BEYOND FAIR TESTING

Beyond fair testing: Teaching different types of scientific enquiry

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Gatsby Science Enhancement Programme
Allington House (First Floor)
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The project team at King's College London consisted of:
Rod Watson (Project leader), Labrini Nikolaou and Kelly Teamey.

In the Beyond Fair Testing booklet,
Introduction was written by Rod Watson, and **Quality discussion** by Rod Watson and Labrini Nicolaou.

The writing team for each enquiry was as follows:
Mystery Powders: Rod Watson
Spiders: Labrini Nikolaou, Tiffany Prince, Rod Watson
Fitness: Labrini Nikolaou, Allie Denholm, Rod Watson
Bubbles: Rod Watson, Steve Hearn
Air pollution: Rod Watson, Kelly Teamey, Labrini Nikolaou
Biodiversity: Rod Watson, Dave Dennis

The materials were prepared for publication by: Miriam Chaplin
Designers: Pluma Design Ltd.
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Valerie Wood-Robinson acted as a consultant for the 'Spiders' and 'Mystery Powders' enquiries.

The Science Enhancement Programme (SEP) is part of Gatsby Technical Education Projects. It undertakes a range of activities concerned with the development of curriculum resources and with teacher education.
For further information, visit www.sep.org.uk

BEYOND FAIR TESTING:
TEACHING DIFFERENT TYPES OF SCIENTIFIC ENQUIRY

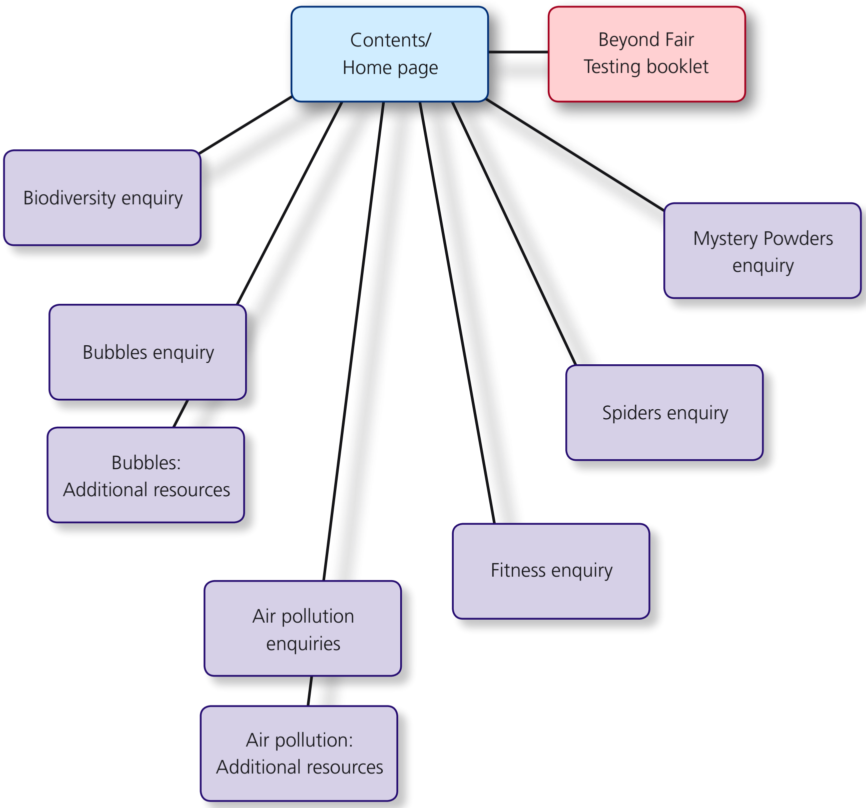
CONTENTS

Outline of CD content

The diagram below outlines the structure and contents of the pages on the CD.

- Each enquiry page contains the **enquiry** pdf file and Word files for relevant Student Activities. You can print directly from either a pdf or word file.
- Each **enquiry** pdf file includes all the Teacher's Guide and Student Materials, ready to print as a single booklet.
- Most of the files in the Additional Resources pages linked to the Bubbles and Air Pollution enquiries can be opened and printed directly from the relevant page of the CD.
- If you want to copy several files onto your hard disk or to install the Modellus application file onto your hard disk you should use Windows Explorer to work within the folders containing all the files for each enquiry and the Beyond Fair Testing booklet.

For example, to find the **Modellus** application on your CD you would go to Beyond Fair Testing/Bubbles/Additional Resources.



INTRODUCTION

'Beyond Fair Testing' and the SKEES project

Beyond fair testing: Teaching different types of scientific enquiry is based on the work of the SKEES (SEP-King's Enhancing Enquiries in Schools) project, funded by the Gatsby Science Enhancement Programme.

The SKEES project and the **Beyond fair testing pack** aim to

- **increase the variety of scientific enquiries** at Key Stages 3 and 4 and
- **provide strategies for the explicit teaching of the procedural understanding** used in these enquiries.

Why are different kinds of enquiry needed?

Scientists use many different ways to collect evidence. Research by the AKSIS project found that many kinds of enquiry were very poorly represented in school curricula: fair tests were carried out much more frequently than other kinds of enquiry and many teachers said they would like more variety. The **Beyond Fair Testing** pack provides examples of different kinds of enquiry.

What are the different kinds of scientific enquiry?

The AKSIS project developed descriptions of six different kinds of scientific enquiry:

- Fair testing enquiries
- Pattern seeking enquiries
- Exploring enquiries
- Classifying and Identifying enquiries
- Making things or developing systems
- Investigating models

Fair Testing Enquiries

These enquiries are concerned with the relation between an independent variable and a dependent variable. The emphasis is on identifying one (or more) independent variable(s) to be manipulated independently of other factors, which must be controlled, for a 'fair test'. Systematic changes in the independent variable are compared with changes in the outcome, or dependent variable. All other relevant variables are controlled.

Examples: What is the effect of the areas of a shoe in contact with the ground on the slipperiness of the shoe?
What is the effect of concentration of acid upon the time taken for magnesium to dissolve in the acid?
What effect does the intensity of light have on the rate of photosynthesis in pond weed?

Pattern-seeking enquiries

Pattern-seeking enquiries are similar to fair tests, but start with readings of the dependent variable and try to identify the cause (the independent variable). These enquiries often involve observing and recording natural events as they occur. For example, a pattern-seeking enquiry might explore the factors affecting the size of anemones on a seashore. One possibility might be the size of pools in which they live. A reasonably sized sample of large and small pools could be selected and the sizes of the anemones measured. In this situation, variables which may be difficult to control might be the shape of the pools, the distance up a beach, and the quantity and types of other organisms living in the pools. It is, therefore, difficult to isolate the independent and dependent variables and a more holistic approach, in which observations and recordings of several variables are made, may be needed. In these enquiries it is often difficult or impossible to control variables and instead particular attention has to be paid to the characteristics of the sample used.

Another type of pattern seeking enquiries is a survey. Surveys are often used in areas such as genetics, epidemiology, psychology, sociology, meteorology, astronomy and ecology. As in other kinds of investigation, the aim is to compare data sets to identify patterns of relationships and propose causal links. For example, the relationship between smoking and lung diseases has been established by epidemiological studies based on surveys. A school survey of pupil fitness and exercise habits is a pattern seeking investigation.

Examples: What factors affect the levels of sulfur dioxide pollution in the air where I live?
What factors affect the speed of 1500m runners?
What factors affect the biodiversity on the school field?

Exploring enquiries

In these enquiries, students look for changes in just one variable or factor at a time. For example, downloading hourly data about levels of sulfur dioxide in the air at particular locations allows students to explore whether there is a pattern in the levels of air pollution over time. Similarly, observation of the development of frogspawn over time can be an exploring enquiry. This exploration could simply lead to a description of part of the life-cycle of a frog, and in the future pupils would come to model patterns in the life-cycles of different animals. Alternatively, the focus could be on the relationship between the changes undergone by the tadpole and how it is adapted to move in and out of the water at different stages. Another exploration may be to study the movement of the leaves of a plant over several days. Often, exploring enquiries lead to questions about the causes of the pattern observed and lead on to other kinds of enquiry.

Examples: How does appearance of a comet, and its location in the night sky, change over several days?
Is there a pattern in the wind direction at my school over several months?

Classifying and identifying enquiries

Classifying is a process of arranging phenomena, either objects or events, into manageable sets. Identifying is a process of recognising objects and events as members of particular sets, possibly new and unique sets, and allocating names to them. Classification and identification both involve pupils identifying features, tests or procedures that discriminate between things or processes that are being studied.

Scientific classification is carried out for particular scientific purposes. Biologists recognise patterns of similarities and differences in the characteristics of the diversity of living things and arrange the organisms in hierarchical sets. Classification is a process, which allows biologists to generalise, and it provides a framework from which to predict structures and behaviour. Similarly, chemists classify chemicals in order to highlight chemical characteristics that both enable chemicals to be grouped and to predict patterns of behaviour of a chemical within a particular group.

Identification involves recognising a specimen as a unique example of a particular set. For example, in qualitative chemical analysis students have to use their knowledge and understanding of science in order to be able to select appropriate tests to apply to an unknown chemical.

