1 The Nature of Science and Science Processes

The nature of science

Defining the nature of science is a matter for great debate. Science has changed over the years and reflects the society and culture of our times. It is important here that we consider very briefly what we understand at this stage, about science.

Resources

For your activities in this section you need:

- two or three different gloves
- four small fizzy drink bottles
- four different fabrics
- thermometer
- notebook and pencil and a timer.

Describing science — **Activity 1**

Write down a list of words or phrases that you think describe your understanding of science.

Commentary

Your list probably included some of the following ideas:

Science is a set of discrete disciplines.
Physics, chemistry and biology.
It has a clearly defined body of knowledge.
It has a set of facts that are true.
It is a way of looking at the world.
It is about exploring and investigating the world around us.
It involves research and exploration into new ideas.
Scientists are curious, studious and systematic.

This list could go on but a clear, universally agreed definition is not easy to find. Each of these statements, if used singly, provides a very narrow and limiting description of what science might be. Collectively they still do not give a rounded definition of what science is all about. Discussion on the nature of science has been part of our history and has influenced the way scientists have and do work. Everybody is affected by science in their everyday lives. How we are influenced is determined by our own experiences of science as pupils, but also as citizens and the ways it impinges on us.

The following list of continuums about science provided by Nott and Wellington (1993) suggests some interesting dimensions to the nature of science to extend your thinking on how you see science.

- Relativism *vs* positivism – truth as being relative or absolute.
- Inductivism *vs* deductivism – generalising from observations to general laws versus forming hypotheses and testing observable consequences.
- Contextualism *vs* decontextualism – science interdependent with or independent of cultural context.
- Process *vs* content – science characterised mainly by processes or by facts and ideas.
- Instrumentalism *vs* realism – science as providing ideas which work versus a world independent of scientists' perceptions.

You may find it useful to discuss with colleagues/friends where along the various continuums you feel your ideas are situated. Each of these continuums highlights key tenets of science. It is important that you think about these ideas, alongside your own on the nature of science, especially if you intend to work as a teacher. Your own ideas on the nature of science will influence how you approach your work. It is important for you to understand the place of science in society and the way in which it influences our lives both directly and indirectly so that you can help others to make informed decisions about issues.

As the bounds of science and technology stretch wider it is important to be aware of the many ethical issues that surround some work in the science field.

The current debate on genetically modified crops is an example of an issue that raises many fears and anxieties. Different groups of people such as farmers, parents and politicians have wide-ranging opinions about the research into genetically modifying plants to enhance particular effects. Much of the anxiety is related to the different results that have been published and the interpretation of these results. There is concern as to whether we have the moral right to manipulate and change the genetic make-up of organisms. Where will it stop? Public pressure has encouraged supermarket chains to stop using GM materials in any of their own products until further notice.

This issue is an example of the way science and scientific research can have dramatic changes on our lives as citizens. It highlights how important it is for us to keep up to date with new ideas and developments. This enables us to make informed decisions as and when necessary, e.g. voting at elections.

Jenkins (1997) identifies several significant features about science that define the role it plays in citizenship. This includes how one views the risks involved, how it affects other aspects of our lives, how we make sense of the information and which social group we belong to.

The Association for Science Education (ASE, 1990) says that science content should have human and philosophical significance along with scientific and personal significance. They define human and philosophical significance as how science:

- contributes to the learner's understanding of the world
- illuminates the way that scientific ideas are developed over time
- shows the impact of scientific ideas on the way we live.

Scientific significance, they say, shows how:

- the content should aim to show how scientists model the world in order to understand it
- ideas should suggest explanations and lead to fruitful development
- the range of ideas chosen should include those currently being used by the scientific community and reflect the history of science.

Personal significance of science content should include:

- ideas which are immediately accessible
- preparation for the future as a citizen in a technological world
- development of ideas within appropriate social, personal and industrial contexts.

Science involves us in making moral and ethical judgements about different research, its methodology and outcomes. In order to be able to do this, it is important to develop the public understanding of science. Developing scientific literacy is a complex and wide-ranging issue that is summarised in the lists above. It shows the interactions that are so important in our roles as citizen, worker and family member.

