The nature of science

Understanding what science is all about

Written by Dorothy Warren
RSC School Teacher Fellow 1999–2000

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How to use this resource

At the start of the 21st century secondary education yet again underwent changes. These included the introduction of new curricula at all levels in England, Wales and Scotland and the Northern Ireland National Curriculum undergoing review. With more emphasis on cross curricula topics such as health, safety and risk, citizenship, education for sustainable development, key skills, literacy, numeracy and ICT, chemistry teachers must not only become more flexible and adaptable in their teaching approaches, but keep up to date with current scientific thinking. The major change to the science 11–16 curricula of England and Wales was the introduction of 'ideas and evidence in science', as part of Scientific Enquiry. This is similar to the 'developing informed attitudes' in the Scottish 5–14 Environmental studies, and is summarised in Figure 1.

In this series of resources, I have attempted to address the above challenges facing teachers, by providing:

- A wide range of teaching and learning activities, linking many of the cross-curricular themes to chemistry. Using a range of learning styles is an important teaching strategy because it ensures that no students are disadvantaged by always using approaches that do not suit them.
- Up-to-date background information for teachers on subjects such as global warming and Green Chemistry. In the world of climate change, air pollution and sustainable development resource material soon becomes dated as new data and scientific ideas emerge. To overcome this problem, the resources have been linked to relevant websites, making them only a click away from obtaining, for example, the latest UK ozone data or design of fuel cell.
- Resources to enable ideas and evidence in science to be taught within normal chemistry or science lessons. There is a need to combine experimental work with alternative strategies, if some of the concerns shown in Figure 1, such as social or political factors, are to be taught. This can be done for example, by looking at the way in which scientists past and present have carried out their work and how external factors such a political climate, war and public opinion, have impinged on it.
- Activities that will enhance student's investigative skills.

These activities are intended to make students think about how they carry out investigations and to encourage them to realise that science is not a black and white subject. The true nature of science is very creative, full of uncertainties and data interpretation can and does lead to controversy and sometimes public outcry. Some of the experiments and activities will be very familiar, but the context in which they are embedded provide opportunities for meeting other requirements of the curriculum. Other activities are original and will have to be tried out and carefully thought through before being used in the classroom. Student activities have been trialled in a wide range of schools and where appropriate, subsequently modified in response to the feedback received.

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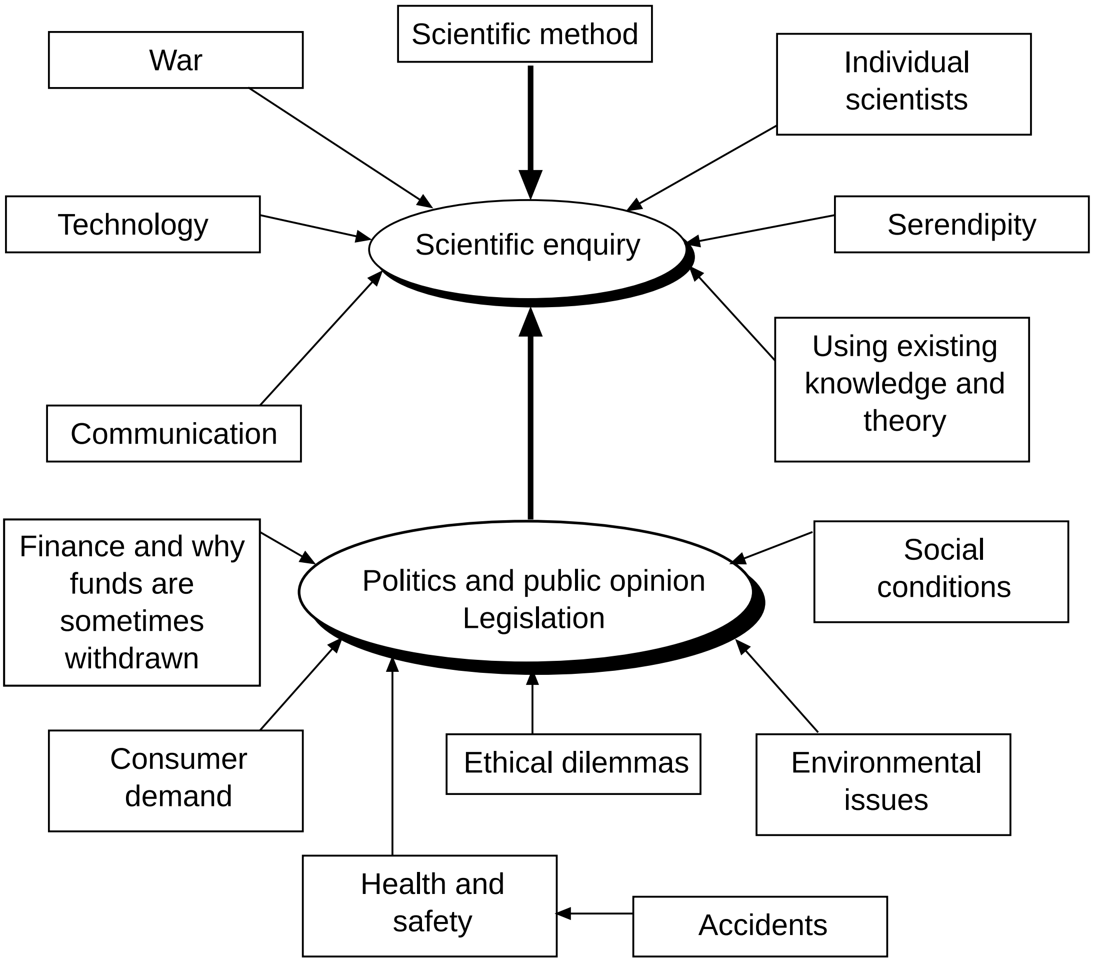

Figure 1 The factors influencing the nature of scientific ideas– scientific enquiry and the advancement of science

