Working Scientifically
Background

Science involves a distinctive way of looking at and thinking about the world. Science has many methods of investigation, but central to all scientific inquiry is the notion that evidence forms the basis of defensible conclusions. Through the processes of scientific inquiry, scientists develop answers to questions and improve explanations for phenomena in the natural world. A scientific idea must be framed in a way that is testable and can be either refuted or confirmed by observation or experiment (empirical evidence). Scientific knowledge is refined and extended as new evidence arises or existing evidence is re-conceptualised.

Introduction

This support material has been designed to assist teachers to understand key aspects of the Working Scientifically skills strand of the *Science K–10 (incorporating Science and Technology K–6) Syllabus* and to incorporate these aspects into their learning program. The introduction provides an overview of the resource, with links to the sections containing more details.

The Working Scientifically processes in the *Science K–10 (incorporating Science and Technology K–6) Syllabus* are:

- questioning and predicting
- planning investigations
- conducting investigations
- processing and analysing data and information
- problem-solving
- communicating.

These processes are at the centre of learning and teaching in Science.

Through investigations that engage them in scientific inquiry, students develop their knowledge of ideas and concepts and gain understanding of the importance of evidence in formulating and evaluating explanations in the development of scientific ideas. At each stage of the teaching program, learning experiences should be provided in which students identify questions or problems to be scientifically investigated. They should use the processes of Working Scientifically to test ideas, gather data/information, and seek evidence to support their explanations, arguments, answers to questions and solutions to problems.

The learning/teaching program should challenge students to be questioning, reflective, critical thinkers and creative problem-solvers. It will do this when the learning experiences in each unit actively engage students in hands-on practical experiences in which they use the skills and apply the processes of Working Scientifically to:

- identify interesting, authentic questions and problems relevant to their lives
- plan and conduct their own investigation
- collect, process and present data and information
- review and evaluate their procedures, findings and ideas
- challenge their ideas and understanding based on the evidence
- communicate their conclusions
- pose more questions.

In each year the learning/teaching program should include scientific investigations with a range of types of practical experiences that provide opportunities to:

- target different syllabus outcomes
- balance the different types of first-hand experiences such as demonstrations, research activities, fieldwork, closed practical exercises and open-ended investigations
- actively engage students in practising and applying a variety of equipment and techniques, including digital technologies, to gather, process and present first-hand data/information and that from secondary sources
- involve students in team, group and class activities to share their ideas and findings and to develop their understanding of science as a collaborative enterprise.

In each year students must actively participate in a range of hands-on practical experiences in which they apply the skills and processes of Working Scientifically if they are to extend their understanding of the nature of science and how scientific ideas, explanations and concepts develop through the processes of scientific inquiry. They need to not only master the skills described in the Working Scientifically strand of the syllabus for each stage, but also develop an understanding about what these skills are for, how they relate and when and how to use them in their own investigations.

Recipe-style, worksheet-based classroom and laboratory exercises may be helpful in developing a specific skill, or illustrating a technique or concept. When these types of activities dominate the learning, however, there is limited scope for students to engage in the range of hands-on experiences needed in each stage to develop the full set of skills or to gain an understanding of the processes of Working Scientifically.

The stage statements and K–10 continuum of learning in the syllabus provide an overview of the development in the skills of the Working Scientifically strand across Early Stage 1 to Stage 5. Students entering each year bring with them understanding and skills from their prior learning experiences. The emphasis in learning would progress towards students practising and applying their skills in Working Scientifically in new and increasingly complex situations as independent learners. Teacher guidance and support will vary, depending on each student's level of skills, knowledge and understanding.

Teachers could use the Science K–10 syllabus outcomes and content mapping grids as a tool in planning and reviewing the skill development within and across stages. The skills learning experiences can be broadly classified into one of three developmental levels. In the learning phase the teacher establishes the student's skill level and uses this as the basis for developing student understanding through explicit teaching of the relevant skills component. In the practising phase the student uses the skills in tasks to achieve specific goals. The application phase is when the student independently uses the skills in the course of regular work and as a foundation for the development of learning. Based on an analysis of the learning experiences in all units of work, the teaching program can be evaluated and modified to ensure that, in addressing the skills content of the syllabus, there is a continuum in the development within a stage and across stages.

When developing the units of work for the Stage 4 and Stage 5 learning program, keep in mind that the hands-on practical experiences:

- must occupy a minimum of 50 percent of allocated course time
- must include in each stage, at least one substantial student research project (SRP), one of which involves a hands-on practical investigation
- in Stage 5 must include at least one SRP which is an individual task
- should be carefully integrated within relevant science ideas/concepts so that students are able to make meaningful links between what they are doing and how this learning relates to developing their knowledge of and understanding about science
- should provide opportunities for students to continually develop their understanding of and expertise in using the skills and applying the processes of Working Scientifically.

In planning and conducting practical experiences, all students need to have a sound understanding of their responsibilities for implementing appropriate procedures in relation to the policies involving:

- safety in science
- use of animals in teaching and research.

Scientific investigations

A review of current literature identifies a range of reasons for the inclusion of practical experiences in the learning program. Depending on students' understanding and skills, practical experiences provide opportunities for:

- motivation and enjoyment of science
- stimulating curiosity and creativity
- conceptual development
- developing investigation and problem-solving skills
- developing techniques and manipulative skills associated with using scientific equipment
- providing concrete experiences of natural phenomena
- experiencing and developing an understanding of the nature and practice of science
- learning to work cooperatively
- language development
- developing positive attitudes towards, and values about, themselves, others, learning as a lifelong process, and science and technology.

The reason for including the practical experience in a learning sequence will determine the type of practical investigation that is selected. In the research literature, science investigations have been classified in different ways. One classification is based on the methods of data collection or the design of the investigation. These methods include:

- comparative or descriptive studies typical of field biology and the earth sciences
- researching, analysing and explaining data collected and reported by other scientists
- testing types of materials, eg strength of steel, durability of paint etc
- chemical analyses
- survey research where populations are sampled to investigate relationships between variables
- investigating a relationship between two variables where repeat trials can be used
- investigating a relationship between two variables where replication can be used
- investigating the effect of several independent variables on one dependent variable (often associated with a design problem).

Types of practical investigations

Students develop their skills in applying the processes of Working Scientifically through regular, active participation in a range of collaborative and individual hands-on practical experiences. Their scientific investigations should emphasise a range of types of hands-on activities and include:

- laboratory investigations including fair tests and controlled experiments
- practical activities outside the classroom including surveys and fieldwork carried out in the natural environment
- open-ended investigations including student research projects
- research using a variety of print and multimedia, as well as internet and electronic sources of data and information
- a range of strategies and technologies to collect and record data, including appropriate use of digital technologies, eg data loggers
- using and constructing models
- using or reorganising second-hand data including those in spreadsheets and databases
- extracting and reorganising information in the form of flow charts, tables, graphs, diagrams, prose, keys, spreadsheets and databases
- using digital technologies, eg computer animations and simulations, to capture and analyse data and information
- presenting data and information in multimodal texts.