Science essentially is about understanding. It involves reaching possible conclusions, exploring relationships and explanations between ideas and events. It includes the testing of ideas and the proposal of new theories and questions. These ideas are subject to change all the time as our ideas, skills and knowledge are developed through new research and evidence. As Reiss (2002) states' science is a 'body of knowledge about the world. The facts that comprise this knowledge are derived from accurate observations and careful; experiments that can be checked by repeating them and as time goes on, scientific knowledge steadily progresses'. Science, being essentially a human endeavour, relies on the imagination and inventiveness of people to push out the boundaries of science. It involves collaboration and co-operation between individuals and groups and is a creative and stimulating area to work in.

Yet there are key ideas which seem to span the centuries and help us to understand the world in which we live. These basic, simple understandings that underpin many branches of science are developed in Part 1, Chapters 2, 3 and 4 of this book. The next section will look at what is involved in carrying out a scientific investigation and provide a context to reflect on your understanding.

In this section we have seen that:

- Science is about the way our world works.
- We all have roles to play, as citizens, in scientific endeavour and ideas.

Planning, carrying out and evaluating investigations

What is involved in a scientific investigation? What is the difference between investigations and experimenting? Why is it so important to work in a systematic way?

In this section you are to look at what is involved in carrying out an investigation. It will include an experiment using a range of fabrics. This will provide the context for analysing the scientific process and the skills knowledge and attitudes needed. The investigation will be divided into sections to enable us to explore the process as you progress through the task.

Activity 2 Posing useful questions

(a) Thinking about choosing a suitable fabric to make gloves to wear in cold conditions provides a suitable context for raising questions and investigating some of them. You may choose this or provide your own topic for investigation. But not all questions raised are suitable for investigation. Working on your own or with another person write down as many questions as you can about the collection of gloves/fabric that you have.

(b) Look carefully at your list of questions. Can you group them into those that are: more a comment or expression of interest, those that are asking for straight information, those that are more philosophical and those that lend themselves to investigation. (Harlen, 2000)?

Commentary

Harlen (2000) categorises questions into the four types, listed in (b) above, and this provides a useful way to classify questions into investigations or those that just need an answer or further observation or discussion.

Which glove is the best?
Which glove will keep my hand warmest?
What are the characteristics that make a good glove?

These are all questions that could lead into an investigation. Investigations cover a wide range of activities and do not have to include experimenting. They could include all or some of the following:

- research into current ideas using secondary sources
- modelling ideas
- observing
- hypothesising and experimenting to test ideas.

Investigating what would be the best fabric to make a glove may involve looking closely at the structure of the fabrics, exploring how gloves are made and what properties the fabric needs as well as carrying out experiments to test some of these properties.

The kind of question posed will define the breadth of the investigation but not all questions lead to an investigation. The question 'Which fabric will make the best glove for winter?' is one of those that supports investigative work and has the potential for lots of practical experimenting with the fabrics. Alsop et al. (2002) regard asking such questions and testing these ideas in reliable and valid ways as the basis of science.

Defining what is meant by best is an obvious starting point to explore these questions further and may give rise to a range of activities before any decisions are made about testing the fabrics to see which is suitable.

Characteristics such as whether or not they are windproof or they keep your hands warmest will need to be considered before experimenting. These discussions and decisions are what you as the person in control of the experiment must make. It should determine how you plan, carry out and evaluate the experiment. It is important that when you report your findings you include these decisions and ideas in your report as it will determine how the reader views your findings and interprets the results.

Planning an investigation

Having raised a suitable question to investigate it is important to find a way to do this that will answer the question posed. This is not always easy. Many scientific investigations have been criticised because the methodology chosen did not allow the question posed to be answered. It is important to define what you mean by 'best' for the glove. In this investigation, having looked at the important properties of a glove and the way they are made, we have chosen one characteristic of the fabrics to test. This will involve us carrying out an experiment to see which fabric retains most heat. We may devise more than one experiment to investigate the fabrics' properties in this area. For this exercise we are doing just one experiment to test our idea and that will now influence all that we do.

Hypothesising and predicting

Predicting and hypothesising are often linked together but they do have distinctive features. Predicting is saying what you think will happen or in our case which will be the best fabric for keeping our hands warm. In predicting this we may also include a hypothesis, i.e., a reason why we think this, based on our previous knowledge, research and experience. Often people have ideas about why they have predicted what they have, even if they do not articulate these to you. Hypothesising is very much about using previous knowledge, evidence and observations to formulate tentative theories about why things happen in the way they do. It is an important skill to develop and helps us to make sense of our understanding of the world as we transfer this knowledge from one situation to another.