Maximising the potential use of this resource

It is hoped that this resource will be widely used in schools throughout the United Kingdom. However, as every teacher knows, difficulties can be experienced when using published material. No single worksheet can cater for the needs of every student in every class, let alone every student in every school. Therefore many teachers like to produce their own worksheets, tailored to meet the needs of their own students. It was not very surprising when feedback from trial schools requested differentiated worksheets to allow access to students of different abilities. In an attempt to address these issues and concerns, this publication allows the worksheet text and some diagrams to be modified. All the student worksheets can be downloaded in Word format, from the Internet via the LearnNet website, **http://www.chemsoc.org/networks/learnnet/ideas-evidence.htm** .This means that the teacher can take the basic concepts of the activity, and then adapt the worksheet to meet the needs of their own students. Towards the end of the teachers' notes for most activities there are some suggestions as to how the resource can be adapted to meet the needs of students of different abilities. There are also some examples of differentiated worksheets included in the resource.

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It is not envisaged that teachers will use every activity from each piece of work with an individual class, but rather pick and choose what is appropriate. For example some activities use high level concepts and are designed to stretch the most able student and should not be used with less able students *eg* Interpreting the weighing experiment methods 1 and 2.

Activities that involve researching for secondary information on the Internet contain hyperlinks to appropriate websites. To minimise the mechanical typing of the URLs and possible subsequent errors, the students can be given the worksheet in electronic form and asked to type in their answers. The websites are then only a click away.

Appropriate secondary information has been included in the teachers' notes for use in class when the Internet or ICT room is unavailable.

Unfortunately, from time to time website addresses do change. At the time of publication all the addresses were correct and the date that the site was last accessed is given in brackets. To minimise the frustration experienced when this happens, it is advisable to check the links before the lesson. If you find that a site has moved, please email both **LearnNet@rsc.org** and **education@rsc.org** giving full details so that the link can be updated on the worksheets on the web in the future.

Strategies for differentiated teaching

All students require differentiated teaching and it is not just an issue for those students with special educational needs. The following definition by Lewis[1] has been found to be quite useful.

'Differentiation is the process of adjusting teaching to meet the needs of individual students.'

Differentiation is a complex issue and is very hard to get right. It can be involved in every stage of the lesson *ie* during planning (differentiation by task), at the end of the activity (differentiation by outcome) and ongoing during the activity. Often teachers modify the activity during the lesson in response to feedback from the class. Differentiation does not only rely on appropriate curriculum material but is also concerned with maximizing learning. Student involvement and motivation effect the learning experience and should be considered and taken into account. It is therefore not surprising that differentiation is one of the areas of classroom teaching where teachers often feel under-confident. Most strategies for differentiated lessons are just applying good teaching practice eg varying the pace of the lesson, providing suitable resources and varying the amount and nature of teacher intervention and time.[2] Rather than just providing several examples of differentiated activities from the same worksheet, a list of strategies for differentiated teaching is presented, with some examples of how they can be used in the classroom. The examples can be found at the appropriate places in the text.

1. Using a range of teaching styles

A class is made up of different personalities, who probably have preferred learning styles. Using a range of teaching approaches makes it more likely that all students will be able to respond to the science that is being taught. The following examples have been included and can be found at the appropriate place in the resource.

Example Scurvy – the mystery disease
Approach 1 – A paper exercise analysing the James Lind experiment
Approach 2 – James Lind role-play

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2. Varying the method of presentation or recording
Giving the students some choice about how they do their work. There are many opportunities given throughout the resource.

3. Taking the pupil's ideas into account
Provide opportunities for students to contribute their own ideas to the lesson. For example when setting up an investigation allow different students the freedom to chose which variables they are going to investigate. The use of concept cartoons provides an ideal opportunity for students to discuss different scientific concepts. **Flickering candles** and **Brewing up** both set the scene for going on to investigate combustion. Essentially the students will all require the same equipment, but they may choose to investigate slightly different questions.

4. Preparing suitable questions in advance
Class discussions are important in motivation, exploring ideas, assessment etc. Having a list of questions of different levels prepared in advance can help to push the class.

5. Adjusting the level of scientific skills required
Example – Using symbol equations or word equations

6. Adjusting the level of linguistic skills required
Teachers may like to check the readability of their materials and of the texts they use. Guidance on this and on the readability of a range of current texts may be found at **http://www.timetabler.com/contents.html** (accessed June 2001).

References

1. A. Lewis, *British Journal of Special Education*, 1992, **19**, 24–7.
2. S. Naylor, B. Keogh, *School Science Review*, 1995, **77(279)**, 106–110.

How scientists communicate their ideas

Effective communication is crucial to the advancement of science and technology. All around the globe there are groups of research scientists and engineers, in universities and in industry, working on similar scientific and technological projects. Communication between these groups not only gives the scientist new ideas for further investigations, but helps in the evaluation of data. Results from different groups will either help to confirm or reject a set of experimental data. Communication is vital when a company wants to sell a new product. Depending on the product the buyer will want to understand how it works and how to maintain it. Several of the employees will have to learn how to use the product, and respond quickly to changing technology and circumstances. Therefore the manufacturers must be able to communicate the science to prospective buyers.

Scientists communicate in a number of ways including:

- Publication in research journals
- Presenting papers at scientific conferences
- Poster presentations at conferences
- Book reviews by other scientists
- Publication on the Internet
- Sales brochures

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- Advertising flyers
- Television documentaries

Publication in research journals
The article is written. The article must have an abstract, which is a short summary.

It is submitted to a journal.

The article is refereed by other scientists, working in a similar area. This is to check that the work is correct and original.

The article may be returned to the author to make changes.

The article is accepted and published by the journal.

The article is published.

Presenting papers at scientific conferences
Conference organisers invite scientists to speak on specific topics and projects.

An abstract is submitted to and accepted by the conference organisers.