Open-ended investigations

Not all investigations can be defined as open-ended investigations. One approach (Hackling 2005) to determining the degree of openness is to classify the practical experience into three levels according to five criteria depending on the choice allowed to students. These criteria are the:

- problem that is to be solved
- equipment/resources needed to undertake an investigation
- procedure planned or proposed for the investigation
- possible answers to the posed problem
- most common answer given to the posed problem.

Using this classification, open-ended investigations would be those in which the student decides the problem to be investigated and the problem has many facets, can be investigated in a number of ways using different equipment and/or resources and does not have an expected or set answer that needs to be verified.

The planning component and the problem-solving nature of open-ended investigations distinguish them from other types of hands-on practical experiences. For open-ended investigations to be meaningful learning experiences, and for students to successfully participate, they need to have developed an appropriate level of skills and understanding of using and applying the processes of Working Scientifically.

Through their experiences in performing different types of hands-on practical experiences, students should develop a range of skills and gain an understanding of the purposes of, and processes involved in, investigations in science. To effectively undertake open-ended investigations, they need to have skills and experience in analysing problems, formulating a testable question, and planning and conducting their own experiments. Those students who are passive followers of instructions in practical experiences will find it difficult to become autonomous decision-makers when attempting open-ended investigation tasks.

Students need opportunities to engage in a variety of open-ended investigations if they are to develop the skills of Working Scientifically, including the critical thinking and problem-solving skills that lead to a more scientific understanding of their world and the way science works. The amount of teacher guidance needed for the open-ended investigation will depend on students' prior experience and skills in performing first-hand investigations. The use of scaffolds is an important strategy to guide students in planning and conducting their open-ended investigation.

Across Stage 4 and Stage 5 students are expected to develop and extend their skills in undertaking open-ended investigations. During Stage 4 and Stage 5 all students are required to undertake at least one substantial student research project that involves a hands-on practical investigation. Student research projects provide opportunities for students to apply their skills and understanding of the processes of Working Scientifically in hands-on, open-ended investigations. By Stage 5 students should need less teacher guidance and demonstrate greater independence in their learning when undertaking their individual student research project.

If students understand the meanings of the key words in the Board of Studies Glossary of Key Words and the relationships between them (Attachment 1), they will have an effective tool for activities involving interpreting, processing and presenting ideas, information and evidence in oral and written text. It is important that key words are not used in an overly prescriptive way, but they are useful in developing students' understanding of and skills to address the requirements of the activity and/or task.

Processing and presenting data and information

Different types of practical experiences will provide opportunities for students to practise and apply different approaches to accessing, collecting, analysing and communicating data and/or information. In planning and evaluating Science learning units, teachers should check that the data-handling skills required are consistent with those identified for the same stage in the *Mathematics K–10 Syllabus.*

In presenting questions, problems, observations, results and findings from their hands-on practical experiences, the mode and media selected should be appropriate to the type of practical experience and the purpose for which it has been included in the unit of work. The students' records of their practical activities should be stage-appropriate and enable them to make meaningful links between the question/problem raised, what they did in seeking evidence, further questions that they identified and how their learning relates to their knowledge of and understanding about science.

In recording their practical experiences students should write in their own words using clear, correct, concise plain English. It is not a syllabus requirement that students should write reports of their practical experiences in the past tense, using the third person, passive voice. Presenting all practical experiences using the headings of Question, Method, Results, Discussion and Conclusion is also not a syllabus requirement and is not appropriate in simple experiments to develop skills in using scientific equipment or those involving the verification of concepts. Their records should be appropriate for the type of hands-on practical experience. Students should clearly communicate why and how they undertook the practical experience and their results and findings.

Processing data in science

Hands-on practical experiences provide opportunities for students to extract data and/or information from graphs, flowcharts, diagrams, databases, other texts and multimedia resources. The syllabus also requires students to demonstrate skills in using a range of representations to organise data and/or information including tables, graphs, flow charts, diagrams, spreadsheets and databases to show trends, patterns and relationships.

From Stage 3 to Stage 5 students should also be able to construct and use a variety of specified types of graphs. At each stage of the Working Scientifically strand in Science the understanding of, and the level of skills required in, graphing are consistent with that for the same stage in the *Mathematics K–10 Syllabus.*

Observations and measurements of variables can be presented as discrete or continuous.

- Discrete data are in categories such as gender, type of animal, brand of paper towel, colour.
- Continuous data are associated with measurements involving a standard scale with equal intervals such as height of plants in centimetres, the amount of fertiliser in grams and the length of time in seconds.

Data may be represented in tables or graphs. A table emphasises the absolute value of the component data while a graph emphasises the relative value of the data and is a visual representation of comparative data.

Tables

Information is presented in tabular form to facilitate organising and accessing the information and to identify any distinguishing patterns. Tables give information in a matrix, that is columns and rows, organised for easy comparison. The deciding factor in the organisation of information in tabular form should be whether it assists the reader or viewer to access or interpret the information.

When presenting information in a table, the following features would be considered good practice:

- the table should have a title
- every column and row should have a label
- the units of measurement should be identified in the column headings
- figures in each column or row should be aligned
- a zero should only be used when a measurement of zero is obtained (a dash is used when no reading is recorded)
- identical results should be written again, not shown with 'ditto marks'
- the same item should not appear in more than one category
- show totals, subtotals, and/or percentages where relevant.

Graphs

Graphs are a convenient method of organising and displaying data/information and can be used to:

- present and interpret data and/or information
- present the results of an experiment
- monitor the progress of an experiment
- make a comparison with theory
- investigate whether data fits the mathematical model
- indicate the degree of reliability of the data
- determine the value of some quantity
- identify an empirical relationship between two quantities or help in the derivation of empirical equations
- express relationships visually to communicate data and/or information clearly and succinctly.

The skills related to graphing enable students to select and construct types of graphs and use graphs to extract and interpret information. By Stage 4 and Stage 5 students should be able to select and construct appropriately a range of graph types to represent particular data, including histograms and column, sector and line graphs. The type of graph chosen should be appropriate for the type of data and the one that best allows the data and/or information represented to be interpreted and explained.

Histograms

This graph type may be used to display frequency distributions. In this graph type the horizontal axis is marked in equal intervals and columns are drawn for the relevant frequency. Adjacent columns in a histogram have a common edge.

Column graphs

This graph type may be used to display discrete data (data which consist of separate or distinct parts). In this graph type the horizontal axis is marked in equal intervals and vertical columns of equal width are drawn to the appropriate height of the vertical scale.