Activity 3 **Which material will be the best fabric to use for a glove to wear in cold weather?**

Our set of materials is made up of three kinds of fabric, suitable to make gloves. One is woollen, one is cotton and the other plastic. Your collection may be different but that will not affect the way you work through the task.

Look carefully at your fabrics and order them from best to worst for allowing heat to pass through them.

Note down your ideas as to why you think this is so. We will return to these at the end of the investigation, when we evaluate our findings. There is no need for a commentary at this stage.

Planning

The next step is to plan and order our work so that we gather the information we need to answer the question posed. What kind of evidence do we need to be able to do this? First we may need to consult resources such as books and collect together appropriate apparatus to help us decide what to do and in what order.

Our investigation will use warm water in small plastic drink bottles to represent the warmth of the hand. Each bottle will be covered with a chosen fabric and one will be left uncovered. The temperature of each bottle will be taken at regular intervals and recorded.

What kind of investigation are we undertaking? The AKSIS Project (Association for Science Education and King's College Investigations in Schools [Goldsworthv, 1998]) lists six types of investigation with sample questions from the project included to exemplify the kind of investigation and type of question to be answered.

1 *Fair testing*. These investigations are concerned with exploring relations between variables or factors, e.g.:

    What affects the rate at which sugar dissolves?
    What makes a difference to the time it takes for a paper spinner to fall?
    Which is the strongest bag?

2 *Classifying and identifying*. Classifying is a process of arranging a large range of 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.

What is this chemical?
How can we group these invertebrates?

3 *Pattern seeking*. These investigations involve observing and recording natural phenomena or carrying out surveys and then seeking patterns in the findings.

Do dandelions in the shade have longer leaves than those in the light?
Where do we find most snails?
Do people with longer legs jump higher?

4 *Exploring*. Pupils either make careful observations of objects or events, or make a series of observations of a natural phenomenon occurring over time.

How does frogspawn develop over time?
What happens when different liquids are added together?

5 *Investigating models*. These are investigations that explore models.

How does cooling take place through insulating materials?
Does the mass of a substance increase, or decrease, during combustion?

6 *Making things or developing systems*. These investigations are usually technological in nature, but have a high scientific content.

Can you find a way to design a pressure pad switch for a burglar alarm?
How could you make a weighing machine out of elastic bands?

You can see from the list the variety of ideas there are for practical activity in science. The emphasis in our investigation of making sure it is a fair test will place it within the fair testing category with strong links to number 5 above – investigating models.

It is important now to ask some key questions in order to make our test fair – so that we are comparing like with like and not changing more than one variable at a time.

The list of questions one needs to ask at this stage includes some or all of the following:

What do we need to measure?
What shall we use to measure?
What do we need to change?
What do we need to keep the same?
How will we measure the changes as they occur?
How often will we measure?
How will we record this data?
Shall we use a table or chart to record the results?
If so what will it look like?

It is important in an investigation to remember that it will involve you in changing something to test the effect and measuring the change.

Activity 4 List some changes

List all the possible things you could change in the glove investigation.

Commentary

Your list might have included some of the following:

- different types of fabric
- temperature of water
- amount of warm water
- size/shape of container
- size of glove closeness of fabric to bottle
- thermometer.

The factors that you could change are called **independent** variables. It is important to decide on your key variable and only change that one keeping everything else constant. The independent variable here is going to be the different types of fabric. We are going to measure the temperature of the water in each bottle at intervals over a period of time. This second variable is the **dependent** variable as it relates or is dependent on the change we have made by using different fabrics. The set-up for the apparatus is shown in Figure 1.

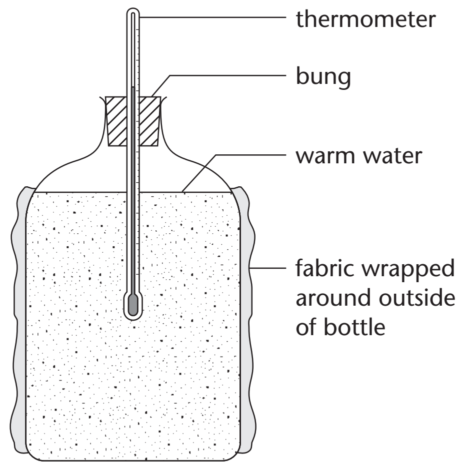

Figure 1 Apparatus to test fabrics for making a glove.