The conference programme is organised and the speakers notified.

The scientist gives their talks, usually aided by slides, which contain the main points.

There is usually time for questions after the talk.

The written paper is given to the conference organisers.

All the papers are published in the conference proceedings. This is usually a book.

Poster presentations at conferences
An abstract is submitted to and accepted by the conference organisers.

The conference programme is organised and the poster people notified.

During the poster session the authors stand by the posters, ready to answer any questions as the delegates read the posters.

Written papers may then be published in the conference proceedings.

Book reviews
Other scientists in the same field often review new books. The reviews are then published in scientific magazines and journals. The review offers a critical summary of the book. The idea of the review is to give possible readers an idea of the contents and whether it is suitable for the intended purpose.

Publishing on the Internet
This is the easiest way to publish. Anyone can create their own web page and publish their own work. In this case the work is not refereed or checked by other people.

However, a lot of the information published on the Internet is linked to reputable organisations. In this case the articles will have been checked before they are published. Much of the information published on the Internet is targeted at the general public, and therefore the scientific ideas are presented in a comprehensible way. There are often chat pages so people can communicate their views and ask questions or request further information. The power of the Internet is that there is the opportunity to get immediate feedback to a comment or question.

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Sales brochures
The information must be presented in an attractive and concise manner. After all you are trying to sell something. There should be a balance between technical information and operating instructions!

Advertising flyers
This must be written with the target audience in mind.

The information must be concise as there is limited space. The format must be attractive and should include pictures as well as writing. The flyer should also be quite cheap to produce.

Teaching students to communicate ideas in science

Students can be taught effective communication skills:

- By encouraging communication between students and a range of audiences in classrooms
- By encouraging them to investigate like 'real scientists' by reporting their findings for checking and testing by others, and participating in two-way communication. (Communicating between groups, classes, partner schools, schools abroad perhaps via the Internet.)
- By setting investigations in a social context which offers the opportunity to communicate the project outside of the classroom. These work best when there is local interest.

When presenting investigative work to an audience, the student should consider the following:

- Who will be in the audience?
- What information does the audience need to know *eg* method, results and recommendations?
- How to present the information in an interesting and professional way *eg* should graphs be hand drawn or done on the computer?
- That the information offered convinces the audience that their investigation was valid and reliable.
- Poster presentations or display boards should be concise, since the space is limited.
- When speaking to audiences remain calm, speak clearly and slowly and try to be enthusiastic. Make sure that information on slides and OHTs can be read from the back of the room.

When writing a report of the findings of a scientific investigation for others to check and test, the emphasis should be on clarity. Another person is going to carry out the same investigation. The only information available is what is written in the report.

The report could be written under the following headings:

- Introduction
- Scientific knowledge
- Planning
- Table of results
- Graphs

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- Conclusions
- Evaluation
- Recommendations.

Further background information

R. Feasy, J. Siraj-Blatchford, *Key Skills: Communication in Science*, Durham: The University of Durham / Tyneside TEC Limited, 1998.

Curriculum coverage

Curriculum links to activities in this resource are detailed at **http://www.chemsoc.org/networks/learnnet/nature.htm**

Curriculum links to activities in other resources in this series are detailed at

http://www.chemsoc.org/networks/learnnet/ideas-evidence.htm

Health and safety

All the activities in this book can be carried out safely in schools. The hazards have been identified and any risks from them reduced to insignificant levels by the adoption of suitable control measures. However, we also think it is worth explaining the strategies we have adopted to reduce the risks in this way.

Regulations made under the Health and Safety at Work etc Act 1974 require a risk assessment to be carried out before hazardous chemicals are used or made, or a hazardous procedure is carried out. Risk assessment is your employers responsibility. The task of assessing risk in particular situations may well be delegated by the employer to the head of science/chemistry, who will be expected to operate within the employer's guidelines. Following guidance from the Health and Safety Executive most education employers have adopted various nationally available texts as the basis for their model risk assessments. These commonly include the following:

Safeguards in the School Laboratory, 11th edition, ASE, 2001

Topics in Safety, 3rd Edition, ASE, 2001

Hazcards, CLEAPSS, 1998 (or 1995)

Laboratory Handbook, CLEAPSS, 1997

Safety in Science Education, DfEE, HMSO, 1996

Hazardous Chemicals – a manual for science education, SSERC, 1997 (paper)

Hazardous Chemicals – an interactive manual for science education, SSERC, 1998 (CD-ROM)

If your employer has adopted more than one of these publications, you should follow the guidance given there, subject only to a need to check and consider whether minor modification is needed to deal with the special situation in your class/school. We believe that all the activities in this book are compatible with the model risk assessments listed above. However, teacher must still verify that what is proposed does conform with any code of practice produced by their employer. You also need to consider your local circumstances. Is your fume cupboard reliable? Are your students reliable?

Risk assessment involves answering two questions:

- How likely is it that something will go wrong?
- How serious would it be if it did go wrong?

How likely it is that something will go wrong depends on who is doing it and what sort of training and experience they have had. In most of the publications listed above there are suggestions as to whether an activity should be a teacher demonstration only, or could be done by students of various ages. Your employer will probably expect you to follow this guidance.

Teachers tend to think of eye protection as the main control measure to prevent injury. In fact, personal protective equipment, such as goggles or safety spectacles, is meant to protect from the unexpected. If you expect a problem, more stringent controls are needed. A range of control measures may be adopted, the following being the most common. Use:

- a less hazardous (substitute) chemical;
- as small a quantity as possible;
- as low a concentration as possible;
- a fume cupboard; and
- safety screens (more than one is usually needed, to protect both teacher and students).

The importance of lower concentrations is not always appreciated, but the following table, showing the hazard classification of a range of common solutions, should make the point.