Examples: You are given 10 bottles of chemicals without their labels. You are also given the labels which have fallen off the bottles. Develop a key to identify the chemicals.
Develop a way of identifying common spiders

Making Things or Developing Systems

In these technological investigations pupils design an artefact or system to meet a human need. Scientific enquiries use scientific knowledge and procedures to answer questions or solve problems. Some technological enquiries have a high scientific knowledge or a strong emphasis scientific procedures and so can be classified as scientific investigations. For example, making a 'Pressure pad' switch involves a working knowledge of an electrical circuit and 'Constructing a weighing machine out of elastic bands' involves an understanding of some of the procedures of science in order to calibrate it.

Examples: Design and test a regime to improve your fitness.
Design a way of separating salt from soil.

Investigating Models

Scientists develop theories that model aspects of natural and physical world, for example, the theory of plate tectonics models how the surface of the earth behaves or Darwin's theory of evolution models how species evolve over time. Similarly students develop their own models to explain both everyday phenomena and phenomena that they meet in the science laboratory: a student may see wood burning to ash and develop a model that heat changes the wood into ash.

This kind of enquiry is distinct from the previous kinds, in that it incorporates a stage where pupils have to decide what evidence should be collected in order to test the ideas embedded in such mental models. Testing models may lead on to one or all of the preceding types of investigations, but which approach is chosen depends on decisions made about what would count as evidence to test the model.

Example: Devise an enquiry to test an explanation of how pollen travels from flower to flower.

Different sized bubbles of air rise through a liquid at different speeds. Devise and test a model of the relationship between bubble size and speed of the bubbles.

What enquiries are included in this pack? How do they relate to Key Stages 3 and 4 of the National Curriculum?

Beyond fair testing contains a set of enquiries for use in Key Stages 3 and 4. Each enquiry has been designed to develop **procedural understanding** in Sc1 **Science investigative skills** at KS3 and **How science works** at KS4, as well as **conceptual understanding** of the relevant aspects of Sc2, Sc3 and Sc4. There are more details of these links in the relevant overview for each enquiry.

Enquiry title	Kind of enquiry	Description	Intended key stage or age groupLevel
Mystery Powders	Identifying	Students use data cards and practical tests to find a way of identifying different chemicals.	KS3/4
Spiders	Identifying	Students use data cards and practical tests to find a way of identifying common spiders.	KS3
Fitness	Designing a system	Students design a regime to increase their fitness, try out the regime and evaluate whether it works.	KS3/4
Bubbles	Testing a model	Students investigate bubbles rising through a liquid and model the relationship between bubble size and the speed of bubbles.	Y9/10
Air pollution Enquiry A: Is there a pattern in air pollution?	Exploring	Students study secondary data from pollution monitoring stations to see if there is a pattern of air pollution in hourly measurements.	KS3/4
Air pollution Enquiries B and C: What causes air pollution?	Pattern-seeking	Students try to find out what variables influence the levels of air pollution, either by using secondary data from air pollution sites and the met office or by collecting data for themselves.	KS3/4
Biodiversity	Can lead to different kinds of enquiries: pattern-seeking, identifying, designing a system, exploring, fair-testing.	Students select a question to investigate related to life in the school field. Students can design a number of different enquiries of different types.	KS3/4

If you are not confident with different kinds of enquiries, it is best to leave **'Biodiversity'** until after you have tried several of the others.

How are the enquiries organized?

Each enquiry is organized in three sections:

- Section 1 - the core enquiry
- Section 2 - conceptual knowledge and understanding related to the enquiry
- Section 3 - procedural knowledge and understanding.

Section 1 contains the core enquiry activities. Students with a good knowledge and understanding of the domain should be able to move straight into tackling the enquiry.

Section 2 contains activities designed to help develop students' conceptual knowledge and understanding. If students are unfamiliar with this particular topic, these activities can be used to give the necessary background for the enquiry.

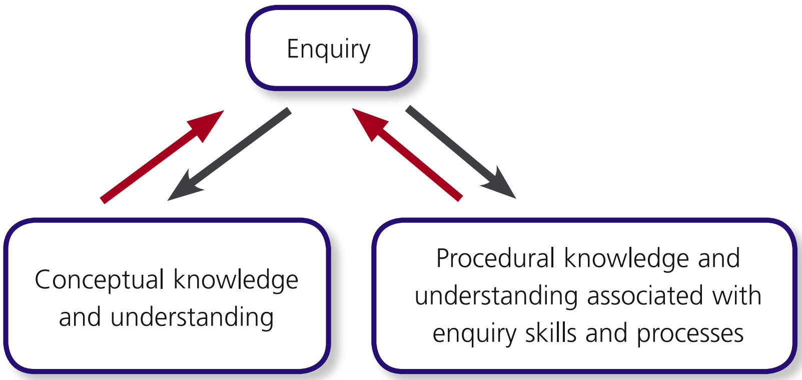
Several of the enquiries are novel and many students will be unfamiliar with some of the procedural concepts that underpin the enquiry. The activities in **Section 3** are designed to be used for teaching these aspects.

Why should procedural understanding be taught explicitly?

There is growing evidence in the science education literature that **the explicit teaching of specific aspects of procedural understanding produces better learning than simply 'learning by doing'**. The AKSIS team developed a range of teaching activities focused on helping students to judge the quality of specific parts of an enquiry (Goldsworthy et al., 1999, 2000, 2000b; Watson et al., 2000). The SKEES project has extended this work to teaching procedural understanding in the context of a range of different kinds of enquiry.

The diagram below shows the contribution of the different components to learning about scientific enquiry, and how these are introduced in a 'learn by doing' approach and in the approach developed in the SKEES project and used in these materials:

Components of Enquiry



Approach

'Learn by doing' approach:
students **start with the enquiry.**
It is assumed that they will acquire the necessary conceptual and procedural understanding as they tackle the enquiry.

'Beyond Fair Testing' approach:
students are **explicitly taught** both the conceptual and procedural understanding they need for the enquiry.

What activities are included for teaching procedural understanding?

Different skills and processes are taught in the activities in section 3 of each enquiry. These activities can also be used as stand alone activities to teach specific aspects of procedural understanding. They have been grouped below into different stages of the enquiry process.

Stage in enquiry	Procedural understanding taught	Where the activity can be found
Preliminary work	**Different kinds of enquiry:** Identifying questions that can be answered using different kinds of scientific enquiry.	**Biodiversity - Activity 3.1:** Different kinds of question – different kinds of enquiry
Planning a scientific enquiry	Deciding measurements to make to answer particular research **questions**.	**Biodiversity - Activity 3.2:** What to observe? What to measure? How to measure?
	Deciding the criteria that can be used to decide good **questions for identification**	**Mystery powders - Activity 3.1:** Ten questions
	Deciding the criteria that can be used to decide good questions for identification	**Spiders - Activity 3.1:** Asking questions to identify
	Constructing a key to identify spiders	**Spiders – Activity 3.2:** Representing groups of animals using a tree diagram
	Using a key for identification	**Spiders - Activity 3.3:** Using an identification key to identify pond invertebrates
	Identifying the criteria for judging the **efficiency of keys**	**Mystery powders - Activity 3.2:** Evaluating keys
Analysing and evaluating results using tables	**Selecting and using data** to assess levels of fitness	**Fitness - Activity 3.1:** Using data to assess fitness
	Identifying and explaining patterns in tabulated data	**Fitness - Activity 3.3:** Working with tables
	Reorganising tabulated data to look for relationships: by hand or using a computer	**Air pollution - Activity 3.2:** **Using** tables to sort out data
	Evaluating the reliability of reported results	**Fitness - Activity 3.4:** **Investigating** the reliability of data
Analysing and evaluating results using graphs	**Reading scattergraphs:** Is there a pattern? Is the sample size big enough?	**Air pollution - Activity 3.1:** Working with scattergraphs
	Creating scattergraphs on a spreadsheet	**Air pollution - Activity 3.1:** Working with scattergraphs
	Interpreting graphs: making judgements about whether a pattern exists and the strength of patterns identified	**Air pollution - Activity 3.3:** Looking for patterns over time
	Interpreting results using graphs	**Fitness – Activity 3.2:** Working with graphs
	Deciding whether there are enough data points on a graph to decide between a straight line and a curve for the line of best fit.	**Bubbles - Activity 3.1:** Dealing with variability in data
	Changing curves into straight line graphs, in order top model relations between two variables	**Bubbles - Activity 3.2:** Using graphs to identify relationships

How can I use the activities in each enquiry with students?

How the activities are used will depend on what the students already know and can do, and the time available. Each enquiry contains an overview suggesting the order in which the activities might be used.

Each enquiry has been developed with the help of teachers, and the materials have been trialled and used successfully in a variety of schools. One aspect that is key to the success of the materials is getting the right kind of classroom discussion. The **'Developing better classroom discussions'** section of this booklet provides examples of good quality dialogue and analyses what the teacher has done to create this discussion.

What are the support materials?