Sector graphs

This graph type may be used to display the component parts of a total. In a sector graph (pie chart) a circle is divided into sectors where the angles at the centre are in the same proportion as the component parts. A simplified way of displaying this type of data is by the division of a rectangle (divided bar) into the proportions of the component parts.

Line graphs

This graph type may be used to display the relationship between two variables for which the obtained data are samples of a continuum (continuous data). Drawing a line of best fit is NOT required of students in Stages 4 or 5. It is a skill addressed in the Stage 6 Mathematics and Science syllabuses.

When presenting information graphically the following features are considered good practice:

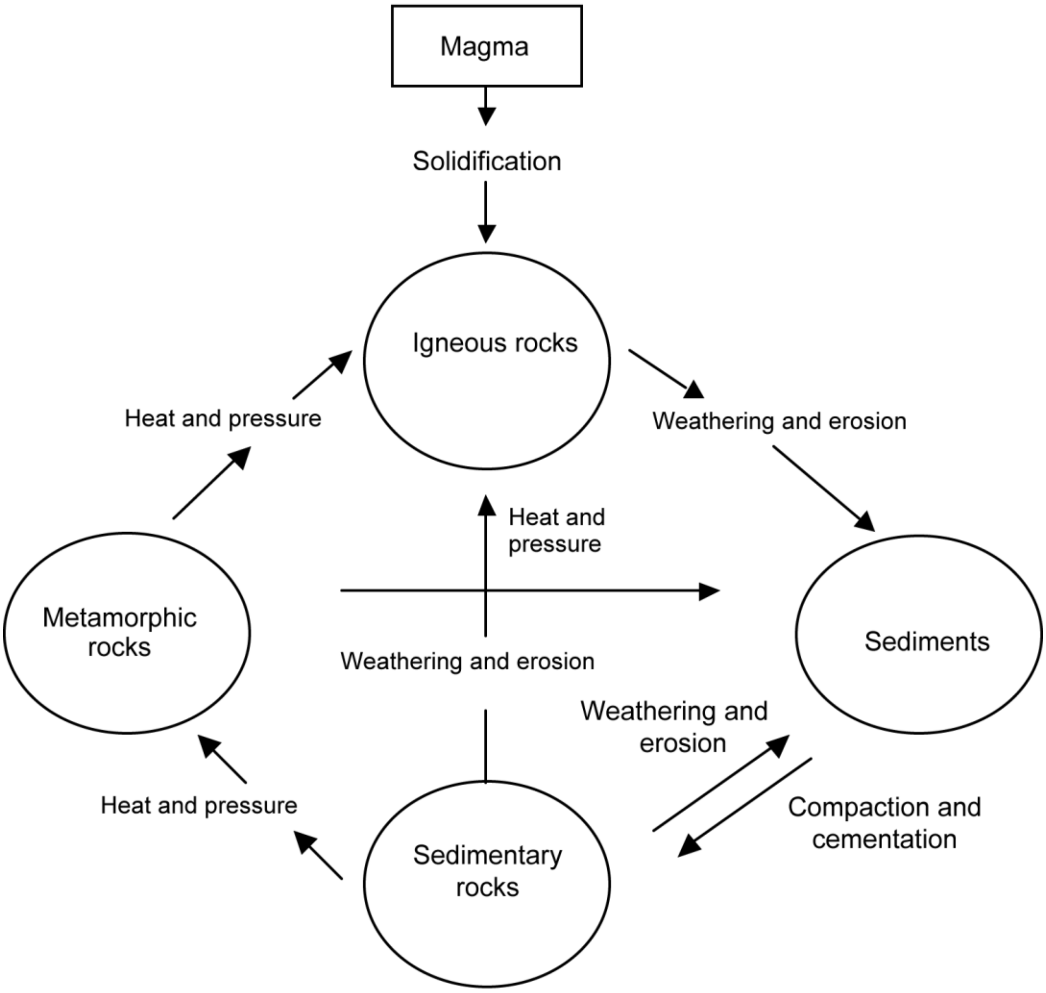
- the graph should have a title
- the x-axis should display the independent variable; the y-axis should display the dependent variable
- axes should be clearly labelled to indicate the relevant variable, including units (where applicable)
- there should be a linear or logarithmic scale, clearly marked with at least three or more points on each scale
- scales should be selected which allow the range of data displayed to extend over most of the available grid
- the axes need not be continuous if a discontinuity marker is shown
- the axes need not start from zero
- there should be accurately plotted data points
- extrapolations, if used, should not be joined to the origin or axes unless this is given in the data or can be reasonably assumed
- a key should be given if there is more than one line shown on a graph or if symbols are used, so that each line or symbol is easily identified.

Composite graphs
Students in Stage 4 and Stage 5 are NOT required to be able to draw composite graphs; however, they should be able to extract information from and interpret these types of graphs. Composite graphs (eg a composite column/bar graph in which each column is itself a bar graph) may be used to display complex data, make comparisons of large quantities of data or enhance clarity.

Flow charts

A flow chart is a diagrammatic representation that shows the steps as boxes and/or circles and their order by connecting them with arrows. The flow chart is used frequently in Science to provide a more visual record that summarises the processes in quite complex cycles.

Consider the diagram of the rock cycle:



By Stage 4 students are required to extract, construct and use flow charts in processing and communicating data and/or information. Construction of flow charts is a useful summarising tool that will allow students to verify their understandings. Students should be helped to distinguish between nouns and verbs describing processes in the construction of a flow chart. To ensure understanding of both the processes and the words used to describe and explain the process, a useful learning strategy is to ask students to write the information provided in the flow chart into text. Students might not find this easy and teachers may then need to model and scaffold the activity.

For example, in the rock cycle, an arrow labelled ‘solidification’ connects the words ‘magma’ and ‘igneous rocks’. Each student could rewrite a description of this section of the cycle in text such as ‘Magma forms igneous rocks by the process of solidification’ or ‘Magma solidifies into igneous rock’. To assist students to clarify the concept it may be better to modify the language to ‘Magma cools to form igneous rocks’. Using this strategy readily identifies student misunderstandings of the purpose of flow charts and the information that they provide.

Communicating in Science

The *Science K–10 (incorporating Science and Technology K–6) Syllabus* provides opportunities for students to engage in the ongoing development of broad literacy skills as well as more science-specific literacy. Literacy is the ability to apply a repertoire of knowledge and skills to comprehend and communicate using a variety of modes and media. Literacy incorporates not only the fundamental skills of listening, reading, speaking and writing, but also using visual and digital forms of expression and communication for a range of purposes and audiences.

Science has its own specific literacy demands that need to be met by students if they are to understand, interpret and effectively communicate scientific ideas, concepts and explanations. Words and phrases in science have meanings that are often quite different both from 'everyday' meanings for words and from the meanings produced in other disciplines, such as English, mathematics and history. For students to develop a sound understanding of the stage-appropriate scientific language relevant to the syllabus content teachers must be explicit in the introduction, explanation and use of scientific terminology. The context of the language influences the meaning and structure of texts. Teachers should model the use of new texts and give students opportunities to use new vocabulary and text structures in their appropriate contexts.