Ammonia (aqueous)	irritant if ≥ 3 M	corrosive if ≥ 6 M
Sodium hydroxide	irritant if ≥ 0.05 M	corrosive if ≥ 0.5 M
Ethanoic (acetic) acid	irritant if ≥ 1.5 M	corrosive if ≥ 4 M

Throughout this resource, we make frequent reference to the need to wear eye protection. Undoubtedly, chemical splash goggles, to the European Standard EN 166 3 give the best protection but students are often reluctant to wear goggles. Safety spectacles give less protection, but may be adequate if nothing which is classed as corrosive or toxic is in use. Reference to the above table will show, therefore, that if sodium hydroxide is in use, it should be more dilute than 0.5M (M=mol dm^{-3}).

CLEAPSS Student Safety Sheets

In several of the student activities CLEAPSS student safety sheets are referred to and recommended for use in the activities. In other activities extracts from the CLEAPSS sheets have been reproduced with kind permission of Dr Peter Borrows, Director of the CLEAPSS School Science Service at Brunel University.

- Teachers should note the following points about the CLEAPSS student safety sheets:
- Extracts from more detailed student safety sheets have been reproduced.
- Only a few examples from a much longer series of sheets have been reproduced.
- The full series is only available to member or associate members of the CLEAPSS School Science Service.

- At the time of writing, every LEA in England, Wales and Northern Ireland (except Middlesbrough) is a member, hence all their schools are members, as are the vast majority of independent schools, incorporated colleges and teacher training establishments and overseas establishments.
- Members should already have copies of the sheets in their schools.
- Members who cannot find their sheets and non-members interested in joining should contact the CLEAPSS School Science Service at Brunel University, Uxbridge, UB8 3PH; tel. 01895 251496; fax. 01895 814372; email science@cleapss.org.uk or visit the website **http://www.cleapss.org.uk** (accessed June 2001).
- In Scotland all education authorities, many independent schools, colleges and universities are members of the Scottish Schools Equipment Resource Centre (SSERC). Contact SSERC at St Mary's Building, 23 Holyrood Road, Edinburgh, EH8 8AE; tel. 0131 558 8180, fax 0131 558 8191, email sts@sserc.org.uk or visit the website **http://www.sserc.org.uk** (accessed June 2001).

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Introduction

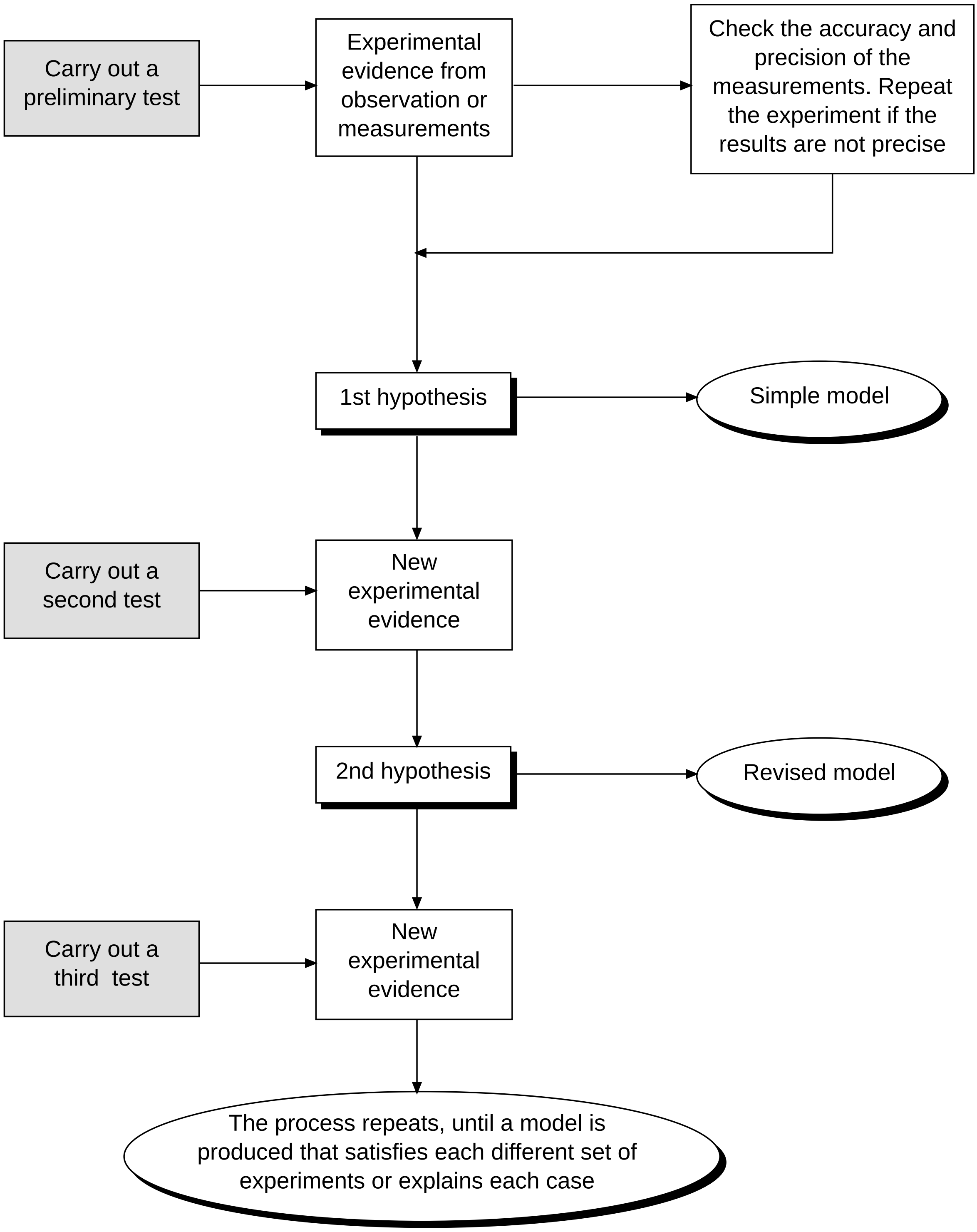
There are many different approaches to science. Included in this book are a range of activities designed to look at different aspects of the nature of science and to teach investigative skills. The scientific method has considerably developed over the last 500 years and **Scurvy – the mystery disease** looks at how the scientific method changed and developed during the 400 year quest to find a cure for the disease. The worksheet overleaf is just one approach that some scientists may use today when carrying out an investigation. It is important for students to understand that a theory or model often changes over time as new evidence is collected and that it is extremely important to check the accuracy and precision of the measurements.