It is essential to keep all the other possible variables constant. So factors such as using same size piece of fabric, same size of bottle and same type of thermometer are important. These are the **control** variables.

Using the list of questions on page 00 design your experiment, working out what order you are going to do things in and what changes you are going to make. How will you measure these? As you now work through the activity note any redesigning or adjustments you have to make to your initial plan.

At each stage try to list the skills and knowledge and understanding you have had to use to complete the investigation.

How to record, analyse and interpret findings

Collecting and recording data

We could use several ways of collecting and recording data, including a chart, a prepared table or a computer spreadsheet. If we had the equipment we could use a sensor attached to a computer so that readings are automatically recorded each time we measure. Depending on where you are doing this work you will have to select the most appropriate means to collect and record data. A possible table could look like that in Table 1.

Table 1 Temperature readings

	Start	3 mins	6 mins	9 mins	12 mins	15 mins
Bottle A Cotton						
Bottle B Wool						
Bottle C Plastic						
Bottle D No fabric						

Looking at the data, can you see any patterns or make links between the factors you were testing? It may be that you wish to display the information in another format that will help you to look more specifically at the results for each fabric. In this case drawing a line graph, with all three fabrics being represented on one graph, will enable you to make comparisons of the rate of cooling for each.

Figure 2 shows as a graph possible results from such an investigation.

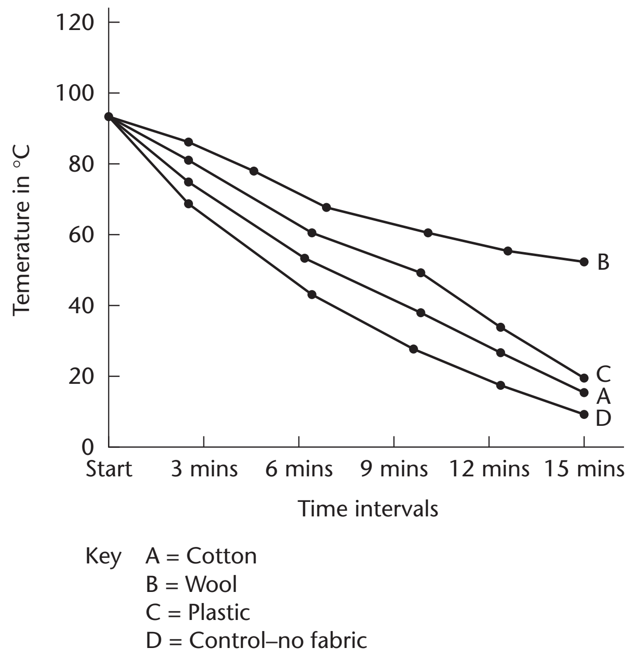

Figure 2 A graph to show results of testing fabrics.

Activity 6 — Ask questions

Using the graph as your resource, list as many questions as you can about the kind of connections you could make with the results as displayed.

Commentary

Some of the more obvious questions you might use to interrogate the graph are given below.

Interpreting results

Which bottle cooled the quickest? Which one took the longest to cool? What happened to the bottle with no cover? Did the cooling for each fabric follow similar patterns? Are the line graphs similar shapes? Are there other factors you want to investigate further? Can you draw any conclusions from this one test?

Evaluation

You might want to repeat the investigation several times to see if the pattern repeats itself. The more evidence one gathers to support the outcome the more sure you can be of any conclusions that you draw.

At this point look back at your predictions and hypotheses. Were the results as you expected? Can you support your reasons for the choices you made?

Do you need to explore more avenues to be able to speak with more authority about which material is best for keeping things warm?

Now return to the notes you made during your investigation. Did you have to modify or adjust procedures and equipment as you went along? If you did, it is possible this was because you had not identified all the possible variables or needed to change the information you needed to gather. This is a quite common part of the scientific process. It is important, all the time you are working, to question your workings and to evaluate whether or not what you are doing will provide the data required.

Having gained some results and drawn some conclusions it is important to evaluate the work, to decide how rigorous your working and findings were. This will help you decide whether you should repeat the experiment or redesign your investigation before starting again.