A wide range of support materials is provided on the CD-ROM included in the **Beyond fair testing** pack:

- PowerPoint presentations
- Data files
- Excel spreadsheet set up to record class data
- A modelling activity
- Worksheets that can be completed by students using a computer
- Student activities that can be adapted by teachers to meet the needs of their particular students.

These are in addition to pdf files for all the Teacher's Guides and Student Activities in this pack.

References and further reading

Goldsworthy, A., Watson, J. R. and Wood-Robinson, V. (1999) ***Investigations: Getting to Grips with Graphs***, Hatfield, Association for Science Education.

Goldsworthy, A., Watson, J. R. and Wood-Robinson, V. (2000) ***Ymchwiliadau: Mynd i'r afael a graffiau.*** Welsh Joint Education Committee Publications Scheme.

Goldsworthy, A., Watson, J. R. and Wood-Robinson, V. (2000) ***Investigations: Developing Understanding,*** Hatfield, Association for Science Education.

Watson, J. R., Wood-Robinson, V. and Goldsworthy, A., (2000) ***Investigations: Targeted Learning,*** Hatfield, Association for Science Education.

You can also find further information on research by the AKSIS project at *www.kcl.ac.uk/depsta/education/research/AKSIS.html*

Mystery Powders: overview
Enquiry type: Identifying enquiry

Section	Activity	Links to KS3 PoS/ Scheme of work	Links to KS4 PoS	Learning objectives Students will be able to:	Assumed prior Knowledge and Understanding
1. Core enquiry	1.1	**Sc1: investigative skills:** The main emphases are concerned with Planning, Obtaining and presenting evidence, Considering evidence and Evaluating. In order to do these students have to use knowledge and understanding from Sc3.	**How science works:** Practical and enquiry skills. Communication skills. The main emphases are selecting suitable analytical tests and ordering them so as to identify chemicals efficiently.	• use their knowledge and understanding of chemical reactions to reveal the identity of the unknown substances (by devising and using an identification key) • use their classification and analytical skills to provide sound evidence for the identity of the different substances, • record observations accurately and evaluate results to make conclusions.	• knowledge of ways of classifying chemicals according to their properties • use of keys to order chemical and physical tests in an efficient way to identify a range of chemicals
2. Background knowledge	2.1	**Sc3: Classifying materials** Patterns of Behaviour	**Chemical and material behaviour:** (b) Patterns of chemical reactions. In particular: • Different groups in the periodic table • Giant structures and small molecules • Substances with covalent, ionic, and metallic bonding	• use knowledge and understanding of specific chemicals to ask questions and to identify chemicals • use knowledge of chemical groupings to ask questions and to identify chemicals which share one or more properties.	None
3. Procedural understanding	3.1	**Sc1 Investigative skills:** Planning	**How science works:** Practical and enquiry skills.	• recognise good questions for identification and understand what makes the questions good or not so good. • write their own good questions.	None
	3.2	**Sc1 Investigative skills:** Obtaining and presenting evidence, Considering evidence and Evaluating.	**How science works:** Practical and enquiry skills.	• know that a key is a tool for doing a job, i.e. classifying or identifying, and that the quality of the key is judged by its efficiency in doing that job. • be able to judge the quality of keys by considering whether general or specific questions come first in the key.	

Spiders: overview
Enquiry type: Identifying enquiry

Section	Activity	Links to KS3 PoS/ Scheme of work	Links to KS4 PoS	Learning objectives Students will be able to:	Assumed prior knowledge and Understanding
1. Core enquiry	1.1	**Sc1: investigative skills:** The main emphases are concerned with Planning, Obtaining and presenting evidence, Considering evidence and Evaluating. In order to do these students have to use knowledge and understanding from Sc2.	**How science works:** Practical and enquiry skills. Communication skills. The main emphases are selecting suitable analytical tests and ordering them so as to identify spiders efficiently.	• use appropriate procedures to collect spiders • handle spiders with care • ask good questions in order to split a group of spiders into sub-groups • ask good questions in order to identify a specific spider • decide what questions would be suitable for each stage of the identification process • construct a key to identify species of spiders • use a key to identify spiders • decide what makes a good identification key.	• different species of spiders, the parts of their bodies and the use and function of their webs • selecting questions to ask when constructing an identification key
2. Background knowledge	2.1	**Sc2: Variation, classification and inheritance** **QCA SoW:** 7D Variation and classification	**Organisms and health:** 5(b) Similarities and differences between species can be measured and classified	• name parts of the body of a spider and describe their role • identify the place of different parts of the body of a spider on a diagram.	None
	2.2			• describe a variety of reasons why spiders build webs. • draw simple diagrams to show how a web is constructed.	None
	2.3			• describe the main differences between spiders and insects • describe the distinguishing features of arachnids and name some of them. • describe how spiders feed • name and describe some types of web.	None
	2.4	**Sc2: Variation, classification and inheritance** **QCA SoW:** 7D Variation and classification	**Organisms and health:** 5(b) Similarities and differences between species can be measured and classified	• name some British spiders and describe some facts about them • write a five-bullet-point description of one British spider • draw a picture of this spider.	None
	2.5			• name groups to which spiders belong • name groups of spiders • name spider species.	None

Spiders (continued)

Section	Activity	Links to KS3 PoS/ Scheme of work	Links to KS4 PoS	Learning objectives Students will be able to:	Assumed prior knowledge and Understanding
3. Procedural understanding	3.1	**Sc1 Investigative skills:** Planning	**How science works:** Data evidence, theories and explanations Practical and enquiry skills.	• decide what criteria can be used to judge good questions for identification. • decide which questions are good for splitting a group of given animals into smaller groups • decide which questions are good for identifying a separate species of spider within a given number of spiders • split a group of spiders gradually so as to separate it into individual species.	None
	3.2	**Sc1 Investigative skills:** Planning	**How science works:** Practical and enquiry skills.	• identify groups to which spiders belong. • identify groups into which spiders are divided. • distinguish between features shared by all spiders and features which are distinctive for some spiders. • use knowledge and understanding of spiders to construct a key.	Information contained in activity 2.5
	3.3	**Sc1 Investigative skills:** Obtaining evidence, Considering evidence	**How science works:** Data evidence, theories and explanations Practical and enquiry skills. Communication skills	• use appropriate procedures to collect pond invertebrates from a sample of pond water • use a key to identify the invertebrates they find • explain how they used the key to identify the invertebrates • describe what is important in a key so as to help identify animals.	Knowledge of how to collect and handle pond invertebrates safely

Air Pollution Enquiry A: overview
(Exploring enquiry)

Section	Activity	Links to KS3 PoS/ Scheme of work	Links to KS4 PoS	Learning objectives Students will be able to:	Assumed prior knowledge and understanding
1. Core enquiry	Enquiry A Activity 1.1A	**Sc1: investigative skills:** Obtaining and presenting evidence, Considering evidence Evaluating.	**How science works:** Practical and enquiry skills. Communication skills.	• look for patterns in graphical data and assess the strength of any patterns observed • look for relations between two variables using a scattergraph • use patterns in data to make predictions and judge the likelihood of these predictions being correct.	None
2. Background knowledge	2.1	**Sc3: Changing materials; Patterns of Behaviour** **QCA SoW** 9G: Environmental Chemistry; aspects of 7E: Acids and Alkalis 7F: Simple Chemical Reactions	**Chemical and material behaviour:** (6a and 6c) **Environment, Earth and universe:** Effects of human activity on the environment (8a and 8b)	• name sources of air pollution and those which cause acid rain. • identify areas which suffer higher pollution levels and account for differences in pollution levels. • describe how acidic air pollution is deposited. • relate information on pollution to their own part of the UK. • describe the chemical reactions involved in the formation of acid rain	Some simple chemical formulae and equations.
3. Procedural understanding	3.1	**Sc1: investigative skills:** Considering evidence Evaluating	**How science works:** Practical and enquiry skills. Communication skills.	• decide whether or not there is a correlation between two variables in a scattergraph • decide whether or not the sample size is big enough to be confident about an apparent correlation. • create scattergraphs on a spreadsheet.	Familiarity with excel spreadsheets
	3.3	**Sc1 Investigative skills:** Considering evidence Evaluating	**How science works:** Practical and enquiry skills. Communication skills.	• identify daily patterns in concentrations of air pollutants • make judgements about the strengths of any patterns identified.	Ability to read graphs

Air Pollution Enquiry B: overview
(Pattern-seeking enquiry)