A scientific theory or model is a simple or complex explanation put forward by scientists to explain various phenomena. A model is used to help scientists visualise things that they cannot actually see. The theory or model is usually based on previous scientific knowledge and experiences, as well as careful observation and measurements. The theory can then be used to explain further phenomena and to make predictions of future behaviour. Therefore scientific theories and models are powerful tools. However, they are only valid as long as they can be used to explain all the available data, *ie* from both observations and measurements. Scientists will often test out theories by carefully designing and carrying out experiments. If new data appears that does not fit the theory, then the theory may have to be modified and updated. It will then have to be tested out again. We could say that scientific theories and models are ‘living’ because they change and evolve. (Of course in practice, life is not usually that simple and other factors interfere.)

Students often find it difficult to distinguish between observation and inference, *ie* putting your own interpretation on an observation. Students often believe that scientific knowledge is provable in an absolute sense, and do not consider science as a creative subject relying to a certain extent on human imagination. It is also common for students to believe that laws are theories that have been proven, and once they are proved they will not change. It is also common for people to believe that there is only one route to the solving the answer. The **Black box activities** should help to dispel some of these myths. They are called Black box activities because the students are ‘working in the dark’ and have to base their inferences on observation.

Accuracy and precision plays an important role in scientific investigations from choosing the correct piece of measuring equipment, to knowing when to discard a data point as anomalous and how many significant figures or decimal places to quote in the final answer. Three student activities have been included to address some of the issues of accuracy and precision.

Experience shows that it is often difficult to get students to put forward their own scientific ideas when introducing an investigation. Concept cartoons are designed to overcome this problem by presenting the students with a range of possible answers to a scientific question. The concept cartoons can be used to promote discussion. Good discussions have many uses, for example they can help students to form their own scientific ideas, which they can use to plan their own investigations. **Brewing up** and **Flickering candles** are two examples of concept cartoons on the theme of combustion.



Making a model or theory

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Black box activity 1: Tricky tracks

Teachers' notes

Objectives

- To help the students distinguish between observation and inference.
- To introduce the concept that all ideas are valid unless there is further evidence to suggest otherwise.

Teaching topics

This activity is appropriate for 11–13 years olds and fits into a scheme of work anywhere where observations are made. It can also be successfully used with lower ability 14–15 year olds. A possible follow up activity would be to carry out a series of class 'test tube' experiments, which required careful observation, followed by interpretation.

Background information

This activity assumes the following definitions:

- An observation is what is actually seen.
- An inference is interpreting what you see.

Teaching tips

This activity could be carried out as a whole class exercise, with individual students recording their own answers or in groups of 3–4 students.

The lesson could be introduced as follows:

Scientists are always putting forward ideas or theories to try and explain the things they see happening in the world.

Scientists often test their ideas and theories by carrying out some experiments. Sometimes new ideas come along which do not fit the old ideas. So more experiments have to be carried out to see if the new idea is correct.

Resources

- OHP – if the activity is carried out as a whole class exercise. Photocopiable worksheets **Tricky tracks 1–3** will need to be transferred onto OHT slides.
- Class sets of student worksheets if the activity is to be carried out in groups
  – Tricky tracks 1
  – Tricky tracks 2
  – Tricky tracks 3
  – Questions

Timing

60–70 minutes. Approximately half the time should be used to carry out the worksheet tasks and the rest of the time discussing the answers.

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Measurement, accuracy and precision

Teachers' notes

Objectives

- Understand that data obtained during experiments are subject to uncertainty.
- Understand that the level of accuracy is linked to the context.
- Planning experiments and investigations.
- Making accurate observations.
- Evaluating data, considering anomalous results.

Outline

The teaching material is divided into three sections, all of which focus on an aspect of accuracy and precision. Each activity stands alone and is independent of the other two.

- Measuring uncertainties and reporting reliable results
- Choosing and using equipment
- Does being accurate really matter?

Teaching topics

The activities can be used at any point in a course to teach investigative skills and are suited to students in the 11–16 age range. The activities can be adapted easily to allow access to students of different ages and of different abilities. In the Measuring uncertainties and reporting reliable results section **The weighing experiment (method 2)** could be modified and used as a post-16 key skills exercise. Although the activities are quite general in nature, they can be used to teach specific skills. Alternatively, they could be used prior to carrying out investigations that require weighing out of materials, or the measurement of volume and temperature.

For example **Choosing and using equipment** and **Does being accurate really matter?** could be taught prior to or after carrying out experiments or investigations into:

- The neutralisation reaction between acid and alkali
- Rates of reaction
- Electrolysis
- Methods of separation.

Experimental details can be found in *Classic Chemistry Experiments*[1] Numbers 48; 29, 64, 65; 81, 82; 1, 4, 71 and 100 respectively.

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Section 1: Measuring uncertainties and reporting reliable results

Background information
Students (including post-16 students) are often confused about the meanings and difference between some of the vocabulary in regular use *eg*

- Accuracy and precision
- Repeatability and reproducibility
- Systematic error and true value
- Error and mistake
- Best fit line and anomalous points.

Definitions
Accurate – the result is close to a reference value or the average of the data is close to a reference value.

Precise – the data points are close together (but there can be a random error).

Repeatability – when the experiment is repeated by the same person, using the same equipment and the results are close together.

