



Investigative Project 6



Getting to know your unit

Assessment

You will be assessed by a series of assignments set by your tutor.

Science helps us to make sense of our world. The fundamental laws and understanding used in our everyday lives have been developed through centuries of questioning and subsequent investigation by those who have an inherent need, both to gain an understanding of the world around them, and also to push the boundaries in scientific discovery and advancement. This unit will enable you to establish your understanding and skills in scientific investigation by carrying out an investigative project. You will learn how to choose a project based on your interests and literature search. You will be able to apply knowledge gained in other units to manage your project, outline the plan to be followed and produce an evaluation supported by your new scientific skills.

How you will be assessed

This unit will be assessed using a series of internally assessed tasks within assignments set by your tutor. Throughout this unit you will find activities that will help you work towards your assessment. Simply completing these activities will not mean that you have achieved a particular grade, but you will have carried out useful research or preparation that will be relevant when it comes to completing your assignments.

In all the tasks in your assignments, it is important to check that you have met all of the Pass grading criteria. You can do this as you work your way through the assignments.

If you are hoping to gain a Merit or Distinction, you should also make sure that you present the information in your assignments in the manner required by the relevant assessment criterion. For example, Merit criteria require you to analyse and demonstrate skilful application of procedures whilst Distinction criteria require you to evaluate your practice.

The assignments set by your tutor will consist of a number of tasks designed to meet the criteria in the table. This is likely to consist of a written report but may also include activities such as:

- ▶ demonstrating correct and appropriate practical techniques confirmed by observational record and/or witness statement
- ▶ presenting findings to your peers and reviewing the procedures and applications of your work during class discussion
- ▶ analysing and reviewing your own performance in a critique which highlights your strengths and weaknesses.

Assessment criteria

This table shows what you must do in order to achieve a **Pass**, **Merit** or **Distinction** grade, and where you can find activities to help you.

Pass	Merit	Distinction
Learning aim A Undertake a literature search and review to produce an investigative project proposal		
A.P1 Carry out a literature search and review into a chosen scientific area Assessment practice 6.1	A.M1 Analyse a literature search and discuss its relevance to inform the investigative project proposal Assessment practice 6.1	A.D1 Evaluate the different methods of investigation considered for the investigative project proposal, justifying the hypothesis chosen Assessment practice 6.1
A.P2 Produce an appropriate project proposal for an investigative project proposal, to include hypothesis Assessment practice 6.1	A.M2 Produce a project proposal for a scientific investigation, to include hypothesis and potential limitations Assessment practice 6.1	
Learning aim B Produce a plan for an investigative project based on the proposal		
B.P3 Produce a realistic working plan for the project, including health and safety and risk assessments Assessment practice 6.2	B.M3 Produce a realistic working plan for the project, including health and safety and risk assessments and contingency planning Assessment practice 6.2	B.D2 Analyse the effectiveness of the working plan, justifying changes made Assessment practice 6.2
Learning aim C Undertake the project, analysing and presenting the results		
C.P4 Demonstrate practical skills to assemble relevant apparatus/equipment and materials, and carry out the project using safe working practices Assessment practice 6.3	C.M4 Justify the choice of experimental and data analysis techniques used as a means of increasing accuracy, reliability and validity Assessment practice 6.3	CD.D3 Evaluate the conclusions of the investigative project and its practical aspects, discussing limitations, improvements and recommendations for further study Assessment practice 6.3, 6.4
C.P5 Accurately collect, analyse and present the results obtained Assessment practice 6.3		
Learning aim D Review the investigative project using correct scientific principles		
D.P6 Produce a report using findings, scientific terminology and protocol appropriately and drawing conclusions Assessment practice 6.4	D.M5 Produce a report using findings, correct scientific terminology, protocol and formatting and drawing valid conclusions Assessment practice 6.4	

Getting started

Undertaking a scientific investigative project is an important part of the duties of an industrial technician and many science-related workplace positions. Completion of a science project of your choice will develop your understanding of the processes involved and help to develop your skills in science for future education or employment. Research an investigation into a chemistry-, biology- or physics-related subject from an article in a scientific journal. Identify, if you can, the following aspects within the report: literature review, project proposal, outline plan, health and safety considerations, method used, data collection, data analysis and presentation, structure of the report, referencing and evaluation with further project proposals.



A

Undertake a literature search and review to produce an investigative project proposal

This section outlines the essential process of deciding on a scientific investigation proposal by carrying out a comprehensive **literature review** to help you make an informed decision. You will be guided through the various types of study and sources of information suitable for your proposal and how you should record your review. The reason for your investigative proposal is an important point which will be addressed since it helps to ensure that you are able to complete the investigation comprehensively, following useful and correct scientific processes and maintaining your full interest throughout.

Key term

Literature review – a search and evaluation of the available information in your given subject or chosen topic area.

Literature review

To determine on which aspect of science to focus your investigation, you need to research areas in which you may have a personal interest or areas which have been provided by your tutor. Science consists of three general sciences; biology, chemistry and physics, and the breadth of study can be quite daunting. Being able to narrow down the field of potential investigation is vital if the project proposal is to stand a chance of ‘getting off the ground’. If your tutor has given you a short and specific list to consider, your job will be much easier.

Identification of criteria

There are numerous areas worthy of investigation in all scientific disciplines. Your final decision will obviously be made by consideration of the equipment available, the degree of difficulty, the results which can be obtained and the time scale involved. Table 6.1 lists some examples which may help narrow the field.