The syllabus requires students to select and appropriately use written and oral factual texts to communicate ideas, explanations and processes, including multimodal texts. In Stages 4 and 5 these texts types are specified and include discussion, explanation, exposition, procedure, recount and reports. An essential skill for students in Stage 4 and Stage 5 is the construction and presentation of scientific arguments – logical descriptions of a scientific idea and the evidence for and against it. The learning program should provide opportunities for students to develop the values, attitudes, skills and understanding to use evidence-based arguments to debate, discuss and evaluate the nature, development, use and influence of science in a range of contexts relevant to their lives.

Structuring learning/teaching sequences including practical experiences

In planning units of work with practical experiences, careful consideration should be given to the reasons for their inclusion. Students should have a clear understanding of the purpose for undertaking the practical experiences and how these experiences relate to and contribute to their knowledge and understanding of science.

Two well-researched models for structuring learning/teaching sequences are the:
- 5Es instructional model
- cognitive apprenticeship approach to teaching and learning of investigation competencies.

The 5Es instructional model

This model is derived from constructivist learning theory. It 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.

Phase of instructional model	Purpose	Role of reading, writing, practical work and discussion
Engage	• Create interest and stimulate curiosity • Raise questions • Reveal students' ideas and beliefs • Compare students' ideas	Motivating (sometimes 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-ended investigation work to experience the phenomenon, observe, test ideas and try to answer questions
Explain	• Compare ideas • Introduce definitions and concept names • Construct explanations • Justify them in terms of observations and data	Small-group discussion to compare ideas and construct explanations
Elaborate	• Use and apply concepts and explanations in new contexts • Reconstruct and extend explanations to new contexts	Further practical activities or problems that provide an opportunity 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

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(s) involve investigation work in which students gain first-hand, and where possible concrete, experience of the relevant phenomenon.
- The **Explain** phase draws on students' beliefs from the Engage lesson. Concepts introduced by the teacher or from text reading are used to construct explanations for the experiences of the Explore phase.
- In the **Elaborate** phase students have more experiences of the phenomenon through practical work in different context(s) and apply explanations developed in the Explain lesson(s) to the new context(s). In this way, they extend and integrate their learning.
- The **Evaluate** lesson provides an opportunity for students and teachers to assess developed explanations and conceptions, and compare them to original beliefs.

The cognitive apprenticeship approach to teaching and learning of investigation competencies

In this approach the teacher's and student's roles in learning the complex craft skills of science are seen as analogous to those of the tradesperson and apprentice.

- 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 **withdrawn**.

Supporting student learning in practical investigations

Scaffolding tools

Depending on their experience, students may need a framework to support them in making decisions about planning and conducting investigations. Planning and recording proforma are useful tools to lead students through a sequence of decision-making steps as they plan and conduct their investigation, process their data and evaluate their investigation. The support provided by these proforma reduces the students' dependence on the teacher for instructions. They provide a mechanism for the students to record their thinking at the various phases of the investigation and help them to gain experience and confidence in designing and conducting investigations, giving them greater autonomy in the decision-making process.

1*. Planning and recording proforma*

Planning and recording proforma can be developed for students at different levels of experience and competence in designing and conducting investigations. Attachment 2 and Attachment 3 provide examples of proforma that could be used for students to scaffold their planning and conducting of their scientific investigations. Resources such as *PrimaryConnections* and *Science by Doing* also provide teacher guidance and scaffolds to support students in planning and conducting open-ended investigations.

The language of the Example A planning and recording proforma in Attachment 2 is simple. It would be suitable for students who have little experience of planning and conducting open-ended investigations in Stage 3 and early Stage 4. After practice and familiarisation with this table in class, this type of planning and recording proforma could be further used to guide students in designing and conducting their Stage 4 student research project.

The Example B planning and recording proforma in Attachment 3 uses more formal language and incorporates more demanding questions. For students with some experience in planning and conducting open-ended investigations, proforma 1 shown in Example B could be used. Example B proforma 2 would be more suitable for students in Stage 5 who have experience in independently planning and conducting open-ended investigations.

2*. The testable-questions algorithm*

Testable questions tend to be used to increase students' skills, when:

- the independent variable is discrete
- there is little prior knowledge and experience of the phenomenon to guide the writing of a hypothesis.

Students often need additional guidance and support to help them write a question for investigation or with planning the design of the investigation by controlling variables. It is important for teachers to model the use of these strategies so that students understand how they are used to make tests fair.

Cows moo softly is a useful mnemonic to remind students how to plan a fair test.

C*hange something*   ***M****easure something*   *and*   *Keep everything else the* ***S****ame*

In the general structure of the testable question below, the gaps correspond to the dependent variable (DV) and the independent variable (IV). This strategy, without naming the types of variables, can be used to help the student write their own questions for an investigation.

What happens to _____________________ when we change __________________?
(DV) (IV)
eg What happens to **the growth of wheat** when we change **the salinity of the water**?

In Stage 5 students are required to formulate questions or hypotheses. From testable questions students can learn to write hypotheses. Hypotheses are statements of tentative ideas to be tested, expressed in the form of a relationship between an independent variable and a dependent variable. The general structure of a hypothesis is:

- This change in the independent variable will cause this to happen to the dependent variable.

Using the example relating to the growth of wheat, the following hypothesis can be developed:

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

To write a hypothesis the students must have sufficient observations, experience and knowledge of the phenomenon to state the expected relationship between the variables.

3. *Variables tables*

Variables tables are a useful planning tool to help students plan controlled experiments and develop an understanding of the three types of variables that need to be considered in the planning phase. The following is a completed variables table for an experiment to investigate the question:

How does the amount of light affect the growth of seedlings?

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

Adapted from: Hackling, MW 2005, *Working Scientifically: Implementing and Assessing Open Investigation Work in Science,* Department of Education and Training, Western Australia.

4. *The five steps of investigation*

The outline shown below provides an example that could be used to guide students in planning and conducting their open-ended investigation.

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?

Source: Hackling, MW 2005, *Working Scientifically: Implementing and Assessing Open Investigation Work in Science*. Reproduced with the permission of the Department of Education and Training, Western Australia.

References

Hackling, MW 2005, *Working Scientifically: Implementing and Assessing Open Investigation Work in Science*, Department of Education and Training, Western Australia. A resource book for primary and secondary teachers of Science, prepared for the Department of Education and Training, Western Australia.

Harlen, W & Qualter, A 2004, *The Teaching of Science in Primary Schools*, David Fulton Publishers, London.

Martin, R, Sexton, C & Franklin, T 2008, *Teaching Science for All Children*: *An Inquiry Approach*, 5th edn, Pearson Higher Education, Needham Heights MA.