Reproducibility – when the experiment is carried out by different persons, using different equipment and the results are close together.

True value – a perfect value of the quantity, *eg* mass, volume, temperature. This is an ideal and can never be known exactly.

Reference value – A value taken to be very close to the true value and usually accepted as a point of reference, *eg* a 'standard weight' has been measured on a balance that has little or no error and so the 'measured weight' is very close to the true value and accepted.

Errors are not the same as mistakes *eg* not reading a scale correctly.

Systematic error – there is some problem with the apparatus, because the results are precise (close together), but not accurate.

Instrumental errors – *ie* quantifying the precision of measurements. For example a 2 decimal place balance is precise to ±0.005 g.

Percentage errors – using a 2 decimal place balance, the errors when weighing 0.1 g and 0.01 g are identical yet the overall percentage errors are ±10% and 100% respectively (including the precision of the zero readings).

Overall percentage error – this arises when several measurements are used to achieve an overall result. It is approximately equal to the sum of the percentage errors in the individual readings although there are more complex treatments.
– In a simple weighing the overall percentage error is based on two readings, a zero or tare and the mass of the sample.
– In a titration the overall percentage instrumental error might be the sum of the percentage errors from the weighing, the volumetric flask, the pipette, the burette and the standard solution.

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Reliability – this is assessed through comparison of an individual result with a reference or class mean.

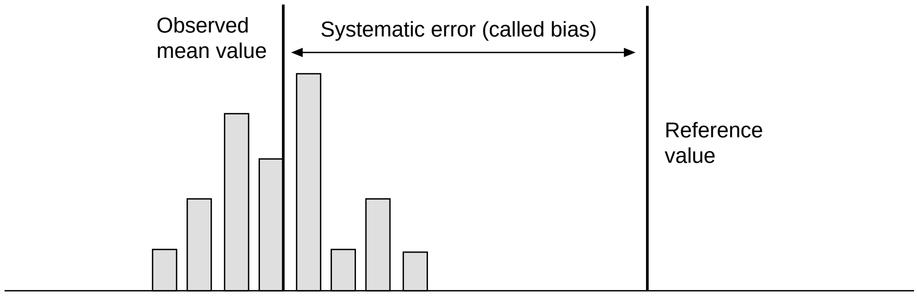
Assessing the reliability of an individual result allows a judgement to be made regarding the level of mistakes. The overall percentage error based on instrumental readings is unavoidable whereas mistakes (human errors) are avoidable through repeating and reproducing the results.

Anomalous point – a data point that does not fit the pattern of the graph.

Trueness

Trueness is defined as: The difference between the observed mean value and the reference value.

A true value is never achievable because there is always some random variation and it is recommended that the indefinite article is always used *ie* 'a' and not 'the'.



Bias is a measure of trueness.
Accuracy comprises bias and precision.

Figure 3 Accuracy, precision and trueness

Teaching tips

Introducing the vocabulary to the class
Professional judgement should be used here to decide how many terms it is appropriate to introduce to each class. The list of definitions given above is meant to be a comprehensive list to aid teaching at all levels.

There are several ways of introducing the terms to the class:

- List some of the words on the board and ask the students to write down the meanings. Discuss their answers.
- Use everyday ideas to introduce the terms and promote discussion *eg*
  – Accuracy and precision are required to succeed at darts and archery.
  – A cookery book must contain recipes that are repeatable and reproducible, otherwise no one would want to buy it.
- Using the student worksheet **Bulls eye to win**. This could also be used as a homework exercise.
- Analysis and interpretation of experimental data. The class could be presented with a set of results if there is not enough time to carry out the weighing experiment first.

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The weighing experiment (method 1)

- Set up the balances at different places in the room.
- Divide the class into groups.
- Present the class with some common identical objects – *eg* Mars® Bars.
- Each group weighs several Mars® Bars, using one weighing device.
- They then record the results and the weighing device used.
- They work out the average mass of a Mars® Bar.
- Add the result to the class table or graph (on the board or OHP).
- Plot the class results (from the table) individually.

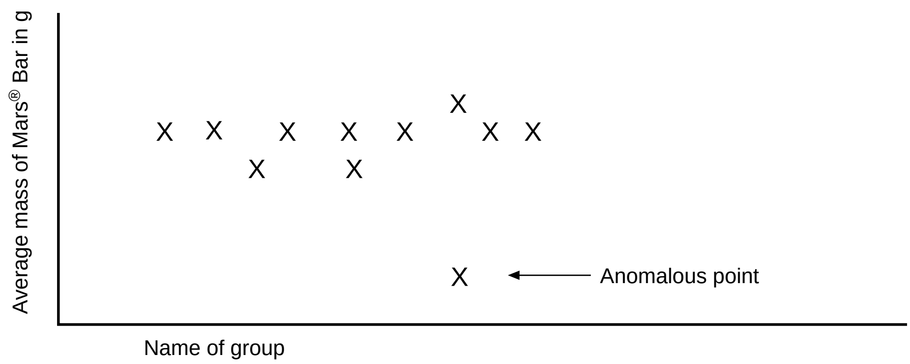

Figure 4 Sketch graph showing simple results

Interpreting the results
The results show a scatter close to a true value of the object (see Figure 4). You need to draw in the line of best fit and highlight any anomalous results. This approach is built on the assumption that all the Mars® Bars are the same mass, and that balances are the only variable. Any difference in the mass of the actual Mars® Bars will be minimised, because each group has used the average mass of several Mars® Bars in their result.

The weighing experiment (method 2)

As homework, ask the class to weigh the same object, such as a Mars® Bar, three times on their kitchen scales.

- Record the mass of the object each time they weigh it.
- Work out the average mass.
- Bring the object into school.
- Reweigh the object using a balance at school.
- Add the result to the class table or graph (on the board or OHP).
- Plot the class results (from the table) individually.