► **Table 6.1** Examples of potential investigations

Physics	Chemistry	Biology
<ul style="list-style-type: none">Resistivity of various metal wiresFinding the factors which affect the length of a ski jumpDetermination of terminal velocity of a ball through fluid using light gates and viscosity tubeInvestigating stress and strain of different materialsResistance change with temperature for thermistorsImproving a pinhole camera with lensesDetermination of relationship between aileron angle and lifting force for aircraft wing models	<ul style="list-style-type: none">Electrical charge calculations from electrolysis of copper(II) sulfate, silver nitrate, lead (II) bromideFactors determining rates of reactionEnthalpy changes in combustion of alcohols or flammable liquidsDetermination of concentrations of unknown samplesVitamin C content in fruit juicesOxidation of ethanol to ethanoic acidElectrolysis of aqueous salt solutionsTesting water hardness	<ul style="list-style-type: none">The effect of penicillin on bacterial growthEffect of exercise on reaction timeTesting for reducing sugarsFactors affecting the rate of photosynthesisThe actions of enzymes in digestionPlant responses to stimuliFactors affecting plant growthEffect of polluted water on seed developmentEffects of caffeine on water fleas (daphnia)Factors affecting transpiration in plants

It is important to try to develop a critical review when researching literature. To review *critically* means that you should analyse both the merits and faults of the information that you are reviewing. You should not allow your review to become a general list of research titles with some additional facts and figures, although your knowledge in the topic chosen may not yet be sufficient to produce a substantial critical review. A literature review is much more than a general list and, if carried out effectively, will help to set the foundation of your project proposal and subsequent investigative project completion.

'Literature' in this context refers to anything which provides information related to your subject. It includes:

- ▶ journals
- ▶ science articles
- ▶ government reports
- ▶ Internet sites
- ▶ newspaper reports
- ▶ textbooks
- ▶ dissertations.

The whole point of a literature review is to give you an overview of your field of study, outlining the current knowledge and theories which may apply and the questions which may still need to be answered. This will also include studies and experiments which have already taken place in the same scientific area. Most laboratory investigative projects which you will carry out should have known outcomes, tested over many years and so your literature review will be useful as supportive information but may also provide an idea of what your **hypothesis** would be or help you to formulate an effective method.

Key term

Hypothesis – an explanation, with some evidence, to be further tested by investigation.

The number of sources of literature and therefore **references** used to help with your study will depend on the chosen topic and the level of the qualification. In this case, for example, a useful number at Level 3 study may be anywhere from 5 to 15 references, but your tutor may also provide you with a suitable number.

Key term

References – a list of sources at the end of a report used to help provide information for an activity.

'Out with the old – in with the new.'

In science, this statement is not always necessarily useful to follow, since much of what is known at present has not changed much in decades. The research in science builds on previous knowledge and there should be an element of caution in using both very new science literature as well as very old. Advancement in science appears to be developing exponentially and keeping up with current knowledge can be a challenge. It is wise to ensure that your literature review reflects the most current information available in your chosen topic but also refers to literature older than 10 years. This will help to reinforce your understanding and also indicate to your tutor that you have considered all relevant times of writing. It is important to note that the most up-to-date studies and information can be found in journals as they are published regularly. Text books may have older publishing dates. Websites may not include the date of publication so it can be difficult to judge how up to date the information is.

These aspects should always be considered when carrying out a literature review:

- ▶ Always use more than one source of information – there are many sources available on the same subject material including tutors, text books, internet, newspapers, magazines, journals and television.
- ▶ Carefully choose your research titles – when searching for information on acid/base titrations, for example, be specific. You may get a lot of information about titrations in general which will take a lot of time to read and may not all be relevant.
- ▶ Select material from an authoritative source – professional experience and qualifications of the authors(s) is important and when more than one source agrees in content, you can develop confidence in sources you are using.
- ▶ Avoid plagiarism of other people's work – sometimes you may need to include a direct quotation of a researched note to help with your report. Keep these to a minimum, do not change the quotation at all and include a suitable reference to indicate where the article came from.

Knowing what material is useful to your field of study and what material to discard is difficult if your knowledge of the topic is not detailed. However, a large proportion of your literature review will involve you reading the background of your topic and helping you to develop your knowledge.

It is helpful to draw up a list of inclusion and exclusion criteria before starting your literature review and to adjust the list as you progress through the investigative project.

The following provides some guidance as to what you could ask yourself before you decide on inclusion or exclusion of the information you have reviewed:

- ▶ Do the sources chosen agree on the science involved?
- ▶ Are you able to identify a common methodology for your investigation?
- ▶ Is the information sufficiently detailed?
- ▶ Does a source provide information not given by any other source?
- ▶ Is the source publication well known or recognisable?
- ▶ Does the source material make use of information provided by well qualified writers?

Research

Choose one topic from physics, chemistry and biology in Table 6.1 and carry out a brief research into the subject topics. Identify which source(s) of information:

- provide the clearest and easiest to understand information
- give an indication of alternative investigations which may be linked
- give reference to other sources
- is the oldest source of information.

Nature of study

Science is a theory-driven practical subject. If you have plans to follow a career in any of the scientific disciplines or advance your education, you will need to know how the knowledge you have acquired in the lecture room has been developed over time. You need to experience the science involved first

hand, by experimentation and investigation. Figure 6.1 shows potential physical areas of study.

Sources of information

Link

Unit 7 – Contemporary Issues in Science (sources of information, e.g. journals, articles, news reports).

The research information used for your planning stage in the investigation should be correctly referenced in your notes. If you used a number of sources, then your eventual working plan will contain information which will have been judged to be common to more than one source, a skill which takes time as your knowledge develops.

It is useful to identify sources of reliable information quickly and to tabulate or record them in an appropriate manner. You may also wish to include any sources which you have discarded, providing reasons why. The example in Table 6.2 may help.

▶ **Table 6.2** How to tabulate sources of reliable information in an appropriate manner

Information source	Brief details of information	Useful	Not useful
Data & data handling for AS level biology, Bill Indge	Suggested use of glass container of water placed between lamp and cambomba (aquatic plant: from internet search) to help eliminate the effects of increased temp. on rate of photosynthesis	✓	

Fieldwork

This involves any work carried out beyond the confines of your educational building. It includes organised or independent trips to gather evidence, physical or observed, which will form the basis of your project. Example – determination of water flow rates at various points in a river profile.