Section	Activity	Links to KS3 PoS/ Scheme of work	Links to KS4 PoS	Learning objectives Students will be able to:	Assumed prior knowledge and understanding
1. Core enquiry	Enquiry B 1.1B	**Sc1: investigative skills:** Obtaining and presenting evidence, Considering evidence Evaluating.	**How science works:** Practical and enquiry skills. Communication skills.	• sort out the causes and effects within the data table and use scientific models in creating and answering questions • judge the qualities of a good problem statement in the context of a pattern-seeking enquiry • plan how they will analyse data to address a problem • manipulate data (work with tables and scattergraphs) to look for patterns of relations between two variables • draw a conclusion based on evidence • explain their conclusion in terms of scientific ideas • evaluate the extent to which the conclusions drawn are supported by the evidence.	Knowledge of possible causes of acid rain and how it is transported.
2. Background knowledge	2.1	**Sc3: Changing materials;** Patterns of Behaviour **QCA SoW** 9G: Environmental Chemistry and aspects of 7E: Acids and Alkalis & 7F: Simple Chemical Reactions	**Chemical and material behaviour:** (6a and 6c) **Environment, Earth and universe:** Effects of human activity on the environment (8a and 8b)	• name sources of air pollution and those which cause acid rain. • identify areas which suffer higher pollution levels and account for differences in pollution levels. • describe how acidic air pollution is deposited. • relate information on pollution to their own part of the UK. • describe the chemical reactions involved in the formation of acid rain	Some simple chemical formulae and equations.
	2.2	**Sc3: Changing materials; Patterns of Behaviour** **QCA SoW** 9G: Environmental Chemistry	**Environment, Earth and universe:** Effects of human activity on the environment (8a and 8b)	• describe how rivers and their drainage systems become acidic and how this affects aquatic life. • describe some ways in which acid rain affects buildings, trees and people. • describe how acid rain and air pollution are word-wide problems, not just something affecting the UK or Europe. • consider the evidence linking effects and their possible causes.	pH scale as a measure of acidity of a solution.
3. Procedural understanding	3.1	**Sc1 Investigative skills:** Considering evidence Evaluating	**How science works:** Practical and enquiry skills. Communication skills.	• decide whether or not there is a correlation between two variables in a scattergraph • decide whether or not the sample size is big enough to be confident about an apparent correlation. • create scattergraphs on a spreadsheet.	Familiarity with excel spreadsheets
	3.2	**Sc1 Investigative skills:** Considering evidence Evaluating	**How science works:** Practical and enquiry skills. Communication skills.	• rearrange data in a table and work out mean values for air pollution by wind direction • describe factors which affect whether or not there is a pattern relating levels of two variables. These include the size of differences between means of values, the variability of the data, the number of readings for each value and factors other than the ones studied which might have an impact on air pollution.	Familiarity with excel spreadsheets

Air Pollution Enquiry C: overview
(Pattern-seeking enquiry)

Section	Activity	Links to KS3 PoS/ Scheme of work	Links to KS4 PoS	Learning objectives Students will be able to:	Assumed prior knowledge and understanding
1. Core enquiry	Enquiry C Activity 1.1C	**Sc1: investigative skills:** Obtaining and presenting evidence.	**How science works:** Practical and enquiry skills. Communication skills.	• retrieve data from the internet • make first hand measurements of the volume and pH of rain water • record data in a table or an electronic spreadsheet.	None
	Enquiry C Activity 1.2C	**Sc1: investigative skills:** Planning Considering evidence Evaluating.	**How science works:** Practical and enquiry skills. Communication skills.	• tabulate data, work out mean concentrations of pollutants and compare the levels of pollution for different wind directions and wind speeds • draw scattergraphs to look for patterns in data.	Knowledge of possible causes of acid rain and how it is transported.
	Enquiry C Activity 1.3C	**Sc1: investigative skills:** Planning Considering evidence Evaluating.	**How science works:** Practical and enquiry skills. Communication skills.	• sort out the causes and effects within the data table and use scientific models in creating and answering questions based upon their data collection • judge the qualities of a good problem statement in the context of a pattern-seeking enquiry. • plan how they will analyse data to address a problem • manipulate data (work with tables and scattergraphs) to look for patterns of relations between two variables • draw a conclusion based on evidence • explain their conclusion in terms of scientific ideas. • evaluate the extent to which the conclusions drawn are supported by the evidence.	Knowledge of possible causes of acid rain and how it is transported.
2. Background knowledge	2.1	**Sc3: Changing materials; Patterns of Behaviour** **QCA SoW** 9G: Environmental Chemistry and aspects of 7E: Acids and Alkalis & F: Simple Chemical Reactions	**Chemical and material behaviour:** (6a and 6c)	• name sources of air pollution and those which cause acid rain. • identify areas which suffer higher pollution levels and account for differences in pollution levels. • describe how acidic air pollution is deposited. • relate information on pollution to their own part of the UK. • describe the chemical reactions involved in the formation of acid rain	Some simple chemical formulae and equations.
	2.2	**Sc3: Changing materials Patterns of Behaviour** **QCA SoW** 9G: Environmental Chemistry	**Environment, Earth and universe:** Effects of human activity on the environment (8a and 8b)	• describe how rivers and their drainage systems become acidic and how this affects aquatic life. • describe some ways in which acid rain affects buildings, trees and people. • understand that acid rain and air pollution are world-wide problems, not just something affecting the UK or Europe. • consider the evidence linking effects and their possible causes.	pH scale as a measure of acidity of a solution.

Air Pollution Enquiry C: (continued)

Section	Activity	Links to KS3 PoS/ Scheme of work	Links to KS4 PoS	Learning objectives Students will be able to:	Assumed prior knowledge and understanding
3. Procedural understanding	3.1	**Sc1 Investigative skills:** Considering evidence Evaluating	**How science works:** Practical and enquiry skills. Communication skills.	• decide whether or not there is a correlation between two variables in a scattergraph • decide whether or not the sample size is big enough to be confident about an apparent correlation. • create scattergraphs on a spreadsheet.	Familiarity with excel spreadsheets
	3.2	**Sc1 Investigative skills:** Considering evidence Evaluating	**How science works:** Practical and enquiry skills. Communication skills.	• rearrange data in a table and work out mean values for air pollution by wind direction • describe factors which affect whether or not there is a pattern relating levels of two variables. These include the size of differences between means of values, the variability of the data, the number of readings for each value and factors other than the ones studied which might have an impact on air pollution.	Familiarity with excel spreadsheets

Fitness: overview
Enquiry type: Design a system

Section	Activity	Links to KS3 PoS/ Scheme of work	Links to KS4 PoS	Learning objectives Students will be able to:	Assumed prior knowledge and Understanding
1. Core enquiry	1.1	**Sc1: investigative skills:** The main emphases are concerned with Considering evidence and Evaluating. In order to do these students have to plan data collection and how to obtain evidence.	**How science works:** Data , evidence, theories and explanations Practical and enquiry skills. Communication skills. The main emphases are concerned with interpretation of data and making judgements about the quality of data and therefore the conclusions drawn from them.	• identify different types of fitness • plan how they will measure and evaluate data to assess the level of a specific type of fitness • manipulate data (work with tables and graphs) to look for changes in a type of fitness • draw a conclusion based on evidence • explain their conclusion in terms of scientific ideas • evaluate the extent to which the conclusions drawn are supported by the evidence.	• different types of fitness • different types of food and their functions • factors affecting fitness • measuring fitness • construction and analysis of tabulated and graphical data • evaluating inferences from data
2. Background knowledge	2.1	**Sc2: Humans as organisms** - nutrition QCA SoW: 8A Food and digestion, 8B Respiration 9B Fit and healthy	**Organisms and health:** Human health (5e)	• identify different types of fitness and • rate different sport activities according to different types of fitness • appreciate that different types of activities are associated with different types of fitness. • define terms related to fitness.	• terms used in relation to fitness
	2.2			• name the different types of food substances (nutrients), • identify the function of each food substance • identify the foods in which each substance is contained. • identify the ingredients of a balanced diet, including recommending amounts of different food groups and fluids • describe the changes in diet that are necessary when attempting to maintain different types of fitness.	• functions of different kinds of food
3. Procedural understanding	3.1	**Sc1 Investigative skills:** Considering evidence Evaluating	**How science works:** Data , evidence, theories and explanations Practical and enquiry skills. Communication skills	• distinguish between information on aerobic and anaerobic fitness • make judgements about a person's likelihood of winning a half marathon based on fitness data. • make judgements about changes in the overall fitness of a person based on changes in indicators of different types of fitness.	• differences between different kinds of fitness • measures of fitness
	3.2	**Sc1 Investigative skills:** Considering evidence Evaluating	**How science works:** Communication skills	• make judgements related to fitness by reading a pulse rate graph	• interpreting graphs
	3.3	**Sc1 Investigative skills:** Considering evidence	**How science works:** Communication skills	• identify patterns in a table showing levels of obesity in the population • account for the observed patterns • suggest what action might be needed to improve young people's fitness.	• interpreting tables
	3.4	**Sc1 Investigative skills:** Evaluating	**How science works:** Data , evidence, theories and explanations. Practical and enquiry skills Communication skills	• evaluate the adequacy of a protocol describing how a test was performed, • make conclusions based on data of pre- and post-training performance. They will consider the number of readings, the variability of the data and the difference between means of values.	• awareness that there is error in empirical data

Bubbles: overview
Enquiry type: Investigating models
This enquiry is best done at the end of KS3 or beginning of KS4, i.e.Y9 or Y10.