Other resources

Board of Studies NSW 2010, *Dictionary of Classroom Strategies K–6 2010*, Board of Studies NSW, Sydney

PrimaryConnections, Australian Academy of Science, http://science.org.au/primaryconnections/curriculum-resources

Science by Doing, Australian Academy of Science, http://science.org.au/sciencebydoing

National Research Council 2000, *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*, National Academy Press, Washington, DC

Understanding Science, http://undsci.berkeley.edu

Student research project

In each of Stage 4 and Stage 5 the *Science K–10 (incorporating Science and Technology K–6) Syllabus* requires the completion of **at least one** substantial student research project (SRP)**.** At least one student research project will involve a hands-on practical investigation and at least one in Stage 5 will be an individual SRP. The SRP should be set within a timeline within the scope and sequence of work units in each stage.

The SRP involves students in an open-ended investigation, providing them with opportunities to engage in scientific inquiry as they use and apply the processes of Working Scientifically over an extended period of time. In undertaking open-ended investigations students should be involved in questioning and predicting, planning and conducting, gathering, processing and analysing data and information, problem-solving, communicating their ideas and findings, and seeking constructive evaluation by their peers.

The SRP requires students to actively engage in inquiry-based learning and includes:

- hands-on laboratory and fieldwork investigations involving controlled experiments
- gathering and processing first-hand data requiring only limited background research
- researching an issue with a major scientific component relating to the applications and implications of science for society and the environment or current research developments in science. This involves the gathering and processing of data from secondary sources and includes a discussion of viewpoints.

Students should choose investigations related to an area of interest or one of the topics they have studied. They should identify problems and develop questions for their investigation that are relevant to their own lives, the immediate environment and the wider community. In conducting their investigations and research, students should use readily available materials and be encouraged to collaborate with people who use science in their work life. Apart from the mandatory Stage 5 individual student research project, SRPs may involve collaboration with peers, and teamwork.

While students will have undertaken investigations in Stages 1 to 3, they may need considerable support in Stage 4 as they are apprenticed into independent time management and planning, and performing first-hand investigations in laboratory and fieldwork situations. Students will be at various levels of skill development in using laboratory equipment and will therefore need teacher assistance at times. Careful guidelines and monitoring to assist students may need to be provided on the questions/problems to be investigated, the procedures and materials used, and appropriate risk assessment and hazard minimisation.

Additional support for students can be provided by linking the SRP directly to the unit of work being covered in class. Class time can be allocated to assist students in clarifying their question, developing the hypothesis, planning their investigation, identifying and accessing sources of data and/or information, selecting methods of collecting, displaying and organising data, and analysing and communicating their findings. The balance between teacher-guided and independent work would be expected to shift towards more independent work as students move into Stage 5.

The opportunity exists for students to complete at least one SRP as part of a team. Each student should keep a journal recording the processes used, their roles and responsibilities and those of other team members in planning, conducting and completing the SRP. The 'Working in a team' feedback table (Attachment 4) is an example of one way that students could be provided with feedback on their progress in achieving outcomes related to teamwork.

Students need to recognise self-assessment and peer assessment methods as part of everyday learning. Peer review is also a valuable learning experience for students as it models the collegial nature of scientific work. If students have little experience with the processes of self-assessment and/or peer assessment, they will need time and teacher guidance to develop the necessary skills. While self-assessment and/or peer assessment are excellent ways to empower and extend student learning, teachers should make the final judgement about the level of achievement of the outcomes demonstrated by the student.

Organising the SRP

Teachers will need to provide students with clear criteria on the requirements and deadlines to be met. By doing this teachers are modelling the processes used by scientists in their research and apprenticing students into the world of the scientist. When the steps in the processes are explicitly modelled, students are more able to learn, practise and apply them to their own investigations. In the same way, revision of strategies for recording and analysing data should be included in the lessons set aside for SRP discussion.

Where mixed-ability classes are involved, it may be useful to organise the work so that each team/group can have instruction on the SRP commensurate with their level of ability, or to encourage some students with a higher level of knowledge and/or skills to mentor others.

An SRP feedback template (Attachment 5), which is to be submitted with the completed SRP, not only provides a guide to the processes involved and skills to be developed during the SRP, but also identifies what will be assessed.

Samples of SRPs from previous years should be kept and displayed so that students can see examples of the range and types of SRPs completed and the variety of presentation methods appropriate for Stage 4 and Stage 5. As part of the introduction to the SRP the students and/or the teacher could suggest some criteria that could be used to assess the displayed SRPs. Students could move around individually or in pairs and record their comments about the samples using the agreed criteria. This could be used in class discussion to assist students to understand the task requirements and the outcomes they are to achieve.

Timelines and journals

Teachers can assist students with the SRP by developing a timeline. Negotiations between the student and teacher should fix a timeline that both agree is realistic. At a number of predetermined points during the SRP, the teacher should monitor student progress to ensure that the schedule is being maintained. If a student has difficulty meeting the deadline, this is discussed and the teacher and student identify strategies to solve the problem and revise the timeline. A student reflection sheet (Attachment 6) is a useful tool once the SRP is under way and, together with the SRP timeline scaffold (Attachment 7), can be used to help the student work within the identified milestones of the project.

Students should keep a journal about their research project to record their planning, their background research, how their ideas develop, strategies and possible solutions to identified problems, resources accessed, and findings from and evaluation of their investigation. Journal records help students to think about what they do and why, and give teachers specific discussion areas with their students. In addition, journals are a tangible record of the SRP's history, the regularity with which students work on the SRP and evidence of their ability to work regularly at a task over a period of time.

When the assessment criteria that will be used to provide feedback to students are included in the SRP information, opportunities for *assessment for learning* can be scheduled to take place following the regular journal monitoring.

An SRP journal information sheet (Attachment 8) provides guidelines to students.

Safety in science

Teachers need to ensure that they comply with the legal obligations of schools in relation to health and safety as well as with any specific system requirements.

The *Work Health and Safety Act 2011* (NSW) and the *Work Health and Safety Regulation 2011* (NSW) (the WHS Regulation) contain provisions that require employers to consult with employees on health and safety matters. The WHS Regulation sets out requirements for workplaces related to putting into place systems to identify, assess, control and/or eliminate health and safety risks.

The WHS Regulation provides broad coverage to managing risks to health and safety for all workplaces, together with specified measures relating to:

- identification of all workplace hazards
- assessment of risks arising from those hazards
- implementation of measures to control those risks
- provision of training, instruction and supervision
- workplace consultation between employers and employees
- control of specific high risk hazards related to particular equipment, machinery, substances and processes
- the supply, transport and storage of chemicals, whether as single chemicals or constituents in mixtures. This includes the operation of dangerous goods stores in addition to labelling and packaging requirements
- the storage, use and disposal of dangerous goods in the workplace. This includes substances used in a range of specialist subjects in schools, together with substances used for cleaning, weed control and other similar purposes.