Laboratory-based

Most forms of science investigation performed in a school, further education college or university will make use of a laboratory. It provides a supervised, well-resourced, well-organised platform for meaningful and relatively safe investigative work. Example – investigating various conditions for optimum plant growth.

Workshop

Studies using science workshops can be used to explore how the population relate to science and how learning is achieved. Workshops are able to provide areas of study linked to practical activity and research. Example – identifying the positive aspect of group discussion prior to scientific problem solving.

Sports facility

The science of sport is a popular and increasingly important area of study. The availability of a sports complex and variety of equipment provides opportunities to investigate a range of aspects related to the sciences. Example – observing the effect of exercise on the body.

▶ **Figure 6.1** Physical areas of study

Extraction of information

When carrying out **extraction** of information, sources include:

- ▶ libraries and resource centres
- ▶ government organisations
- ▶ science organisations
- ▶ charities.

Key term

Extraction – a means to obtain information from different sources.

The method of taking information from each of these example sources will vary in accordance with their individual procedure which should be made available to the customer.

Resource centres and libraries will no doubt have a thorough system in place to log each available item in their collection. A visit to your school or college resource centre is a useful starting point if you haven't already done so.

Here you will notice that the resources are set out within subjects and further ordered into alphabetical sequence. This is essential to ensure that students are able to find relevant information quickly and to become independent in their research.

Items available to support your literature review will include:

- ▶ academic and leisure magazines
- ▶ network computers
- ▶ non-fiction resources such as journal papers or textbooks
- ▶ DVDs in science and general topics
- ▶ audio-visual sections for use when practising presentations.

Your research often depends on gaining access to either people or data from an organisation. As a result, you may need the cooperation of the organisation before you can extract the information needed. This may mean asking their permission or approval before you can continue with your research and use their information in the literature review. Such organisations can include: animal research, Universities, Animal and Plant Health Agency.

Most government and charity organisations allow access to their findings for research purposes, provided the information source is noted in the work and that any findings are not changed or misrepresented.

Source listing protocol

Your research sources must be listed at the back of your final report in a recognized manner. Most countries use the **Harvard referencing system**, or variations of it, which depend on the type of article, portion used and number of authors.

Key term

Harvard referencing system – a style of referencing system used to mention sources of information which have been looked at to inform your work.

- ▶ Suggested format for webpage referencing (journal article example): Author surname, forename or first initial (where applicable), year published, title, website URL *Example:* Smith, J, 2016, Journal of Everything, [online], P.140 Available at: <http://www.pearson.edu.au/guides-services/research.html> [accessed 10 Jan.2016]
- ▶ Suggested format for textbook referencing: Author surname, first initial, year published, title, edition (if not the first), city where published, publisher, page(s) *Example:* Smith, J, 2016, Textbook of Everything, 2nd Edition, London, Pearson Publ., pages 6–10.
- ▶ Suggested format for in-text referencing (citations): Author surname, first initial, year published, edition, city of publication, publisher, page. *Example:* If we agree that Black is an absence of colour (Smith, J, 2016, Textbook of Everything, 2nd edition, London, Pearson Publ., page 6) then we can assume ...

All reference material used must be listed at the end of your report in alphabetical order. You should note that if author surnames begin with the same letter, then the first to be listed in your references will be dependent on the second letter in their names and so on.

Example: You have used reference material from two texts, one written by author J. Smith and one by author B. Smythe. The first to be listed in your references will be J. Smith, because the third letter of the surname is 'i' which comes before 'y' in the alphabet.

Once completed, your literature review must be written in a format which resembles that of a science investigation (see Figure 6.2):

- ▶ introduction
- ▶ main body
- ▶ conclusion.

Introduction:

- 1 Nature of the topic
- 2 Why you chose the literature
- 3 What the topic includes

Main body:

- 1 Mainstream views and alternative ideas
- 2 Background to the hypothesis
- 3 Definitions of key terms
- 4 Research studies performed, if any exist
- 5 New discoveries, if available
- 6 Questions asked
- 7 Methods used and to be followed by you
- 8 General conclusions

Conclusion:

- 1 Summary of general conclusions
- 2 Have you been able to focus your hypothesis clearly following review?
- 3 Points where you agree/disagree with the literature

► **Figure 6.2** Structure of review

Discussion

Have a general discussion in your group on the benefits of carrying out a laboratory-based investigation as opposed to a fieldwork investigation. You could focus on equipment, other resources, personnel and time.

Investigative project proposal

Thorough completion of the literature review will ensure that you will be in a position to provide a project proposal for investigation. This section of your work should include an outline of what you intend to investigate, the reasons for your choice, information in support of your topic choice, what you hope to achieve and problems you expect to encounter.

Rationale

Having chosen your area of study, based on your literature review, you must now write down the reasons why you have chosen this project and what you intend to gain from its completion.

This section of your project proposal is an opportunity for you to explain why you are performing this investigation and perhaps describe how the investigation results may be of further use or what implications your study may have on your present understanding of the topic.

- Identify the background information concerning your chosen topic that you have found by research.
- Identify how this information relates to your study topic – is any of it relevant?
- Comment on the science principles involved.
- Use appropriate and a sufficient number of sources of information to help you plan your investigation.
- Link your current knowledge of the subject in question to your investigation.

Remember

- Keep your rationale concise and short.
- Use clear language.
- Identify the main point of the investigation.
- Use and reference appropriate sources.
- Outline the scientific principles involved.
- Explain why you have chosen this topic.

Background

The information you need to include in the background section should identify and describe what the subject of your proposal is and its scientific history. You should refer to the literature review information and include the context of the work you are about to undertake. The background should present the scientific information which currently exists, outlining your knowledge development and explaining what is known about the science of the subject.

A well written background section will help other readers and your tutor determine how well you understand the subject in your project proposal. Demonstrating a clear understanding will promote further confidence in the quality of your overall investigative project. Summarise all you know about the subject, highlighting literature using **citations** and write it as though you are telling an interesting and engaging story.