Section	Activity	Links to KS3 PoS/ Scheme of work	Links to KS4 PoS	Learning objectives Students will be able to:	Assumed prior knowledge and understanding
1. Core enquiry	1.1	**Sc1: Investigative Skills** Planning Obtaining and presenting evidence Considering evidence Evaluating evidence	**How science works:** Data, evidence, theories and explanations Practical and enquiry skills. Communication skills.	• decide a data collection strategy for generating meaningful graphs • draw graphs and describe the relation between two variables • formulate a qualitative model of the forces acting on bubbles • formulate a mathematical model to express the relation between two variables by plotting graphs • evaluate the quality of the evidence used to generate a mathematical model, in particular evaluate the range of values used, the number of values and the number of repeat readings of each value.	Different kinds of forces. Unbalanced forces change the speed and direction of movement of objects. If forces are balanced, (or the total force is zero)
2. Background knowledge	2.1	**Sc4: Forces and motion**	Relates to forces units and modules in Additional Science and Double Award GCSE specifications.	• state that a force called upthrust pushes upwards on objects placed in a liquid • state that the size of the upthrust increases as the size of objects placed under a liquid increases.	None
	2.2	**Sc4: Forces and motion**	Relates to forces units and modules in Additional Science and Double Award GCSE specifications.	• identify air resistance and drag as forces that oppose motion (through air and through fluids in general, respectively) • state that the size of air resistance or drag increases with the size of objects.	None
	2.3	**Sc4: Forces and motion**	Relates to forces units and modules in Additional Science and Double Award GCSE specifications.	• identify the forces acting on air bubbles in a liquid, when the bubbles are at rest, accelerating or in a state of uniform motion • construct a model showing how the forces balance when the bubble is at terminal speed • consider the effect of the size of the bubbles on both the upthrust and the drag.	None
3. Procedural understanding	3.1	**Sc1 Investigative skills:** Considering evidence Evaluating	**How science works:** Practical and enquiry skills Data, evidence, theories and explanations Communication skills	• judge the confidence that can be placed in a line drawn through a set of points • explain how the confidence to be placed in the shape of the line will depend on the number of points, the variability of the data and whether the line makes sense in relation to the real situation that it represents.	Plotting graphs. Lines of best fit.
	3.2	**Sc1 Investigative skills:** Considering evidence	**How science works:** Communication skills	• describe the shapes of different graphs, including the use of the term 'directly proportional to' for straight-line graphs going through the origin • write formulae to describe the relationship between two variables in straight-line graphs • transform some curved graphs into straight-line graphs to check whether or not they have identified the correct relationship.	This activity should ideally build on graphical work done in Mathematics lessons.

Biodiversity: overview.
Enquiry type: This enquiry is fairly open, allowing pupils to choose a question to investigate. Likely enquiry types that pupils might choose are exploring, pattern seeking, fair testing and designing a system.
This enquiry is designed for use with KS3 students, but can also be used effectively with students at KS4.

Section	Activity	Links to KS3 PoS/ Scheme of work	Links to KS4 PoS/ Scheme of work	Learning objectives Students will be able to:	Assumed prior Knowledge and Understanding
1. Core enquiry	1.1	**Sc1: investigative skills:** Planning Obtaining and presenting evidence, Considering evidence, Evaluating	**How science works:** Data, evidence, theories and explanations Practical and enquiry skills Communication skills	• generate a suitable question for a scientific enquiry, • decide on an approach to enquiry that matches their research questions, • make decisions about what to observe or measure and how to - make those observations or measurements.	• Different kinds of enquiry. • How to obtain reliable evidence • Background knowledge needed will depend on the enquiry chosen.
2. Background knowledge	2.1	**Sc2: Living things in their environment** **QCA SoW:** 7C Environment and feeding relationships 8D Ecological relationships 9M Investigating scientific questions	**Organisms and health** (5a and 5b)	• explain and use scientific words relating to the school field as an ecosystem.	
	2.2			• describe what worms eat, their habitat and the effects worms have on the ecosystem.	
	2.3			• describe the key features of grass and dandelion plants, • apply their knowledge of the features of plants to explain why certain plants may not survive well on a school field.	
3. Procedural understanding	3.1	**Sc1 Investigative Skills:** Planning	**How science works:** Data, evidence, theories and explanations. Practical and enquiry skills Communication skills	• ask questions that can be investigated scientifically and decide on an appropriate approach to find the answers.	
	3.2	**Sc1 Investigative Skills:** Planning		• look at a research question and identify what must be measured, • identify criteria to be used in deciding how to measure biological variables.	

QUALITY DISCUSSION

The research background

A key feature of the quality of teaching and learning that goes on in science lessons is the quality of the talk that goes on between the teacher and the students in the class. This section focuses on the kind of discussion that should occur when teaching procedural understanding and in particular, what the teacher can do to raise the quality of this discussion. A key feature of teaching procedural understanding is that students learn why specific skills and procedures are used in particular ways in particular contexts. This involves understanding the criteria that are used to judge the quality of decisions made in the enquiry.

Research evidence is clear about the kind of classroom discussion that can help to support the development of the kinds of reasoning required for developing and using understanding such as procedural understanding. For example, Alexander carried out a large-scale comparative study of primary school teaching in five countries, and showed that there was evidence of improvements in students' achievements using what he called 'dialogic teaching' (Alexander, 2004). Alexander's 'dialogic teaching' involves creating a learning environment in which students learn together in a reciprocal learning environment in which students listen to one another's ideas, share ideas and consider alternative viewpoints. The learning environment is a supportive one in which students can articulate their ideas freely. Learning is cumulative in that teachers and students build on their own and each other's ideas. Learning is also purposeful, being directed by the teacher towards particular educational gaols.

Similar approaches have been used by Mercer ***et al.*** (2004) in science teaching. Mercer ***et al.*** (2004) carried out a study in which they 'aimed to develop children's use of language as a tool for reasoning together and to enable them to use the discussion skills they developed in carrying out science activities'. Mercer described the talk being developed in the lessons as

> that in which partners engage critically but constructively with each other's ideas. Relevant information is offered for joint consideration. Proposals may be challenged and counter-challenged, but if so reasons are given and alternatives are offered. Agreement is sought as a basis for joint progress. Knowledge is made publicly accountable and reasoning is visible in the talk (Mercer et al., 2000, p 98).

A key aspect of the intervention was for the teacher to guide both the whole class and group discussions. Qualitative and quantitative data were collected for the intervention and control group. The results showed that this kind of talk could be learned and that students' performance improved significantly as a result.

As the **'Beyond Fair Testing'** materials were developed we carried out observations in the classroom and collected examples of the teacher talking to students in the class, whilst teaching procedural understanding. We drew from research literature to identify criteria for judging the quality of the discussion in different transcripts of sections of lessons and then we developed 'Indicators of Quality Discussion' (figure 1), which describe what the teacher must do to encourage high quality talk in his or her classroom.

In this section, first 'Indicators of Quality Discussion' are introduced and then these are used to illustrate what is meant by quality in the following contexts:

- Identifying enquiries **'Mystery Powders'** and **'Spiders'**: In these pieces of discussion the focus is on identifying the criteria for selecting suitable questions to use as tests for identifying.
- Investigating models enquiry **'Bubbles'**: These pieces of discussion focus on using graphs to explore patterns in data and in particular focus on whether enough data has been gathered to decide between drawing a straight line or a curve through the points on a graph.
- Exploring and pattern-seeking enquiries in the context of **'Air Pollution'**: These pieces of discussion focus on interpreting graphs and trying to decide whether the graphs show patterns in the data.

Evaluating the Quality of Enquiry Discussion

Indicators of Quality Discussion

Using the quality indicators
When judging the quality of a piece of enquiry discussion, evidence should be sought under each of the categories:

- Purposeful
- Supportive learning environment
- Constructive
- Reflective

Sometimes the evidence may not be there, because the piece of transcript is too short.

The indicators under the category headings are given either a letter or a roman numeral. Where letters are used, evidence could be shown by one or more of the indicators, while the roman numerals provide hierarchical descriptions within a particular category and so evidence would be shown by only one of these.

1. Purposeful
Description: The teacher plans and facilitates discussion with particular educational aims in view. There are two aspects that affect this quality: one is the quality of the educational aim itself and the second is how effectively the aim is pursued.

Indicators:

a. The aims of the discussion are concerned with the understanding needed to carry out scientific enquiry.

b. It should be possible to identify the educational aims of the teacher from a piece of discussion. The continuous transparency of the aims is one indicator of quality.

2. Supportive learning environment

Description: Learning is seen as a collaborative process. The teacher communicates that listening to each other and sharing ideas is important.

Indicators:

a. The emphasis is on learning together rather than getting right or wrong answers

b. Teacher uses 'we' or 'our' to indicate inclusive nature of the classroom environment

c. Teacher shows respect for or interest in students' ideas in his/her discussion. Students are encouraged to contribute more. This sometimes results in students asking questions. Students' ideas and responses are not simply ignored.

d. Teacher tries to involve all members of the class in the discussion.

e. The teacher writes students' ideas on the board.

f. Teacher justifies why incorrect ideas have been rejected and does not reject them based on teacher authority.

3. Constructive

Description: The teacher uses or selects students' ideas to move towards his/her aims.

Two types of student ideas can be found: on-target ideas and off-target ideas. On-target ideas are the ones which can be used to move towards the aims of the piece of discussion. Off-target ideas are ones which are not leading towards the aims of the piece of discussion.

