discrete.	I 3.2 Uses simple equipment in a consistent manner using standard measurements and records data such as in simple tables, diagrams or observations.
Processing data Students translate and analyse information to find patterns and draw conclusions to extend their understanding.	I F.3 Responds to an object or event.	I 1.3 Shares observations.	I 2.3 Makes comparisons between objects or events observed.	I 3.3 Displays numerical data as tables or graphs, such as bar graphs, and identifies patterns in data and summarises the data.
Evaluating Students reflect on an investigation, evaluate the process and generate further ideas.	I F.4 Demonstrates choice-making skills.	I 1.4 Expresses their feelings and thoughts about the experiment and can point to a part of the experiment that went well or where they had difficulty.	I 2.4 Comments on what happened and can say whether what happened was expected.	I 3.4 Identifies difficulties experienced in doing the investigation.

LEVEL 4	LEVEL 5	LEVEL 6	LEVEL 7	LEVEL 8
YEAR 9 I 4 **The student:** Plans and conducts different types of investigations, taking account of the main variables; collects data using repeat trials or replicates; explains patterns in data or information prepared in different formats; and makes general suggestions for improving the investigation.	I 5 **The student:** Interprets a situation to formulate a plausible relationship to investigate using experimental techniques, including the control of several variables and the use of preliminary trials or various information sources; develops scientific explanations that are consistent with the data; and makes specific suggestions for improving the investigation.	I 6 **The student:** Uses scientific knowledge to analyse a problem, identify variables and formulate questions for investigation; develops methods that provide specific, accurate, consistent information which can be used to evaluate the question; recognises inconsistencies with the data; and suggests ways of reducing error.	I 7 **The student:** Identifies from research a significant scientific issue for investigation and develops procedures to systematically produce a series of precise, accurate data and/or information; draws credible conclusions that are consistent with own and other detailed data; and recognises limitations, acknowledges sources of error and proposes various improvements.	I 8 **The student:** Shows an a priori knowledge of the need to take into account particular issues and factors when conducting an investigation; and analyses critically procedures and results to produce valid and reliable information to inform the ongoing refinement of investigation designs and techniques.
I 4.1 Identifies the variables to be changed, the variable to be measured and at least one variable to be controlled or, in a descriptive study, plans for the types of observations that need to be made.	I 5.1 Interprets a situation, formulates a question or hypothesis for testing, and plans an experiment in which several variables are controlled.	I 6.1 Analyses problems, formulates a question or hypothesis for testing, uses scientific knowledge to identify main variables to be considered and make predictions, and plans for accurate measurement.	I 7.1 Identifies own real-world problem for investigation, uses reference material in developing an understanding of the problem, and plans one or more experiments in an ongoing investigation.	I 8.1 Shows, in planning and working independently, an *a priori* recognition for the need for control of variables, accuracy of measurement, adequate sample size and repeated trials or replications.
I 4.2 Takes care with data collection so that data are accurate; uses repeated trials or replicates; and uses independent variables that are usually continuous.	I 5.2 Uses equipment that is appropriate for the task; and uses preliminary trials of the investigative procedure to improve the procedure or measurement techniques.	I 6.2 Decides what is needed and requests equipment for the investigation; and selects equipment and instruments that enhance the safety and accuracy of measurements and observations.	I 7.2 Makes systematic observations and measurements with precision, using standardised techniques and recognises when to repeat measurements.	I 8.2 Makes judgements about the accuracy required; range and intervals of measurement, and decides what observations are necessary and sufficient in qualitative work.
I 4.3 Calculates averages from repeated trials or replicates; plots data as line graphs where appropriate; and makes conclusions which summarise and explain patterns in the data.	I 5.3 Makes conclusions which are consistent with the data and explains patterns in the data in terms of scientific knowledge.	I 6.3 Selects the type of graph and scale that display data effectively; and draws conclusions which are consistent with the data, explained in terms of scientific knowledge and related to the question, hypothesis or prediction.	I 7.3 Draws conclusions which are consistent with the data, explains them in terms of scientific knowledge and does not over-generalise; and questions whether the data are sufficient to support the conclusions drawn.	I 8.3 Identifies anomalous observations and measurements and allows for these when drawing graphs and conclusions; and draws conclusions which show awareness of uncertainty in data and does not over-generalise, and includes a discussion of limitations, the methods of data collection and/or design.
I 4.4 Makes general suggestions for improving the investigation.	I 5.4 Suggests specific changes that would improve the techniques used or the design of the investigation.	I 6.4 Recognises inconsistencies in the data, identifies the main sources of error and suggests improvements that would reduce the source of error.	I 7.4 Recognises sources of measurement error, limitations in sampling and inadequacies in control of variables, and explains how these deficiencies can be remedied.	I 8.4 Evaluates the findings and the experimental design, reformulates the problem and plans follow-up experiments in an ongoing investigation, and makes refinements to experimental techniques and design.

Science investigations self-evaluation checklist

What I can do well:

Level	Skills of planning the investigation	Yes / No
1	When we plan the investigation I can say what I know about the topic and can say what we want to find out.	
2	When we plan the investigation I can say which things we could change or measure.	
3	When we plan the investigation I can say how to make it a fair test.	
3	I can say what will happen before we do the test.	
4	I can identify the thing we will change, the thing we will measure and one thing that we must keep the same.	

Level	Skills of doing the investigation	Yes / No
1	I can say what I have done and what happened.	
2	I can use pictures and write words to say what happened.	
3	I can make measurements and record what happened as lists, diagrams or as a table of results.	
4	I am careful to make sure my measurements are accurate and to do three trials for each test.	

Level	Skills of analysing the results	Yes / No
1	I can say what happened.	
2	I can say what happened differently when we changed things.	
3	I can show my results as a table and bar graph and explain the pattern in the results.	
4	I use averages when I draw graphs, can explain the pattern in the results and say why it happened that way.	

Level	Skills of evaluating our investigation work	Yes / No
2	I can say if what happened was what we predicted.	
3	I can explain the difficulties we had doing the investigation.	
4	I can say how we could improve our investigation.	

Student self-evaluation

	Planning investigations	Doing the experiment and collecting the results	Recording and explaining the results	Evaluating our investigation work
My strengths				
My weaknesses				
What I need to do better				

Teacher's evaluation

	Planning investigations	Conducting investigations	Processing data	Evaluating the investigation
Strengths				
Weaknesses				
How you can improve your investigation work				
Level attained				