Key term

Citation – a quotation or reference from a paper, article, book or specific author.

Background of the study

Cockroaches are common pests in the tropics. They have been known to cause allergic reactions to most people and chew holes in clothes. According to Bato Balani for Science and Technology, Vol.14, No.2, the real danger of cockroach lies in their ability to transmit sometimes lethal diseases and organisms such as *Staphylococcus spp.*, *Streptococcus spp.*, Hepatitis viruses and Coliform bacteria. They have been known to contaminate food, at the same time infect it with the bacteria they carry. The bacteria they spread in food can cause food poisoning. People have used various instruments to control the cockroach problem in homes. The most popular is the commonly used insecticide sprays. Most of these can destroy cockroaches but they can also do serious damage to humans as well. According to the experts of the website toxalbumin carcin. Along with other ingredients like sap, onions and weeping willow leaves, are Tubang Bakod seeds feasible to be used as cockroach killer? www.bayer.co.th, the active ingredients in these sprays, like tethramethrin and petroleum distillates can cause severe chest pains and cough attacks when inhaled. The second most popular instrument is the cockroach coils. These coils can kill roaches yet the active ingredients in these coils like allethrin, pynamin forte, prothrin and pyrethrin, can cause harm to humans when inhaled. It also has an ozone-depleting ingredient. The third most popular is the flypaper. The concept of the flypaper is simple. The roaches just stick into it. But when they are stuck the roaches die and carcass can spread more bacteria. In addition to the side effects of these materials, the costs of these insecticides are high. All these set aside, the question on everyone's mind is: 'What can be an effective and natural insecticide?' Tubang Bakod (*Jatropha carcas*) is a common plant in the Philippines. According to the website www.davesgarden.com, its seeds contain a certain toxic substance known as Toxalbumin Carcin, along with other ingredients like sap, onions and weeping willow leaves, are Tubang Bakod seeds feasible to be used as cockroach killer?

Source: <https://www.scribd.com/doc/60715657/Background-of-the-Study-Sample>



PAUSE POINT

Read the above passage carefully and re-write it so that it will be more easily accessible to your fellow students.

Hint

Bullet point or number the key points in the passage but retain the referencing and scientific wording.

Extend

Outline the main methods proposed to control the problems which cockroaches introduce. Identify and comment on the main aspects associated with natural and man-made methods at controlling transmission of diseases by cockroaches.

Remember

- Position the 'background' in the report abstract section and make it brief.
- Outline what information is already known about the subject.
- Outline what your investigation intends to find out or test.

Hypothesis

A hypothesis is an assumption based on your knowledge, understanding of the topic and observations. When carrying out an investigation, you can hypothesise about the outcome of the investigation and you may change this when other observations are made. Your hypothesis will then lead you to a prediction or predictions which you will be able to test.

To produce a meaningful hypothesis, you will need to identify the scientific question.

Example: 'Do plants need fertiliser to grow bigger?'

Your hypothesis will be developed from research you carry out and knowledge which you already have on the subject.

Example: 'Plants need a variety of nutrients to grow well. Adding fertiliser containing these nutrients helps them to grow bigger.'

Your prediction(s) will involve you applying the information you have researched to a situation which you will be able to investigate and test.

Example: 'Using two sets of tomato plants, if I add fertiliser containing nutrients to one set of tomato plants and do not fertilise the other set, there should be a significant increase in height and leaf size of the fertilised set of plants.'

Null hypothesis

Your hypothesis is an explanation of what you have observed and can be supported or refuted by the evidence in your investigation. This is generally demonstrated by confirming a relationship between two variables. A null hypothesis would state that there is no relationship. By disproving the null hypothesis, you provide support for your hypothesis, i.e. there is a relationship between the variables. There are a range of statistical tests that can be used to determine the probability that your null hypothesis is incorrect and the degree to which there is a significant relationship between the two variables. These include chi-squared and t-test.

Example

It is accepted that concentration is related to the quality of sleep that you get. Your hypothesis to be tested could be 'A better quality of sleep increases your concentration levels.' Your null hypothesis could be 'Concentration levels are unrelated to quality of sleep'.

By testing and disproving the null hypothesis, you can conclude that there is a relationship between levels of concentration and quality of sleep.

Hypothesis checklist:

- ▶ Is it based on information from reliable sources about the topic in question?
- ▶ Can the hypothesis be tested in an experiment?
- ▶ Can you identify at least one prediction from your hypothesis?
- ▶ Does this prediction have both an independent variable and a dependent variable?

Aims and objectives

The purpose of the activity undertaken, and identification of what the activity is attempting to achieve, is called the **aim** of the investigation. The aim should be kept brief and to the point.

Steps to be taken to achieve the aim of the investigation are referred to as the **objectives** and are details of the specific tasks intended to help achieve the goals outlined in the aim. In many scientific reports, they may also be referred to as 'outcomes'.

Key terms

Aim – overall general statement of the purpose or intentions of the study.

Objectives – stages to be completed to successfully achieve the aim.

Example aim

A thermometric titration could involve titrating sodium hydroxide (NaOH) solution with hydrochloric acid (HCl). The change in temperature would then be recorded for every addition of a quantity of the acid and the highest temperature recorded would indicate the 'end-point' of the titration. This can then be used to find the concentration of the acid.

Aim *To measure and record the maximum temperature during the reaction of sodium hydroxide with hydrochloric acid solutions. The volumes of solutions which have reacted at the maximum temperature signify the titration 'end-point'.*

Example objectives

When microorganisms are initially introduced into a growth medium, they make sufficient use of the nutrients supplied by synthesising the available enzymes. This does not happen immediately but rather slowly at first, then quite rapidly. This is called the growth phase. By counting the bacterial population at suitable time intervals, a graph of population size (log scale) against time can be developed, from which the bacterial colony growth rate can be found.