What skills, knowledge, attitudes and values did you use as you worked? Table 2 adapted from *Progression in Primary Science* (Hollins and Whitby, 1998) is a list of the key process skills alongside a more detailed breakdown of what each might involve. Compare your notes with this detailed list and you will see that you have probably been involved in more activities than you have listed. Carrying out investigations is a very important way of developing skills and understanding of the scientific process. It is only by doing activities that we understand the finer detail and the need to constantly evaluate our ways of working. It also provides a very real context to develop our thinking and relate our previous knowledge to new experiences.

Table 2 Key process skills

Observing	Looking closely at similarities and differences Comparing and contrasting Regularities and irregularities What do you notice about … type of questions Describing patterns Ordering and sequencing events
Raising questions	Raising questions whilst working Restructuring questions into useful ones for investigation Defining testable questions
Measuring	Selecting appropriate measuring techniques Recognising when to use estimating Using measuring devices with accuracy Recognising arbitrary nature of units Recognising need to repeat and check measurements Recognising variability and reliability of measurement

continues

Hypothesising	Attempting to explain observations in terms of concepts or principles Recognising the fact that there are several possibilities to explain phenomena Applying knowledge already required Using the explanation to make predictions of something that can be observed or tested
Planning	Defining the problem Identifying which variables are to be controlled Identifying the independent and dependent variable Considering how observations made will be used to solve problems Selecting appropriate equipment, materials Giving careful consideration to order of working Considering methods of recording findings
Interpreting	Eliciting what can be deduced from the observations and measurements taken Recognising sets and subsets Making use of keys or taxonomies Appreciating the tentative nature of conclusions Making generalisations Making and justifying inferences Making predictions based on patterns
Communicating	Following verbal instructions Describing activity orally Using diagrams/drawings and writings to tell about findings Following written and diagrammatic instructions Using tables and graphs, models etc. to represent information Selecting appropriate ways of presenting information Responding to a range of audiences, selecting appropriate methods of communication Listening to reports/ideas of others and responding to them Contributing to group discussion Using secondary sources to acquire information Using information technology as appropriate

Source: Hollins and Whitby, 1998.

Close observation of Table 2 shows the wide range of skills and experiences that make up a scientific investigation. It is important that we are able to identify which aspects of these skills we are using in a particular investigation.

In this section we have seen that:

- Not all questions lead to investigations.
- There are different dimensions to and processes involved in an investigation.
- There is a need to identify the dependent and independent variables in carrying out an experiment.

Health and safety considerations

This final section is concerned with health and safety issues in science particularly as they apply to primary schools. Sections 7 and 8 of the Health and Safety at Work Act (1974) are most pertinent to work in science and the ASE booklet *Be Safe* (1994) is an important document that should be in all schools alongside any locally agreed safety advice.

There are three important dimensions to health and safety in science. The first of these is the legal requirements that must be obeyed. The second is awareness and assessment of the risks in any practical activity. Clear policies and procedures for when an accident or incident does occur is the third important strand of health and safety.

The Health and Safety at Work Act (1974) is concerned with the health, safety and welfare of all people at work. This includes protecting people at work from risks to health and safety as well as the risks associated with the use, possession and acquisition of dangerous substances. Much of this Act links directly to the workplace. Most education employers have followed advice given in COSHH (Control of Substances Hazardous to Health Regulations 2002) and the Approved Code of Practice that is given with the Management of Health and Safety at Work Regulations 1992. These encourage employers who control a number of similar workplaces containing similar activities to provide a basic model risk assessment that highlights the core hazards and risks associated with particular activities. Every employee therefore has to take reasonable care of the health and safety of themselves and other people with whom they work. They are also obliged to follow any procedures laid down by the organisation or by law. Section 8 of the Act requires employees not to interfere or alter any safety precautions or equipment provided. The reality in school is that any teacher must ensure that everything they do in the course of their teaching takes account of the risks to the pupils. Therefore assessing any science activity for risk is vital.

Be Safe (ASE, 1990) addresses all aspects of health and safety in the primary classroom in a manner which is sensible rather than alarmist and Ofsted Inspectors (1996) are encouraged to be familiar with this. It provides clear guidance on hazards associated with most areas of science. The ASE has also published *Safety in Science for Primary Schools, an INSET Pack* (ASE, 1994) which provides more detailed information about safety. This last section of this chapter highlights some of key areas, identifying possible hazards and suggesting ways to minimise risk.