Indicators:

a. The teacher draws upon on-target ideas so as to move towards the educational aims.

b. The teacher considers off-target ideas and

- addresses the student idea and provides justification of why it is wrong or irrelevant, or
- decides to ignore or pay little attention to student ideas in order to maintain the purposefulness of the discussion towards achieving its educational goals.

Note: *It is not always necessary to seek justification as this may come in conflict with (2) above. Constantly seeking justification may have a negative effect on providing a supportive environment, particularly for students who are reluctant to speak publicly.*

4. Reflective
Description: Teachers communicate that explanation of ideas is important. They encourage students to reflect on their ideas and explain or elaborate them.

Indicators:
This is a hierarchy of indicators with (i) being better quality than (ii).

i. Teacher responds to student's idea by asking for justification or elaboration. This strategy can be seen to be successful when students explain ideas using words like 'I think', 'Because', 'I should', 'I could', or they use complete sentences in replies, rather than one or two words or short phrases.

ii. Teacher gives a scientific justification rather than relying on teacher authority.

The first category of indicators explores the purpose of the discussion. There are two aspects to this. The first is the **transparency of the aims:** is the discussion clearly moving towards achieving some educational purpose? In some pieces of discussion it was difficult to identify the aims of that particular piece of discussion. If this was difficult for experienced science educators to see, we thought that it would be impossible for many students. The second aspect relating to purpose is **whether the purposes being followed were worthwhile.** Whether the purposes are worthwhile can be judged against whether they are concerned with procedural **understanding,** rather than just learning how to do certain skills or processes. Students should be learning about the criteria against which a particular aspect of procedural understanding can be judged. For example if they are learning how to design an identifying enquiry (e.g. chemical analysis), they will need to understand the criteria for deciding whether a particular test that is selected is a good test for discriminating between the chemicals.

The second category describes an environment in which students feel that the purpose of the discussion is to learn, where the concern is not so much on right and wrong answers but on learning together. The environment should be one in which students feel free to express their ideas, without fear of criticism. This does not mean that the discussion should not be critical, but that it should involve reasoning rather than judgement. There is a possible conflict here between this category and the fourth one. The teacher needs to be sensitive to the needs of individuals, in particular those who find it difficult to explain or elaborate their ideas in front of others, so a balance has to be struck between asking for elaboration, but avoiding destroying a supportive learning environment.

The third category is concerned with whether the members of the class and the teacher work together to build on one another's ideas. This means that the teacher needs to address students' ideas and build on them by asking students to elaborate or justify their ideas. Rather than being a one-to-one question and answer session, where the teacher asks a question, gets a student to answer and then evaluates the answer, the aim is to move towards a discussion which is cumulative and helps all the students to move towards understanding. As always, the teacher has to use judgment in deciding which ideas to focus on. There is a balance to be struck between getting students to elaborate or explain misconceptions, and selecting better answers which can then be used to guide the discussion towards the educational purposes of the particular piece of discussion.

The final category is concerned with the extent to which the students display their reasoning. The indicators of quality here show whether the teacher is encouraging students to explain or elaborate their ideas.

Identifying enquiries: 'Mystery Powders' and 'Spiders'

The first pieces of discussion come from a lesson with the '**Mystery Powders**' enquiry (**Mystery Powders**: ***Activity 3.1***). The students had been given the following problem:

> Your school has a new state of the art chemistry laboratory. Unfortunately there is a problem with the roof. Over the weekend there have been heavy thunder storms and you come in to school to find the laboratory has been flooded. Some bottles of chemicals have lost their labels. By careful searching, you find the labels, but the problem is
>
> **Which label goes with each bottle?**
>
> Your job is to design a way of identifying the chemicals so that your teacher can put the right labels back on each bottle.

The class was an above average group of 14 and 15 year-olds. They had spent a previous lesson revising the different groupings that chemicals can be placed in and the properties associated with those groups. In today's lesson they were given thirteen bottles, labelled A to M, containing different solids and data cards describing the properties of the solids. Two aspects of procedural understanding associated with observation were being addressed in this lesson:

- deciding the criteria that can be used to judge good questions for identification,
- being able to arrange the questions in a suitable order in a key.

The lesson started with the students having to think up ten questions to identify a chemical that the teacher was thinking of. They were only allowed to use questions that gave a yes/no answer. The teacher emphasised that the students had to choose their questions carefully. We join the discussion after the following questions and answers:
Q: Does the solid have a melting point over 500C? A: Yes.
Q: Is it soluble in water? A: No.
Q: Does it conduct electricity when solid? No.
Q: Is it white? A: Yes.

Transcript 1:[1]

1. Mr. Watt: Were all these good questions to ask?
2. Ss: (many replies) No. Yes. It's ionic etc…
3. Mr. Watt: OK. Denis?
4. Denis: Conduction when solid is a bad question because when it is yes…Um…It can only be no.
5. Mr. Watt (referring to the data cards): Are there any in there which conduct when it is solid?
6. Denis: Yea, the metals. When it's a metal.
7. Mr. Watt: So if you ask this question, conduction when solid…?
8. Denis: It has to be a metal, when its yes.
9. Mr. Watt: And why is that?
10. Denis: Because when it's a liquid…(stops talking)
11. Mr. Watt: No, you are on the right lines. You are classifying there into metals and not metals. Sadie?
12. Sadie: There are only metals and all of them are insoluble.
13. Mr. Watt: OK. I think… Which is the best question here to split our compounds into two sets?
14. Jordan: Ionic or covalent.
15. Mr. Watt: From their properties. Tom?
16. Tom: Is it white?
17. Mr. Watt: (strong confirming voice) That's the best question, I would say. Why is that the best question?
18. Tom: Because that's about half and half. About half of them are white.

The *purpose* of the discussion clear: to identify good questions (lines 1, 17) and one criterion for selecting good questions early on in the analysis becomes clear in line 18: that questions should divide the substances into fairly equally sized groups. After line 18 the teacher got the students to check the data cards to make sure that the 'Is it white?' question did that.

(Footnotes)

[1] Note: in all the transcripts unless names are used, T represents the teacher, S the students, G a girl and B a boy.

Later in the lesson the students are working in small groups and the teacher joins a group:

19. S: We are going to do the boiling point. Boiling point of over 800.
20. T: Could you do that test in the lab? You are going to do this test in the lab next Monday.
21. S: No, you couldn't do that easily.
22. T: No, that's probably not a great one to do…
23. S: I t would be hard to do
24. T: It would be hard to carry out. Maybe I could let you try it and you would find out it does not work. (Teacher leaves)

Here a second criterion for judging the quality of a question emerges: its practicability.

There is little evidence in the discussion to indicate a ***supportive learning environment***, although examination of the longer discussion showed that the teacher sometimes included the students by using the word 'we' when talking about the class activity. He also encouraged many students to answer questions and there was even one unsolicited question from a student.

There is some evidence of the discussion being ***constructive*** but Mr Watt allowed the discussion of whether electrical conductivity was a good criterion for a question to fizzle out inconclusively (lines 4-12). After this the teacher refocused the students by saying that one criterion for a good question is that it divides the substances into two groups (line 13) and this is picked up by a student in line 18. The discussion is strong in ***reflection***. Mr. Watt asked 'why' questions that promoted the use of the word 'because' (lines 4, 10, 18) and of complete sentences, rather than single words or short phrases (lines 8, 12 and 18).

Summary of analysis of transcript 1

Category	**Was the discussion good with respect to this category?**	**Why?**
Purposeful	Yes	Clear focus on developing criteria to identify good questions for tests.
Supportive learning environment	Fairly	Teacher involves several of students in the discussion. One student question.
Constructive	Fairly	Students' ideas used but not always effectively.
Reflective	Yes	Use of why by teacher prompted use of 'because' and of whole sentences.

The discussion below from a fairly average year 9 class working on the **'Spiders'** enquiry **(Spiders: *Activity 3.1, exercise 2*)** is similar. The lesson follows one in which the students had been looking at the different characteristics of ten kinds of spiders on 'spider cards' and trying to use these characteristics to divide them into groups.

Transcript 2:

1. T: What were you doing with the spider cards? Put your hands up when you can remember.
2. S: We were trying to identify the spiders.
3. T: We were trying to identify the spiders doing what? What were we trying to come up with to identify the spiders? Yeah?
4. S: We were classifying the spiders into groups, so that we could identify them.
5. T: Excellent. Another important word there, if you're listening. We are *classifying* spiders into groups, identifying them using questions. What sort of questions were they that we were using? Daniel?
6. Daniel: Has it got long legs? Does it live in the house?
7. T: Its habitat, different features about the way that it looks. You have to look at them to classify them. Were the questions open-ended? What type of questions were we asking though, that we were thinking we need to use in order to make a key, to flow from one place to another? Any ideas?
8. S: Descriptive?
9. T: Yeah. But if I just said, 'where does the spider live' why would that question not be as good as 'does the spider live in grassland'? Aisha?
10. Aisha: Because then it might be hidden low.
11. T: Possibly, but …

The discussion is ***purposeful:*** the educational aim is clear and the teacher manages the discussion so as to get the students towards the target. The teacher avoids evaluating students' answers. Therefore, the ***environment*** looks supportive. In terms of the discussion being ***constructive***, the teacher starts by drawing upon a student's contribution building upon it (line 3), but then only superficially attends to the students' contributions (by repeating, rephrasing or accepting them) and re-focuses the discussion with statements which do not follow from the students' answers (lines 5,7,9). The last student's contribution was not addressed (line 10). The discussion is not very ***reflective***. Students are not asked to elaborate on their contributions or explain their ideas.