Interpreting the results
The results should show a scatter close to the declared value of the mass of the object. Manufacturers are given a tolerance on their products and therefore there is no true value or reference value. (Refer to notes in background information.) There will be a scatter of results, because in practice not all Mars® Bars will weigh exactly the same. You need to draw in the declared value (on the packet), allowed variability and highlight any anomalous results as shown in Figure 5.

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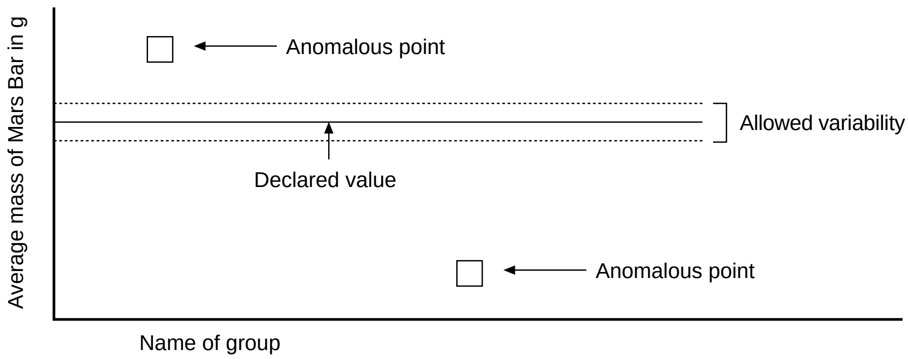

Figure 5 Sketch graph showing results, allowing for the variability in the mass of the Mars® Bar

The graph should be discussed either in groups or as a whole class. This could then be followed up by giving the students the worksheet **Interpreting the weighing experiment** either as a class exercise or a homework exercise.

Calibrating equipment

This should take the form of a teacher demonstration and discussion, and could be used in the final stage of the lesson. Some teachers may want their students to carry this out for themselves because it really depends on the quantity and quality of your balances. If available you could use a range of balances that read to a different number of decimal places. You may wish to demonstrate this to small groups at a time.

The class weighing exercise above should have already highlighted the fact that not all balances give an accurate reading, even if the readings are precise. It should be pointed out that from time to time, all balances need calibrating or resetting to make sure that they do give an accurate answer. An analytical chemist, carrying out measurements on a microscale (*eg* weighing to 0.001 mg) may have to calibrate the balance each time they use it. Even airflow can upset very sensitive balances as can the temperature of the object being weighed. The level of accuracy required is usually dictated by the application.

Resources

Classwork

- Mars® Bars or another product to weigh
- Kitchen scales (different types if available)
- Top pan balances of differing sensitivities
- Graph paper or graph plotting software or OHP.
- Student worksheets
  – Bulls eye to win
  – Interpreting the weighing experiment (method 1)
  – Interpreting the weighing experiment (method 2)

Demonstration

- Object of known mass such as a 10 g or 100 g weight
- 3 balances (if possible of different sensitivities). The least sensitive balance should not be calibrated correctly, as this will be done during the lesson.

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Practical tips

Class experiment
You may wish to add in an anomalous result, which could be used to discuss systematic errors later in the lesson. This could also save students from embarrassment, if there was only one other anomalous result. But in practice kitchen scales often provide the anomalous results. This could be checked before the lesson.

Demonstration

1. Using an object of known mass such as a 10 g or 100 g weight, place it in different positions on the most sensitive balance you have and record the results on the board. Dependent on the balance the reading will vary. How close is the reading to a 'true' value?

   Potential problem – make sure that you know a true value of your object at the start of the demonstration. Do not assume a 10 g weight has a mass of 10 g without checking it. It could be 10.1 g or 9.9 g.
2. Place the weight on a second balance (of different sensitivity). Do you get the same result?
3. Place the weight on a third balance and reweigh it. This time make sure that the balance is not zeroed correctly. If the balance has a setting-up levelling bubble, it should be off centre. The reading should be quite a bit out.
4. Show the group how to centre the bubble and carefully adjust the balance.
5. Re-weigh the object. It should now indicate the correct mass.
6. Stress the importance of correct setting up of equipment and of calibrating equipment, especially if accurate readings are required.
7. This leads naturally into a discussion about situations when accuracy is important and when it is not important.
8. The student worksheet **Does being accurate really matter?** could provide extension work or a follow up piece of homework.

Timing

2 hours (divided between classwork and homework)

Adapting resources

The student sheet **Bulls eye to win** could be adapted to meet the needs of the less able by turning question 3 into a cut and stick exercise and omitting questions 4 and 5.

Opportunities for other key skills

- Application of number

Background information

Industrial trading standards
Industry must comply to the Weights and Measures Act of 1985 and the Weights and Measures (Packaged Goods) Regulations 1986.

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In general terms the Act states: Goods which are sold in packages by weight or measure can be packed either to minimum quantity or to average quantity.[2]

For the minimum quantity each pack must contain at least the quantity marked on the pack (the nominal quantity). If equipment is used to make up the packs then the equipment must be tested and approved for trade use. The equipment does not have to be used, but if the quantity is estimated incorrectly, then the industry will have no defence.

For average quantity there are certain rules which must be followed called the Packers' Rules which are regularly monitored.

Packers' Rules

- The average content of the group must on average be at least the nominal quantity.
- No more than 2.5% (1 in 40) of the group may be non-standard *ie* (the nominal quantity) – (tolerable negative error).
- No package in the group may be inadequate *ie* (the nominal quantity) – 2 (tolerable negative error).

The tolerable negative error (TNE) is dependent on the nominal quantity.

Nominal quantity g or cm^3	Tolerable negative error
5–50	9% of nominal quantity
50–100	4.5 g or cm^3
100–200	4.5% of nominal quantity
200–300	9 g or cm^3
300–500	3.5% of nominal quantity
500–1000	15 g or cm^3
1000–10000	1.5% of nominal quantity
10000–150000	150 g or cm^3
Above 15000	1% of nominal quantity

Table 1 Legal industrial tolerance levels

The mass of the Mars® Bar

Teachers need to be aware of the common use of the word 'weigh' to determine mass. The average mass of a batch of products should be no less than the declared mass of 65 g.