Objectives *1. To develop data on bacterial growth over a suitable time period. 2. To identify the exponential growth of bacteria in a growth medium. 3. To be able to calculate bacteria growth rates from measurement.*

Case study

Tom Michaelson is a project advisor responsible for the development of text books and other published resources for science related to schools and colleges at KS3, KS4 and KS5. His team are currently deciding what information should be included in the latest edition of their textbook, *Science at Advanced Level*.

One member of the team suggests that, in order to determine what should be included, it is first necessary to understand what the aims and objectives of the book actually are.

Check your understanding

Using this text book as your example.

- 1 Outline the aim of the book in no more than four lines.
- 2 Identify the main objectives of the book.

The following aims and objectives passage has been taken from a research report into 'Evaluating the success of a

public engagement project for the conservation of the Ural Saiga population in Kazakhstan':

Investigative Project

This thesis **aims** to evaluate the success of the EE [Environmental Education] campaign which provided local communities with information on the ecology and conservation status of the Uralsk Saiga 3 population. No previous Saiga education has been carried out in the region, so the campaign offered a unique opportunity to establish a baseline and to assess any changes in attitudes, knowledge and behavioural intent. The study provides insight into not only how attitudes effect conservation, but also how 'external' conservation measures and processes are judged by local people.

Research **objectives** 1. Evaluate if/how levels of knowledge, attitudes and behavioural intentions toward Saiga changed, during the study period. 2. To assess any differences between socio-demographic groups regarding their experience of the campaign, in addition to knowledge of and interactions with Saiga. 3. To understand local people's perceptions of threats to Saiga and their conservation requirements and their own potential future role in Saiga conservation 4. To make recommendations for future awareness campaigns and Saiga conservation within the target villages.

Source: <http://www.iccs.org.uk/wp-content/thesis/consci/2011/Samuel.pdf>



PAUSE POINT

Read the passage and simplify what the study was all about.

Hint

You will firstly need to determine by research what 'Saiga' refers to – unless you already know.

Extend

Identify any similarities and differences between this passage and the examples of aims and objectives shown in the section above.

Limitations

Even the most experienced and established scientific researchers will encounter aspects to a practical investigation which will need to be clearly identified and planned for well in advance of carrying out the activity.

The limitations of *your* study will generally depend on a number of different factors. Three of the most important considerations are outlined in Figure 6.3.

Implications for resources:

Most laboratories have an allocation of finances which can limit the number of different resources they may have. A booking system is standard practice and ensures that all are able to carry out their investigations eventually. Knowing exactly what is needed, by producing a resource list and presenting this to the technician early, can offset possible delays in completing the practical work.

Use of facilities:

You will need to identify the kind of laboratory and the types of instruments necessary, since some are designed with either chemistry or general science as a focus. Again, the use of specific equipment and laboratories is limited by factors such as timetabling or priority investigations. Early planning will help to reduce the possible need to re-think the course of your investigation.

Time constraints:

The time available to learners for carrying out scientific investigations has been reduced over the years, leaving highly constrained investigations to be preferred by most educational establishments. This approach does not allow more genuine, speculative science to develop. Planning your time is vital if the work is to have purpose and meaning. Negotiate with your tutor and technical staff, outlining the project proposal and the timetable of events so that you can successfully complete the work.

► **Figure 6.3** Limiting factors on study

Assessment practice 6.1

A.P1

A.P2

A.M1

A.M2

A.D1

Produce a simplified single A4 page literature review on the topic of variation of plant growth as a result of different light sources for possible further investigation.

You will need to include:

- 1 A full listing of the sources you use for research, their dates and relevance to the topic such as articles, websites, journals etc.
- 2 Complete and accurate referencing from the source information using the Harvard referencing system.
- 3 Identification of the form of study that is most suitable for the topic, outlining any previous studies which have informed your decision and the direction of your study.

Plan

- What is the task? What am I being asked to do?
- How confident do I feel in my own abilities to complete this task? Are there any areas I think I may struggle with?

Do

- I know what it is I'm doing and what I want to achieve.
- I can identify when I've gone wrong and adjust my thinking/approach to get myself back on course.

Review

- I can explain the results obtained from the task.
- I can apply the activity to other situations.

B

Produce a plan for an investigative project based on the proposal

Producing your investigative project proposal is the first step in the process of providing a clear direction in your topic of study. Your project plan must now be considered in terms of the timing of each part of the project, outlining the method and relevant use of resources. In addition to this, you must now include important aspects of health and safety, identifying the hazards involved and the level of risk.

Schedule

Timeline for project

Any master chef will tell you that the key to producing a top-class meal as opposed to a culinary disaster is the timing. Although, in your studies of science at Level 3, you may not be expected to cook any food, producing and adhering strictly to a timeline for your project is vital if you are to complete the activity with sufficient time allocated for specific tasks within the investigation.

Ensure that you have given due consideration to the key aspects of time shown in Figure 6.4.

If all the information and times of start, completion and milestones are noted, the possibility of problems arising – such as running out of time, the need to carry out repeat experiments, being unable to use the laboratory because of a lack of prior booking etc. – will be reduced a great deal.

Start date:

After discussion with your tutor and technicians, set a suitable date for starting the practical part of the project. This will involve assembly of the equipment, collecting data or results, collating the evidence, analysing and presenting the data. Note the times when you are undertaking tutorials and laboratory hours.

Milestones:

Important sections of your practical work which need to be recognised. This could include; initial assembly and checking operation of equipment, identifying H&S aspects, performing the main functions and observing, recording results, analysing data, presenting data.

Completion date:

Dependent on the centre timetable, identify a suitable date to draw the physical aspects of the activity to a close. Remember that you will now need sufficient time to be able to finalise your report with a full evaluation of your findings.

► Figure 6.4 Important time factors

Link

See Unit 2: *Practical Scientific Procedures and Techniques* (Fig. 2.27, page 134, keeping a detailed laboratory notebook).