It can be seen that the preconditions for learning are present here, i.e. having a clear purpose and a supportive learning environment, but that the teacher did not use these to build on students' ideas or to encourage them to be reflective. To improve this discussion more attention could have been paid to what the students actually said. For example, Daniel (line 6) gives two possible questions to ask. Stopping and addressing each of these and considering why one might be better than another would have helped to move the students towards the aim of the lesson by identifying criteria by which the quality of a question could be judged. Asking students to elaborate and explain their ideas would have led to the more thoughtful discussion needed when trying to develop ***procedural understanding,*** i.e. the understanding needed to explain why certain procedures are used, rather than simply how to use them.

Summary of analysis of transcript 2		
Category	**Was the discussion good with respect to this category?**	**Why?**
Purposeful	Yes	Clear focus on developing criteria to identify good questions for tests.
Supportive learning environment	Fairly	Student contributions accepted without being evaluated as right or wrong by the teacher.
Constructive	No	Students' ideas not used to develop the discussion.
Reflective	No	Students not asked to elaborate or explain.

Investigating models enquiry: 'Bubbles'

In the **'Bubbles'** enquiry students collect data about different-sized air bubbles travelling up through glycerol and try to model the relation between bubble size and speed of the bubbles. The discussion comes from the beginning of this enquiry, when the teacher is trying to get the students to make a prediction based on their scientific knowledge. This is a below-average class of 13 and 14 year-olds and this is the first time the teacher has taught this class.

Transcript 3:

1. T: I've drawn the diagram of a small bubble and a big bubble in the tank. It's not very good diagram, because I am not very good at drawing. I'm going to ask you a question and I'm going to choose two of you to give an answer, which I am going to write down. OK? To answer the question you are going to think what your teacher has been talking to you about over last few weeks, OK? So thinking hats on. Which one of these two bubbles, if I could release these two bubbles at the same time in the tank, just like tank in front of you, which one do you think would go up fastest through glycerol, which is thick gooey liquid? Which one will go up fastest?

   When you answer this question, (some students' hands go up) when you answer it, I want you to give me a word, 'I think it is the little one because' (emphasising because). So I don't want you just say, big one or the little one. OK? So, I am going to give some time to think, and I am going to write down two answers… When people are ready. Who's going to be brave enough to have a go? I am going to choose two because these two were first.
2. S: I think the big one is, because of more upthrust.
3. T: OK. What's your name?

4. S: Joshua
5. T: So Joshua says, my writing is really bad as well, upthrust is big. What did you say?
6. S: …on the big bubble.
7. T: So what did you say? Upthrust is big on a big bubble (writes this sentence on the board). So that will go through the liquid fastest. Alright.

   OK, that's fine. Does anyone think the little one will go fastest? (pause) Anyone think the little one will? (pause) So everybody in here thinks the big one will go fastest and everyone thinks that the reason is because of upthrust. Anybody think anything different? It's OK. Different is fine. Good. (pause) No? All in agreement? (pause) Somebody over there who is just itching to say something… I am not quite sure. Be brave. If you think different, if you think different reason or if you think little bubble should go fastest, say so. (pause). So we've got everyone in this room… Sorry? Are you going to say it? OK, fine. Alright. You are going to say?
8. S: Because I think I'm wrong.
9. T: Sorry, because you think you're wrong? What do you think?
10. S: Same time … because bubbles are at the same levels.
11. T: Fine. That's fine. What is your name?
12. S: Aisha.
13. T: Aisha thinks because the bubbles are at the same levels, that they will reach the surface at the same time. That's fine. I could write that. That's a prediction. Aisha, same time (writes on the board) Aisha 'same time'. And this young lady?
14. S: Big one because its got more air.
15. T: Big one because its got more air in big bubble. (writing down on the board) More air in big bubble. Alright. Okay, now. What we've done there, we've got some ideas. And we put some reasons down. It doesn't matter whether those are right or wrong, because we are going to investigate this bubble behaviour.

This discussion is ***purposeful***. It is clear that the aim is to make predictions supported by explanations. The teacher works hard at trying to establish a ***collaborative learning environment*** with this new class. He encourages students to contribute (line 1) and waits to give people time to think. He encourages a variety of views and encourages a girl who is reluctant to put forward the second prediction (lines 7-9). The sharing of views is emphasised by writing the different points of views on the board. Although students sometimes offer incorrect ideas, the teacher emphasised ***collaborative learning*** by not addressing these ideas at this point, because the purpose of the discussion is to make predictions, which will be explored later. This sets up the lesson for a ***constructive*** discussion later in order to explore the students ideas further, after they have collected data. The teacher is very explicit about students' justifying ideas. He provides a 'talking frame' saying that their answers must fit into the wording, 'I think…because…' (line 1). This results in ***reflective*** discussion in which all the students justify their ideas (lines 2, 10 14).

The quantity of talk from the teacher is much greater than the quantity of talk from the students. This seems appropriate in this piece of discussion where the teacher was setting the ground rules for what was to follow.

Summary of analysis of transcript 3		
Category	**Was the discussion good with respect to this category?**	**Why?**
Purposeful	Yes	Clear focus on making predictions supported by explanations.
Supportive learning environment	Yes, very good.	Teacher encourages student contributions. Student contributions accepted without being evaluated as right or wrong by the teacher. Plenty of wait time. Students' ideas written on board.
Constructive	Not yet	Students' ideas were accepted to be evaluated in the light of experimental data later in the lesson.
Reflective	Yes	Teacher provides a clear 'talking frame' emphasising explanation.

In the next piece of discussion we see the same teacher working on the **'Bubbles'** enquiry (**Bubbles: *Activity 1.1, part 3***) with an above average group of Y9 students. This time the teacher knows the class and has taught the class for many lessons already. The class has already spent two lessons on the enquiry, both exploring the forces that act on bubbles and collecting some data about bubble sizes and their speeds of travel in glycerol. The lesson took place in an IT room and was based around looking at some bubble data collected by a student in a parallel class. A graph of the radius of bubbles on the x-axis and speed of bubbles on the y-axis was displayed in excel on a large whiteboard.

The procedural understanding being addressed in this lesson was understanding the confidence that can be placed in the shape of a line drawn through a set of points. The teacher wanted them to know that the confidence to be placed on the shape of the line will depend on the number of points and their distribution on the graph, the variability of the data and whether the line makes sense in relation to the real situation that it represents. In the transcript below the teacher is focusing on the factors in the real experimental situation that affect the accuracy of the data.

Transcript 4:

1. T: Let's think about the experiment that we did? …What do you think were the problems?… What do you think were the most difficult bubbles to measure? To measure the size? This is an experimental thing. You have all done the experiment.
2. S1: The really big ones.
3. T: The really big ones. Right I am going to write that up. Why the really big ones?
4. S2: Because they went up so quickly, you didn't really have time to measure them.
5. T: Right. Measuring their size because they moved quickly. Now, remember that in the experiment we were measuring size and we were measuring speed. Because they were moving quickly, there were lots of problems to measure size. Because we had that problem, we have to think about that problem when we are looking at our data… Right, if they are moving fast, is it quite difficult to measure the speed?
6. S3: Not really.
7. S4: You've got to be quite quick to start the clock.
8. T: Oh, you mean reaction time. OK, so the big bubbles could be quite difficult: measuring the size is a problem and measuring speed is a problem with the apparatus that we use… What about small bubbles?
9. S5: Easier.
10. T: Easier what do you mean?
11. S5: You can see them more easily if they are moving slower so it is easier to measure size.
12. T: What about speed?
13. S5 And speed as well.
14. T: So with smaller bubbles it is easier to measure the size and speed. Is there a limit to the smallness of the bubble that we can measure, or can we keep going down and down? What's the smallest bubble we can measure? That's really the problem. Imm?
15. S6: We did one of 1mm.
16. T: The smallest bubble. Did anyone measure one smaller than that?
17. S: We did half a mm.
18. T: Did anyone do smaller than that?….

This piece of discussion is again ***purposeful*** (line 1). This time it is easier for the teacher to maintain a ***collaborative learning environment***, because the class is used to the way in which the teacher interacts with the class. This results in a different balance between the amount of teacher talk and student talk. The teacher still talks more than the students, but not so much more. The teacher emphasises collaboration by using 'we' (in lines 5 and 14) and by writing students ideas on the board (line 3). He also involves a wide number of students in the discussion, with at least six being involved in this short segment. The discussion is ***constructive***. The response from student 1 about large bubbles (line 2) was used to generate further response from his partner (line 4). The teacher then builds on this by asking the class to consider small bubbles (line 5). This results in a response from student 3 who then, without further teacher intervention, is immediately contradicted by student 4, who also explains why he disagrees. The whole discussion gives a sense of everyone working together towards a common purpose. The teacher also encourages the students to be **reflective** by asking 'why' (line 3), providing justifications for his own assertions (line 5) and asking students to elaborate (line 10).