The three main implications for schools are:

- Dangerous goods must be stored safely with consideration to their relative hazards and to their compatibility with other substances.
- Containers of dangerous goods must be labelled with the appropriate class labels when certain quantity thresholds are reached.
- Where quantities of dangerous goods stored on site exceed limits specified under the regulations, schools will require a Dangerous Goods Licence.

It is a legislative requirement that a register of all hazardous substances stored on site be kept and is readily accessible to all staff. Schools should be familiar with the requirements and responsibilities under this Act and Regulation.

School policies and procedures should be developed, implemented and monitored to ensure compliance with the Act and the Regulation. There are various offences and penalties associated with the *Work Health and Safety Act 2011* and the Regulations made under this Act. These include penalties for organisations found guilty of breaches of the Act or the Regulation. There are also penalties for staff and other people, including students and visitors, found guilty of breaches of occupational health and safety law.

Chemical Safety in Schools (CSIS)

Chemical Safety in Schools (*CSIS*) is a resource package for schools, developed by the Department of Education and Training (DET) to provide schools with up-to-date information on chemical safety and to assist schools to meet the mandatory requirements under the Hazardous Substances and Dangerous Goods legislation. The package also promotes best practice in the use of chemicals for teaching and learning in schools.

The package addresses the *Occupational Health and Safety (Hazardous Substances) Regulation 1996*, which requires:

- training for staff in the management of risks associated with the use of chemicals
- ready access to risk and safety information on hazardous substances
- a register to be kept of hazardous substances used or stored on site
- the labelling of chemical containers with risk and safety information
- the assessment of risks to health from exposure to hazardous substances
- the implementation of control measures to protect health and safety
- the maintenance of records of training and risk assessment
- the appropriate labelling and storage of dangerous goods
- licensing by WorkCover NSW, where stocks of dangerous goods exceed storage limits.

Contacts

Dangerous goods licences www.workcover.nsw.gov.au

Information about or purchase of current Australian Standards www.standards.org.au

Material Safety Data Sheets Australia www.msds.com.au

Waste disposal regulatory requirements www.environment.nsw.gov.au

Resources

Australian Radiation Protection and Nuclear Safety Agency, *Use of Radiation in Schools,* Australian Government, 2012

WorkCover Authority of NSW, *Codes of practice*, eg 'How to manage work health and safety risks', 'Labelling of workplace hazardous chemicals', 'Preparation of safety data sheets for hazardous chemicals', www.workcover.nsw.gov.au => Law and policy => Codes of practice

Use of animals in teaching and research

Teachers of science are aware of the importance of animals to teaching and learning in the school curriculum. Studying animals provides opportunities for students to gain knowledge, acquire skills and develop appropriate, positive attitudes towards the welfare of animals.

The use of animals in research and teaching in NSW is regulated by the *Animal Research Act 1985* (NSW), which places the responsibility for the care and welfare of animals in schools on the staff involved with their use. Under the Act, 'an animal' means *a vertebrate animal, and includes a mammal, bird, reptile, amphibian and fish, but does not include a human being*.

This legislation requires researchers and teachers to consider and apply three general principles (the 3Rs). They are:

- the replacement of animals with other methods
- the reduction of the number of animals used
- the refinement of techniques used to reduce the impact on animals.

Teaching and research activities involving animals may only be performed when a decision has been made that the activity is justified. The decision-making must consider:

- the educational value weighed against the potential negative effects on the welfare of the animal
- non-animal or less sentient animal alternatives.

The Animal Research Act requires all schools to have access to an Animal Ethics Committee (AEC). The Schools Animal Care and Ethics Committee (SACEC) was established by joint agreement between the Association of Independent Schools of NSW (AIS), the Catholic Education Commission (CEC) and the Department of Education and Communities (DEC). Its role is to ensure that the use of animals by schools in all sectors complies with the Act. The responsibilities of the SACEC are described on the Animals in Schools website at: www.schools.nsw.edu.au/animalsinschools.

If the staff decide that animal use for teaching or research is justified, they should check that the activity is included in the list of approved activities on the Animals in Schools website. If the activity is not on the approved list or is a category 4 or 5 activity, a written application must be made to the SACEC. Application forms are available on the Animals in Schools website.

Every school using animals for research or teaching purposes must hold a current, completed *Animal Research Authority*. The SACEC issues an *Animal Research Authority* each year on behalf of the respective school sector, to schools in NSW. This authorises those staff who sign the authority to use animals for the purposes of teaching and research, provided that the activities are in accordance with the provisions described on the Animals in Schools website. Compliance with the SACEC advice is mandatory for all schools.

The school principal is responsible for identifying, and listing on the *Animal Research Authority*, all appropriately qualified staff who have the principal's approval to use animals for teaching or research. The authority must be kept in the principal's office and be available for inspection by appropriate officers from the Animal Welfare Unit or members of the SACEC.

Each school in which animals are used must have an Animal Welfare Liaison Officer (AWLO). In a primary school the AWLO is to be the principal of the school. The AWLO in a secondary school is to be appointed for the school by the principal. The duties of the AWLO are provided on the Animals in Schools website.