Plan

Producing a working plan or method for an investigation involves the use of all your notes, literature review, tutor guidance and preliminary testing (where appropriate). If the working plan is thorough, the investigation should produce no real surprises but useful results. You should try to include detailed descriptions of the following points in your working plan.

- ▶ A hypothesis (if possible) – suggestions for explaining what may be happening.
- ▶ Theory – literature review notes on the topic of your project proposal.
- ▶ Apparatus to be used – include labelled diagrams, include the number and sizes of pieces of apparatus.
- ▶ Notes of preliminary tests (if appropriate) – if you have time planned into your project to carry out a preliminary test, include all the notes to guide the main investigation. This could include trying different methods or refining a method so that it will give meaningful results.
- ▶ Step by step instructions – details of how the investigation will be performed, generally in numbered or bullet point format. It may well be worth attempting to provide a method of a relatively basic procedure as a practice run, such as ‘making a cup of tea’, to give you some insight into the need to identify every specific point if others are to follow your method. The method should be in third person past tense and should include enough detail so that someone else can replicate the experiment exactly as it was performed, without having to ask any questions about what was done.
- ▶ A prediction – what you think will happen, guided by your research notes.
- ▶ Variables – which will be kept constant and how they will be kept constant; which will change.

Your investigation planning stage will take time to develop. Your completed plan needs to be monitored by your tutor and/or technician regularly before the investigation can be given the go-ahead. What may look feasible to you may not be appropriate to experienced members of staff.

Resources

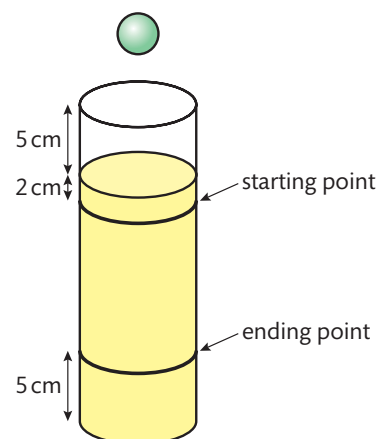
Scientific investigation resources, in the context of the plan, refers to all those commodities available to the investigator within the confines of the laboratory. This includes:

- ▶ equipment and instrumentation
- ▶ materials
- ▶ participants.

Providing an equipment or apparatus list may not sufficiently address the use to which they are to be put or the reasons for their use in a certain activity and so you need to ensure that this is included in the resource section of your plan. It is important to outline the nature of the experiments to be undertaken, detailing the standard procedures applicable and whether they would need to be modified in any way to suit the requirements of the investigation.

Consider the example in Figure 6.5.

- ▶ Equipment and instrumentation – the tube would need to have markings set at an appropriate distance to ensure that sufficient time is allowed for measurements to be taken as the marble is dropped into the liquid and flows through the liquid to the bottom. A preliminary set of tests will need to be performed. How is the marble retrieved after falling, for example? Instruments used to measure the diameter of the marble will need to be precise, for example a micrometer screw gauge, but practice is required to ensure that this instrument is used correctly. Timing devices will need to be responsive to touch and in good working order. Should a light gate type be used instead?



- ▶ **Figure 6.5** Viscosity (or velocity) tube method of determining the viscosity (resistance to flow) of liquids using a marble. The speed of the marble through the liquid is related to the viscosity of the liquid.

- ▶ Materials – the type of spherical object used may play a part in the results obtained. Using spheres of different mass will give different readings, but does this affect the aim of the investigation? The density of the liquid medium will necessarily need to be altered to demonstrate that the spheres fall at different speeds through different liquids and illustrate valuable points concerning liquid flow. Should the liquid be kept at constant temperature or varied?
- ▶ Participants – how can one person drop the ball and begin the timer at the precise time necessary? Using other people to help in measurement is important in many forms of investigation to obtain useful results. In this activity, the additional participant would need to be used to either drop the marble or start and stop the timer at the precise times. This additional participant will need to be firmly briefed beforehand and given preliminary tests to ensure that there is good understanding between all parties.

Contingency planning

'The best laid schemes o' mice an' men / Gang aft a-gley.'

This line, taken from a Robert Burns poem and adapted by writer John Steinbeck in his novel *Of Mice and Men*, is often quoted (albeit in present-day English) to indicate that whatever plans have been put in place and whatever the intentions, not all are started or carried out in the manner intended.

Contingency planning (often referred to as 'Plan B') is now built into all large projects by multinational companies and governments to ensure that all possible manner of events are identified to manage the possible risks. Not everyone makes a **contingency plan** because they may:

- ▶ be overconfident about the completion of their work at the first attempt
- ▶ not have considered the possibility of problems occurring.

Key term

Contingency plan – a plan or action designed to be introduced in response to circumstances which may or may not actually happen.

Case study

The crew of Apollo 13 (unluckily on 13 April 1970) suffered a large explosion in one of their oxygen tanks while on their way to the Moon. They survived by transferring themselves into the Lunar Landing Module for much of the trip back to Earth, a contingency plan worked out one year earlier and almost dismissed as impractical by NASA at the time. Nevertheless, NASA developed written procedures for the possibility of this occurring.

Check your understanding

- 1 With a partner, discuss any time in the recent past when you have needed to refer to your contingency plan. This may not be an obvious plan B, but could be something as simple as a necessary change of direction when walking to school or college or decision to change a playing position following the absence of a member of the hockey team.

Your contingency planning and any remedial action you may have to take will need to be written into your initial science plan and probably informed by carrying out some preliminary testing. The following list provides some guidance.

- ▶ Keep your contingency plan simple and use clear language which is easy to follow by others.
- ▶ Identify possible triggers of your contingency plan and the actions to take. Who will be responsible at each stage?
- ▶ Quickly identify whether you need extra resources. If your initial method needs amendment, do it and continue.
- ▶ Change your schedule of events and timings if you need to. You should try to identify any operational areas which you regard as inefficient.
- ▶ Manage the risks, looking for ways to reduce risk so that full contingencies need not be used if possible.
- ▶ Repeat readings sufficiently to help eliminate the need for a contingency.