Summary of analysis of transcript 4		
Category	**Was the discussion good with respect to this category?**	**Why?**
Purposeful	Yes	Clear focus on experimental error.
Supportive learning environment	Yes, very good.	Teacher encourages student talk. Many students contribute. Use of 'we' by teacher. Students' ideas written on board.
Constructive	Yes	Teacher's and students' talk build on one another.
Reflective	Yes	Teacher asks for explanation and elaboration.

Pattern-seeking and exploring enquiries: Air Pollution

In this transcript the Y11 (age 15-16) students were looking at tabulated data (**Air Pollution: *Activity 3.2***) to see whether the levels of sulfur dioxide pollution in the air in a particular location were related to the wind direction. The students had rearranged the tabulated data as indicated in questions 1 to 3 in this activity and had spent some time in groups discussing the points in question 4. The rearranged data showed that there were only two readings for sulfur dioxide concentrations when the wind was from the south and seven when the wind was from the north. The teacher then led a plenary session:

Transcript 5:

1. T: What about your value for South? How many readings did you take for South, Nick?
2. Nick: Seven.
3. T: And how many readings did you take for North?
4. Nick: Two.
5. T: Two. Do you think that it is fair for me to make a conclusion about the North direction with only two readings? What do you think, Ben?
6. Ben: You need more proof.
7. T: You need more proof. What would I do to get more proof?
8. Ben: Get more readings.
9. T: Take more readings. How many readings do you think would be a reasonable amount to take to get some reliable data?
10. S3: Equal amount.
11. T: Equal amount each time; take the same amount each time. Good. What else? How many would be a good amount?
12. S4: Five.
13. S3: Three and above.
14. T: Three and above. OK. So, minimum of three.

The purpose of the discussion was to clarify how many readings were needed to produce a reliable average for a particular wind direction and, in particular, to be able to compare the levels of air pollution when the wind was from different directions. The number of readings needed depends on both the variability in the data for a particular wind direction and on the extent of any differences between wind directions. The ***purpose*** in terms of deciding the number of readings needed is made clear in lines 1, 3, 5, 9 and 14. However, the attempt to elucidate the reasons for needing more readings from the north is weak (lines 5, 7 and 9) and results in the student indicating that an equal number of readings is needed from both the north and the south (line 10) and this is accepted by the teacher (line 11). The purpose of the discussion was to clarify how many readings were needed to produce a reliable average for a particular wind direction (the north). This ***purpose*** is made clear in lines 1, 3, 5, 9 and 14. However, the purpose itself is weak: emphasis on procedural understanding would require focusing on the factors which determine the number of readings that are necessary and which depend on both the variability in the data for a particular wind direction and on the extent of any differences between wind directions. The fact that the educational aim of this discussion was limited undermined the quality of the rest of the discussion.

The teacher makes some moves to create a ***supportive learning environment***. She focuses on eliciting the students' ideas rather than focusing on right or wrong answers and she encourages many of the students to join in the discussion (four in this short transcript). However, she tends to accept students' ideas without asking them to contribute more and without addressing incorrect ideas (line 10). Instead she simply moves on to the next student, often without achieving any more depth of explanation and the feel of the discussion is of moving through the teacher's agenda without being too clear about the teacher's purpose. This leads to a discussion, which is not very ***constructive***. The teacher asks the students to elaborate (lines 5, 7 and 9) but without a clear sense of direction this elaboration is not as purposeful as it might have been.

Summary of analysis of transcript 5

Category	**Was the discussion good with respect to this category?**	**Why?**
Purposeful	No	The purpose was clear, but the procedural understanding required to select an appropriate number of measurements is absent from the purpose.
Supportive learning environment	Yes	Teacher encourages student talk many students contribute. Student responses are not evaluated as right or wrong.
Constructive	No	Teacher accepts answers without building on them.
Reflective	Yes	Teacher asks for explanation and elaboration, although weak purpose weakens its quality.

The next piece of transcript with this year 11 class comes from a part of a lesson based **Air Pollution: *Activity 3.3***. The purpose of this activity is to enable students to identify daily patterns in concentrations of air pollutants and make judgements about the strengths of any patterns identified. The activity is based on a graph showing hourly levels of nitrogen dioxide pollution in the air in Manchester over a one week period. Students had worked through questions 1 to 6, which involved students in exploring whether there were patterns in the levels of air pollution over time. The students now move on to discuss question 7, which is concerned with whether there are patterns in the frequency with which troughs occur in the graph. We join one group of girls discussing this.

Transcript 6:

1. G1: Whereas, you know when you get to number (hour) 7, the bottoms, they are actually spaced out better than the peaks apart from that one.
2. G2: Yeah, but this one is…
3. G3: Because when you look at them, they are fairly similar
4. G1: But look at this one (pointing to the spacing for the last days of the week, which is larger), this is much bigger than the other ones. This is closer together.
5. G3: Yeah, but if you look at all this type, they are closer together.
6. G: Nah, but if you look here, that's got more space and between here it's less. That part is the same.
7. G: So, they aren't fairly evenly, because at different days …
8. G: Yeah.

They then move to discuss with a group of boys:

9. G: What do you think?
10. B: They are spaced evenly.
11. G: No. Because if you look closely, they are not spaced out properly.
12. B: Did you measure them? Because if you are talking about fair they have to be equal, which here they are not. And that would depend on the day and the time.

The girls then work together to consider the evidence more carefully:

13. G3: Why are you writing the time?
14. G1: Just comparing them. Comparing the times on the peak and the trough on the seventh hour with the times on the eleventh hour. Then if Miss asks why, then we can back up our answer.
15. G: It's six, darling.
16. G1: Six am.

After that, the students continue measuring and comparing values. The teacher then arrives:

17. T: Is it evenly spaced, fairly?

18. Gs: No.

19 T: You don't think so?

20. Gs: No.

21. T: Is it roughly?

22. G: They are not evenly spaced.

23. T: Fairly evenly means not exactly but is it roughly the same? Roughly?

The last section of this discussion (lines 13-19) suffers from the same weakness as transcript 5. The aim of trying to decide whether there is a pattern is clear, but the second aim of, identifying the criteria which can be used to make the judgment, is missing from the teacher-student discussion. This is a pity because the preceding group discussion had revealed a clear understanding of the ***purpose*** of the discussion, particularly after the discussion between the boys' and girls' group (line 14). The ***supportive learning environment*** evident in the girls' discussion (lines 1-8 and 13-16) and in their willingness to consult another group (lines 9-12) was not exploited by the teacher, who seemed to be operating in an IRE mode (teacher **I**nitiates – student **R**esponds – teacher **E**valuates) rather than showing interest in students' ideas. The ***constructive*** nature of the girls' work is clear throughout the discussion, with the girls' working closely together and also using the ideas of the boys. The ***reflective*** nature of their discussion is evident in their use of evidence when arguing (e.g. lines 1, 2, 5, 6, and 14) and their use of the word 'because' and 'why' (lines 11, 12 and 14).

What is encouraging in analysing this last piece of discussion is that the quality of student discussion is so good. The conditions for high quality discussion have been set earlier in the lesson by the teacher and through the materials with which the students were engaged. This lesson also is just one of many that the teacher has had with this class and the students are aware that the teacher is going to ask them for their ideas and to justify them (line 14). Contrasting transcript 6 with transcript 3 illustrates the effort needed to create the conditions for effective discussion in enquiry settings. The amount of support and guidance by the teacher to create the conditions for high quality enquiry discussion in transcript 3 is much greater than that in transcript 6, where the students were already used to a particular style of discussion in their enquiry lessons.

Summary of analysis of transcript 6		
Category	**Was the discussion good with respect to this category?**	**Why?**
Purposeful	Partly	The purpose is clear to students, but only one of the two aims is clear in the teacher-student discussion.
Supportive learning environment	Yes	Students are mutually supportive.
Constructive	Yes	Students work closely together and use each other's ideas.
Reflective	Yes	Use of evidence and 'because' in discussion.

Summary: How can teachers encourage quality discussion in enquiries?

- A clear educational ***purpose*** should be ***continuously transparent*** in a whole class discussion of procedural understanding and this purpose should focus on ***understanding***, not just learning routine procedures.
- A ***learning environment*** which emphasises ***learning together,*** rather than getting the right answer, is important.
- Teachers should seek to ***address students' ideas and build on them*** to create a ***constructive*** learning environment. However, teachers have to keep in mind the educational purposes of the discussion and guide it towards those purposes. This may mean sometimes ***deciding*** to ignore students' wrong ideas in order to keep the discussion moving towards the purposes.
- Simply accepting students' ideas is not enough. Teachers should challenge students' ideas by getting them to ***explain and elaborate*** them. The classroom should be a place where students are ***reflective*** and where those ***reflections are transparent*** and available for others to consider.

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HEALTH AND SAFETY

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