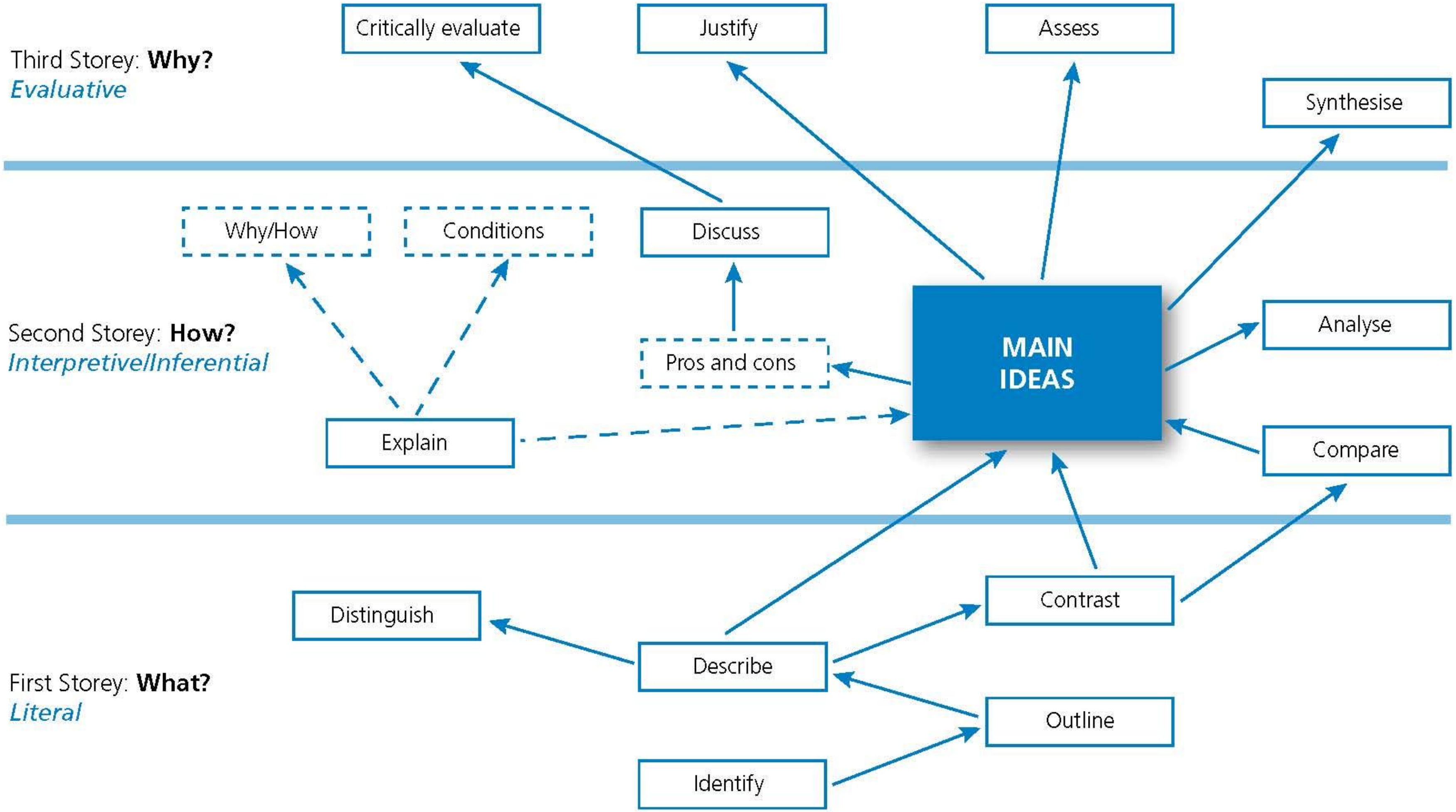
All staff involved in using animals in schools need to keep informed of the ongoing ethical debate and community expectations about the use of animals in research and teaching, and the consequent changes that occur from time to time in the relevant legislation.

Teachers who wish to keep native animals for educational purposes must obtain a scientific licence. An application form for SACEC approval for this licence is available on the Animals in Schools website. Inquiries relating to collecting aquatic organisms may be made to the NSW Department of Primary Industries.

All inquiries relating to the use of animals in teaching and research may be made to the Schools Animal Welfare Officer at the NSW Department of Education and Communities.

Attachments

Attachment 1: Pathways of key words



(See Board of Studies *Glossary of Key Words*; see also *Bloom's* Taxonomy)

Attachment 2: Example A – Planning and Recording Proforma

Questions	**Answers**
What am I going to investigate?	
What do I think will happen?	
Why do I think it will happen?	
What am I going to do?	
What will I need?	
How will I make it a fair test?	
What happened?	
How did what happened compare to my prediction?	
Why did it happen?	
What was difficult for me?	
How could I improve this investigation?	

Adapted from: Hackling, MW 2005, *Working Scientifically: Implementing and Assessing Open Investigation Work in Science*, Department of Education and Training, Western Australia.

Attachment 3: Example B – Proforma 1 Planning and Recording

Questions	**Answers**
What am I going to investigate?	
What do I think will happen? Why?	
Which variables am I going to: • change? • measure? • keep the same?	
How will I make it a fair test?	
What equipment will I need?	
What happened?	
Can my results be presented as a graph?	
What do my results tell me? Are there any relationships, patterns or trends?	
How can I explain the relationships, patterns or trends in my results?	
What did I find out about the problem I investigated? How was the outcome different from my prediction?	
What difficulties did I experience in doing this investigation?	
How could I improve this investigation, eg fairness, accuracy?	

Adapted from: Hackling, MW 2005, *Working Scientifically: Implementing and Assessing Open Investigation Work in Science*, Department of Education and Training, Western Australia.

Example B – Proforma 2 Planning and Recording

Questions	Answers
What is the problem I am investigating?	
What do I know about this topic from personal experience and from science?	
What variables may affect the phenomenon I am investigating?	
Which of the variables am I going to investigate as the independent variable (the variable that I 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 (the variable that responds to changes in the independent variable)?	
How will I measure the dependent variable?	
What question am I investigating? OR What hypothesis (the relationship between the independent and dependent variables) am I testing?	
What do I predict will happen? Why?	
What variables are to be controlled (kept constant) to make it a fair test?	
How will I collect my data? (Give a description and explanation of the experimental set-up using a labelled diagram.)	
Are there any special safety requirements?	
Were there any problems with the preliminary trials?	
How did I modify my experiment to fix the problems?	
What data did I collect to test my hypothesis?	
How did I make sure that my data were accurate?	
What is the best way to present my data? Is it appropriate to draw a graph? What type of graph is most suitable?	

Questions	Answers
What are the patterns or trends in my data? What is the relationship between the variables I have investigated? Is the hypothesis supported by the data?	
Using science concepts, how can I explain the patterns, trends or relationships I have identified in my data? What is my conclusion?	
What were the main sources of experimental error? (eg, sample size and selection, measurement error, poor control of variables)	
How confident am I with my conclusion?	
How could the design of the experiment have been improved to reduce error?	
What have I learned about the topic of my investigation? How was the outcome different from my prediction?	
What further investigations could be performed?	
What have I learned about the methods of investigating in science?	

Adapted from: Hackling, MW 2005, *Working Scientifically: Implementing and Assessing Open Investigation Work in Science*, Department of Education and Training, Western Australia.

Attachment 4: ‘Working in a team’ feedback table

Teamwork criteria	**Low**	**Satisfactory**	**High**
Defines team responsibilities	With teacher guidance outlines team responsibilities and goals	Defines team responsibilities and goals	Demonstrates confidence in describing team responsibilities and goals
Identifies and allocates specific roles	With teacher guidance identifies specific individual roles within the team	Identifies specific individual roles within the team and makes suggestions as to how they should be allocated	Matches team members to roles according to the specific requirements of the task based on the skills of the individual
Sets goals and timelines	With teacher guidance identifies goals and sets timelines for the task	Identifies goals and sets timelines	Demonstrates high-level skills in setting realistic goals and timelines
Communicates opinions/ideas	With teacher guidance expresses opinions and ideas	Clearly expresses opinions and ideas	Communicates opinions and ideas succinctly and logically
Uses listening and negotiation skills	With teacher guidance uses active listening and negotiation skills	Demonstrates some skills in active listening and negotiation	Demonstrates high-level active listening and negotiation skills
Engages in and monitors teamwork	With teacher guidance takes responsibility in a negotiated role to follow a plan to meet goals and timelines	Takes responsibility for roles within the team and works with others to meet goals and timelines, and monitor progress of the task	Demonstrates responsibility in a number of roles and in decision-making so that goals and timelines are met and the progress of the task is monitored
Accepts responsibility for maintenance of a safe working environment	With teacher guidance takes responsibility for maintaining a safe working environment	Takes responsibility for maintaining a safe working environment	Demonstrates a high level of responsibility for maintaining a safe working environment
Determines the effectiveness of the team in completing the task	With teacher guidance identifies some processes that assisted the team to complete the task	Describes the effectiveness of some parts of the plan and some processes used by the team to complete the task	Evaluates the effectiveness of the plan and processes used by the team in completing the task

Attachment 5: Student research project feedback template

This template could be used for self-assessment, peer assessment and/or teacher feedback.