Health and safety and ethical considerations

Hazards

The final stage (and probably the most important) in your preparation for carrying out the physical investigation of your proposed project is the development of a detailed and well-considered risk assessment based on correct identification of hazards which may be encountered during the activity.

A hazard is something which has the potential to cause harm and it is very important that you identify all the possible hazards in order to minimise or even eliminate the possible occurrence of harmful conditions. Of course, listing all possible hazards is virtually impossible since almost every piece of equipment or action could give rise to an accident or danger, either predictable or purely an unforeseen event.

Table 6.3 lists the more common types of hazard that can occur in the school or college laboratory.

► **Table 6.3** Potential hazards in a laboratory

Hazard	Details
Flammable substances	Take note of any materials which can catch fire.
Chemicals	Skin and eye burns can occur with many acids and alkalis. Organic chemicals such as phenols are corrosive.
Excessive heat	Thermal burns occurring from a Bunsen Burner flame or heat produced by chemical reactions.
Cuts	A very common accident, generally a result of removing tight stoppers on glass tubing or careless use of beakers.
Chemical absorption	Some chemicals when touched can be absorbed by the skin, cause severe dermatitis or seriously affect the eyes.
Chemical inhalation	Solvents, for example, are extremely toxic if inhaled and other compounds can affect the eyes, nose, throat and lungs.
Explosion	Unvented systems for chemical reactions can be explosive, e.g. distillation.
Chemical ingestion	Entering the mouth by hand contact, pipette use, contaminated food and drink.
Trips and falls	Occur frequently where bags, materials and other items are not removed from the site.

Link

Unit 3: *Investigation Skills*, page 146.

Unit 4: *Laboratory Techniques and their Application*, pages 228–235.

Biological hazards are also commonly encountered in some specialist laboratories (see Figure 6.6). This may involve the use of bacteria and viruses for testing and different animal blood types, including human blood. In the school or college science environment, contact may be made with organs, blood, tissues and other fluids from animal dissection. If not dealt with carefully, diseases could be easily spread.



► **Figure 6.6** Standard hazard symbols

Technical requirements

Equipment which should always be used in scientific investigations to protect from health and safety risks is called **Personal Protective Equipment (PPE)**. This includes: safety goggles, laboratory coats, face shields, gloves and helmets. Most laboratory environments are equipped with a fume cupboard or laminar flow cabinet, designed to prevent contamination of samples such as delicate electronic semiconductors or biological samples.

Investigations in all three science disciplines carry hazards and potential risks but chemistry has more than most. When carrying out a chemical investigation, use every available resource (**COSHH, Hazcards** from CLEAPSS, ‘Topics in Safety’ by ASE) to help you prepare your risk assessment and to understand fully what potential risks are associated with the substances that you are about to use. COSHH Regulations, 2002, are responsible for carrying out research and publishing data providing information such as the amount of chemical to use and length of exposure time for industry workers, before their health may suffer. Employers have a legal duty to report all incidents, however slight, and to record these incidents in a suitable register. If an incident needs investigating, the Health and Safety Executive (HSE) will require access to the register.

The Health and Safety at Work Act provides the law which covers all aspects and areas in the workplace. Organisations with more than five employees must develop their own Health and Safety Policy, which must be endorsed by the HSE, who give guidance for each section of the policy, including: writing the policy, Risk Assessment, facilities, training of staff and poster displays.

Key terms

Personal Protective Equipment (PPE) – equipment designed to protect the wearer by limiting the risk of injury or infection.

COSHH – Control of Substances Hazardous to Health Regulations in place for education and industry to limit the exposure to workers of chemical effects.

Hazcards – a set of documents from CLEAPSS (Consortium of Local Education Authorities for the Provision of Science Services) giving information on storage, disposal and potential risks of chemical and biological substances.

Research

Under supervision, identify one chemical in the school or college laboratories which has one or more of the hazard symbols on its label. Refer to 'Hazcards' to outline the main dangers of the chemical when being used and how it should be handled.

Risk assessment

Before you perform any practical work, complete a risk assessment thoroughly and have it checked by your tutor. Your place of learning has a responsibility to ensure that this is carried out following the Health and Safety at Work Act of 1974. Remember, a risk assessment is your way of minimising the potential risks which can occur during all your activities and to identify how you would deal with any risk occurring, not just when spills and breakages happen. This would include lab coats, fume cupboards, tongs etc . . .

Ensure that your risk assessment is completed thoroughly and in clear terms. It must include the type of hazard, the level of risk, and how the risk of hazard can be prevented or minimised. Before any investigation:

- 1 Identify the equipment and substances that you intend to use.
- 2 Research the hazards and the potential risks which can occur.

- 3 Outline the measures needed to deal with spills and breakages.
- 4 Have your risk assessment checked properly by a member of the science staff.

Remember

Before any investigation, you should:

- ask your teacher / tutor for the standard risk assessment paperwork used in your college or school
- identify the equipment and substances
- research the hazards and potential risks and include the type of hazard, the level of risk, prevention methods and ways of minimising the hazard
- identify measures to deal with spills and breakages
- have your Risk Assessment checked.

Link

Unit 4: Laboratory Techniques and their Application, pages 230–1 (a useful procedure for completion of a risk assessment when using sulfuric acid after guidance from the relevant Hazcard pages).

Ethical considerations

It is accepted that the range of ethical considerations involved with laboratory science investigations in a school sixth form or college may be limited. It is unlikely, for example, that there will be serious ethical implications when carrying out many physics investigations, but there may be ethical considerations in specific biological activities where small animals are tested or when using other people within the study.