The mass stated on the pack does not include the mass of the packaging.

Millions of Mars® Bars are produced daily. The few Mars® Bars weighed in class may not be representative of the batch.

Confectionery items weighing less than 50 g are not legally required to show a mass on the wrapper and this exemption applies to both standard and promotion packs.

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Smarties and Milky Bar Buttons
These are packed by mass rather than by the number of sweets. The manufacturing process is a fast and highly automated one and it is impossible to pack exactly the same quantity into each pack. As with any average there will be some packs with above average mass and some below. All packs will, however, be above an agreed minimum level.

Sources of information

http://www.tradingstandards.gov.uk/ (accessed June 2001)

Answers

Bulls eye to win
1. Jamal
2. The bulls eye
3. a) David, b) Helen, c) Jamal, d) Marie
4. David
5. Try an aim a bit lower and further over towards the right.

The weighing experiment (method 1)
1. Read off the value of the best fit line.
2. Use the value on the packet.

3 & 4 Accept sensible answers.

5. Mass of object (from graph) +/– difference (calculated in 4).
6. Accuracy of scales, precision of experiment, age of the product. Remember the manufacturer is allowed some variability.
7. See graph.
8. Dependent on results.
9. The balance has an error or the average was worked out incorrectly, or the individual results were not precise.
10. Accuracy is important; the customer should be getting the amount of product they are paying for.

The weighing experiment (method 2)
Questions 1–7 as method 1 above

8. To obtain the raw data of the anomalous result, go to the graph and find out whose measurement is incorrect. Go back to their exercise book and check the original readings. Write these readings up on the board. This should show if:
   (a) the average has been worked out incorrectly
   (b) if the results are not very precise
   (c) if there is a systematic error in the scales.
9. Dependent on results.

10&11 Refer to the raw data of the anomalous result.

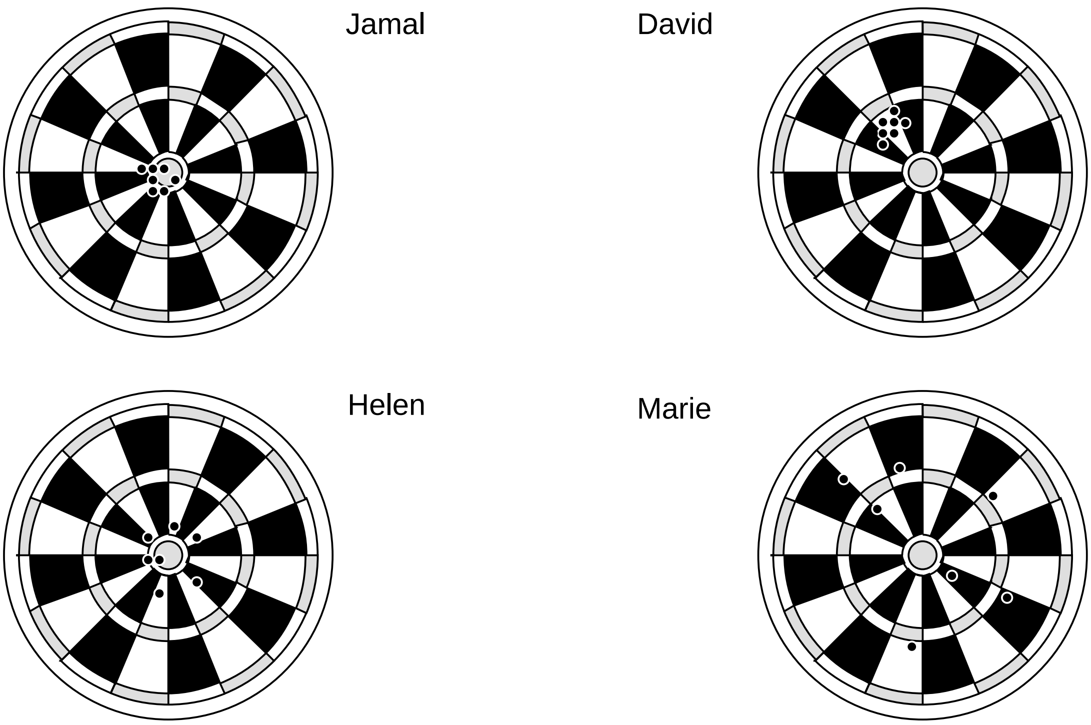
12. Dependent on results.

13. See reasons given under 8.

14. Make sure that you know how to work out averages, each time the object is weighed make sure that the balance reads zero and that nothing has been spilt on it *etc.*

Bulls eye to win

Jamal, David, Marie and Helen spent the afternoon playing darts. In the last round they set the target as the bulls eye. Each person was allowed seven throws. The results of their game are shown below.



Questions

1. Who won the game of darts?
2. What did the players choose to have as their reference value?
3. Whose game would you describe as:
   (a) Precise but inaccurate
   (b) Imprecise but accurate
   (c) Precise and accurate
   (d) Imprecise and inaccurate?
4. Who do you think needs to improve their game to avoid experiencing the same systematic error next time they play?
5. What advice would you give that person?

Interpreting the weighing experiment (method 1)

1. From the graph produced what is the mass of the Mars® Bar?

2. What is the expected value of the mass of the Mars® Bar? (Look at the wrapper.)

3. Is there a difference between the measured value and the expected value?

4. What is the size of the difference?

5. How would you write down the mass to include this error?

6. How can you explain the difference in results?

7. Are there any anomalous results?

8. Are the anomalous results showing a systematic or random error?

9. Suggest a reason to explain the anomalous result.

10. Discuss the importance of accuracy in the manufacture of Mars® Bars.