OUTCOMES AND CONTENT	Feedback		
	Needs to improve	**Satisfactory**	**Well developed**
(a) Identifying problem and data sources • develops a question or hypothesis for investigation • describes the problem under investigation • describes different strategies and evaluates their appropriateness for solving the problem/testing the question • identifies the type and sources of data/information that need to be collected • identifies information relevant to the problem, including background information • identifies how the data and information will be collected and recorded			
(b) Planning the investigation • develops an appropriate timeline • gathers information from a range of recorded sources • selects an appropriate strategy to solve the problem/test the question • identifies the variable(s) that will be kept the same and those that will be changed • identifies ways of reducing risks and addressing ethical guidelines • describes and justifies the planned procedure			
(c) Choosing equipment • lists equipment and/or resources needed to perform the investigation • carries out initial testing, making necessary modifications to equipment and/or procedures • justifies changes made to equipment and/or procedures • assesses risks and addresses ethical issues in using equipment, materials and chemicals safely			
(d) Performing first-hand investigations • follows planned procedure using time and resources effectively • locates and gathers first-hand data and information from a variety of sources • makes observations and measurements over a number of trials • records data using appropriate units • evaluates and modifies the experimental procedure			

OUTCOMES AND CONTENT	Feedback		
	Needs to improve	Satisfactory	Well developed
(e) Processing information • organises data using a variety of methods • checks the reliability of gathered data by comparing with data from other sources • applies mathematical concepts to assist analysis of data • identifies trends, patterns, relationships and contradictions in data			
(f) Critical thinking • identifies data that supports or discounts the hypothesis/question being investigated • makes generalisations in relation to results • generates plausible explanations directly related to observations • recognises errors and identifies areas for improvement • evaluates the appropriateness of the strategy used to address the problem/question			
(g) Presenting information • selects and uses appropriate text type(s) • selects and uses clear and appropriate ways of presenting information • selects and uses appropriate types of tables, graphs, spreadsheets, databases, flow charts or diagrams to convey information and relationships clearly and accurately • selects and uses an appropriate method to acknowledge sources of information			

Student comments:

Student signature ______________________________

Teacher comments:

Attachment 6: Student reflection sheet

My student research project (SRP)
How am I going?

My SRP is due on ____________________________.

I have now had my SRP for __________ days/weeks.

I have spent ___________ hours on my SRP.

1. What is my SRP about? (Use point form.)

2. Have I followed my plan? What changes have I had to make to my plan? Why were the changes needed?

3. What I have done so far in my SRP is:

4. How do I feel about the work I've done so far?

5. What do I still have to do to complete my SRP? (Outline of my plan, which includes dates and what I will do each day/week.)

I have ____________ days/weeks until my SRP is due.

Parent's comment:

Attachment 7: Student research project timeline scaffold

This table could be subdivided into smaller progressions with a more explicit scaffold depending on the skills of the student involved.

Date due	Student research project	Student comment	Teacher comment
Week A	Teacher: • introduces SRP • sets class timeline Students: • purchase journal • brainstorm and record ideas for the SRP • review the process, establish expectations, requirements and assessment criteria for SRP	It is important that the student is able to honestly self-monitor throughout the project if there is to be genuine development of organisational and analytical skills	Comments could relate to: • degree of student's success in following their plan and timeline • suggestions for improving student's research, procedure, processes and quality of product
Week B	Student: • identifies problem to be investigated and sources of information • records question/hypothesis • identifies strategies and solutions • outlines investigation plan • sets own goals and individual timeline • discusses proposed question and plan outline with teacher • submits journal for checking		
Week C	Student: • discusses proposed question, planned investigation and risk assessment with teacher • carries out initial testing using proposed equipment • evaluates procedure, makes and records modifications • performs investigation		
Week D	Student: • prepares outline of report including procedure, results, preliminary discussion and conclusions • submits and discusses report outline with teacher		
Week E	Student: • presents final report in an appropriate format • presents journal • provides SRP timeline, self-evaluations and peer evaluations		
Week F	Teacher: • provides individuals and teams with feedback		Comments and feedback to be based on the SRP marking criteria

Attachment 8: Student research project journal information sheet

Instructions to students

Part of the assessment of your SRP is for the final report and part for your planning and the work you complete along the way. To help your planning and work during the research project you will need to keep a journal. This is a record of what you do each time you work on your SRP.

Note: **Your journal is a diary of your research project only.**

Here are some suggestions for your journal:

- **Begin your journal with an outline of what your SRP is about** – information provided by the teacher, what you want to investigate, what activities you think you will carry out and why you have chosen this topic. Discuss this outline with your teacher and make any changes suggested.
- **Set out a week-by-week plan** (a timeline) of what you plan to do. This plan may change as you go along, but it will help to set the work out at the beginning – it will surprise you how much there is to do.
- **Treat your journal as a diary** – record every piece of work you do (eg library visits, interviews, telephone calls). This is your way of showing your teacher that you have taken the SRP seriously and worked consistently.
- **Record the details** of all books, magazines, websites etc, while using them so that it is easy to complete a bibliography for your final report. Include author, title, publisher, date of publication and the page numbers if relevant. This will save time later.
- **Record details of all** letters/emails and phone calls made as well as surveys handed out and interviews conducted. Include rough drafts of surveys and letters/emails as well as a copy of the final ones.
- **Record your failures as well as your successes** – keep a record of strategies you considered to solve the problem and why you rejected some and kept others. Note phone call details, even if the person you called was no help; record details of library visits even if you could not find the information you needed; and record all letters/emails sent, even if you did not receive replies.
- **Record all the details of the hands-on investigations you carried out** including the planned procedure, equipment used, modifications to the procedure and why these were made, risk assessment and how hazards were minimised, and the results obtained.
  Taking photographs over the period of the SRP is a good way to record your investigation procedure, observations and results.
- **Include** the outline of your report and subsequent drafts of your final report.

Do not rewrite your journal – it is meant to be your original work.