First some general common sense advice.

- Plan for a safe working environment by giving clear advice about safe ways of working and procedures to follow if an incident occurs.
- Protective clothing and apparatus, such as goggles and disposable gloves, must be worn if there is any risk of contamination or of objects jumping, falling, slipping or spitting. If such equipment is not available then the activity should not be attempted.
- Never use the mains electricity for investigations – dry batteries and rechargeable batteries are suitable sources of power. Make sure electrical goods are in good working order.
- Give clear guidance and training on the correct and safe use of any equipment including tools and glues. 'Super glues' should not be used at all and be aware of solvent misuse. Always supervise the use of glue guns, if your LEA allows their use in school.
- Make sure people are aware of the safety issues.

The following short sections highlight some more specific areas of risk and suggest ways of working. These are not exhaustive and it is important to consult other resources such as *Be Safe* and LEA guidelines.

Ourselves

It is important, when working within this topic, to be sensitive to the differences between children. Situations that put individuals under physical, emotional or mental stress must be avoided. Be aware of any allergies or other medical conditions that could place pupils under stress.

The strictest hygiene practices should be followed when using food for investigations and experiments. Ensure that all equipment and surfaces are clean. Disinfect all equipment that is to be used by others.

Food and hygiene

Any food activities must be done with great care and attention to health and hygiene. Store any food correctly and be aware of those individuals with specific allergies to food and food additives. Be aware of cultural and religious requirements about food.

Do not let people taste food or other substances unless you are sure it is safe and have given permission.

Animals

There are various regulations about keeping animals in school that must be followed. Wild birds and mammals, venomous animals or plants should not be brought into school. Rare plants and animals are often protected by law; flowers such as wild orchids and cowslips should not be collected at all.

Some people may have allergic reactions to particular animals and plants. This must be taken into account when keeping animals such as mice or hamsters in school.

The RSPCA (Royal Society for the Prevention of Cruelty to Animals) provides excellent information and guidance on all matters concerning having live animals in schools.

Heating

If heating or cooking substances make sure the cooker or heat source is safely sited, with good access and ease of use. Do not use spirit burners, picnic stoves, portable bottle gas burners or hot paint strippers as a heat source. Suitable sources of heat include warm water, candles, night lights, hair dryers and kilns.

Wear goggles if there is danger of spitting when heating.

Heat substances in containers that are safe and appropriate for the task. Any glass containers, such as test tubes, should be heat resistant. Stand candles/night lights in a sand tray.

Any burns should be flooded with cold water for at least ten minutes to cool the skin and medical help sought if necessary.

Chemicals

Do not use any corrosive or flammable materials. Many household chemicals should not be used at all. The list below, taken from ASE *Be Safe* (1994), identifies the main ones:

bleach	firework, sparklers and party poppers
caustic soda	some plant growth substances, e.g. rooting powder
de-rusting solutions	hydrogen peroxide
dishwasher detergent	lavatory cleaners
disinfectants	Milton
dry-cleaning fluids	pesticides, scale removers, weedkillers
some fertilisers	oven cleaners, paint strippers.

Make sure that clear procedures are given for handling chemicals so that they are not contaminated or spilt.

Outside activities

When working outside it is important that:

- clear expectations of behaviour are given
- children are supervised effectively
- local regulations of staff/pupil ratios are met

- protective clothing is worn, e.g. gloves when litter or collecting pond animals
- correct apparatus and methods are used to collect small animals, e.g. pooters and paintbrushes
- all hazards have been assessed.

This list applies to all science activities, inside and outside the classroom, but it is very important when working outside that they are considered early in the planning process.

The CLEAPSS School Science Service provides an excellent service to schools and local education authorities. This includes a help line if you are not sure about an activity or need advice. There is a list of publications that advise on good practice and offer evaluations of resources. A regular newsletter gives up to the minute advice and guidance on ways of working. Contact details are given at the end of the book.

Many other agencies also provide guidance and support that will advise you about such things as keeping animals in school, e.g. the RSPCA.

Science is an exciting and challenging subject. Careful preparation and assessment of the risks will help science to remain a stimulating experience for all.

In this section we have seen that:

- It is necessary to carry out a risk assessment for all investigations.
- There are legal requirements regarding health and safety.
- There is a need for a clear set of procedures to be followed if an accident happens.