Since ethics is concerned with the essential rights and wrongs or moral principles of a person's behaviour, the issue becomes important in many forms of science investigation. Some examples are:

- ▶ using live animals, e.g. daphnia in caffeine solution
 - ▶ effect on an ecosystem where live samples are taken
 - ▶ using people for timed experiments after stimulants are used to determine change in reflexes
 - ▶ using personal comments or details in survey information
 - ▶ adjusting data to suit the investigation outcome.
- If you have an idea of the expected outcome of an investigation, it is very easy to mistakenly drive your experiment to provide the data which matches your expectation while not accepting the 'real' data. This introduces 'Bias'.

If you intend to use other people as part of your investigative project, for example, in reflex testing when caffeine has been introduced, or exercise to test heart rate changes, you should obtain informed consent. This indicates that the subjects have been given a good explanation of the activity and have willingly agreed to take part. When asking for consent from an individual, you must inform them of their rights, the purpose of the investigation, what procedures will be carried out, what

the data will be used for, the possible risks involved and the potential benefits of the study.

Confidentiality of information must be ensured in the above investigative examples, ensuring that important and personal information on health issues or other personal aspects are not divulged to persons without the express permission of the individual concerned in the investigation.

Assessment practice 6.2

B.P3

B.M3

B.D2

Chemical titration is an activity which involves many pieces of equipment and chemical solutions. It needs to be well planned because of the potential hazards which are inherent in the procedure.

- 1 Produce a comprehensive risk assessment for a chemical titration of an unknown concentration solution of hydrochloric acid with a 0.5 mol dm^{-3} solution of sodium carbonate.
- 2 Use a suitable document for the purpose.
- 3 Identify the types of hazard involved and the level of risk.
- 4 Identify preventative measures and how hazards are minimised.
- 5 Use the appropriate 'Hazard' information.

Plan

- What is the task? What am I being asked to do?
- How confident do I feel in my own abilities to complete this task? Are there any areas I think I may struggle with?

Do

- I know what it is I'm doing and what I want to achieve.
- I can identify when I've gone wrong and adjust my thinking/approach to get myself back on course.

Review

- I can explain the results obtained from the task.
- I can apply the activity to other situations.

C

Undertake the project, collecting, analysing and presenting the results

All the background research, literature review and planning has now been completed and the practical element of the investigative project is about to begin. This section deals with the essential aspects related to the physical collection of results from setting up your apparatus to your final presentation of the data collected. The setting up stage of the scientific apparatus is of fundamental importance to the investigation and you must ensure that the health and safety information gathered has been understood and is in place. Your skills in using the equipment and observation of important experimental events will need to be perfected so that your results are both **valid** and reliable.

Key term

Valid – the degree to which the method and results obtained reflect the real results.

Experimental procedures and techniques

Assembly

Having produced your literature review, research and planning for the investigative project you have proposed, it is now time for the practical work. Your laboratory and equipment have been booked according to the timescales you have identified and you may need to confirm that your detailed list of apparatus is both available and relevant. Ensure that the tutor and technician are happy with your choice of equipment and that there are no other aspects to be explored before you begin setting up for the activity.

To do this, it is wise to set out your equipment, especially glassware, before you on the same bench where possible and to tick them off on your checklist. It is very easy to

'lose' items in the array of others available and so placing them back after using them, in the very same spot that you originally placed them, will always help to keep the investigation in order.

You should also provide specific information when placing your orders for equipment to the technician. This will include concentrations of acids and alkalis, number and volumes of beakers, etc. Doing this will help to minimise confusion and avoid possible time delays.

Finally, have your bench and equipment/apparatus display checked by your tutor and the technician so that you may begin your investigative project in practical terms.

Reflect

'I always wore [safety] glasses whenever I was at my bench, and while I felt I conscientiously observed safety measures, my experience proves [...] there's simply never an adequate excuse for not wearing safety glasses in the laboratory at all times.'

Source: From an extract of a document written by Dr. K. Sharpless after losing the sight in one eye following an accident in 1970 at MIT in the United States of America.

- 1 Why is it important to check all your equipment and apparatus prior to and during your investigation work?
- 2 In a few clear steps, explain the importance of producing a risk assessment.
- 3 What would you do if someone working with you does not take the matter of safety seriously?

Adhering to health and safety, rules and regulations

Before carrying out any practical work, it is always wise to revisit your risk assessment and make yourself fully aware of the hazards involved and the potential risks.

The health and safety of you and others in the laboratory should be considered at every major stage in your activity.

Your planning stage will have helped you to understand clearly the hazards and possible risks involved with the activity that you are about to undertake. Revise them and if necessary, review them. Perform your investigation using the utmost caution and with respect to the people around you – including yourself.



- ▶ Students and tutor carrying out scientific investigation observing safe practices.

Discussion

In your group, identify any points of good safety practice that you can see in the photograph. Are there any aspects which are not safe and could cause potential problems?

Apply your knowledge of materials, equipment, chemicals, biological and physical hazards to ensure that you do not take unnecessary risks.

This checklist may help as a reminder:

- ▶ Refresh your knowledge of the Hazcard information.
- ▶ Check your Personal Protective Equipment for your own personal safety.
- ▶ Are your chemicals easily to hand but also safely positioned?
- ▶ Is your flame source in clear line of sight and not interfering with other equipment?
- ▶ Inspect your apparatus, especially glassware, before use – are they clean or do they have small cracks?
- ▶ Keep a large printed note on the bench in case you have to leave the investigation.
- ▶ Are your safety goggles available?
- ▶ Are you fully aware of the safety procedures in case you need to use: eye wash station, fire alarm, fire extinguisher and first aid kit?

You can then notify your tutor and technician and begin your investigation.

Handling skills

It is very important that you know the correct method to transfer materials from one place to another and what amounts are safe to transfer. If in any doubt, you must

seek further advice. Liquids and chemical solids present some hazards and difficulties during transfer and should be moved with caution, but also with a high degree of firmness in your grip. Ensure that the distance to be transferred is limited, possibly even to a slight rotation of your body or even just your arms in many cases. Keep focussed on the transfer you are making and make sure that your apparatus does not impede your movements. You should ensure all of the equipment is at hand and laid out on the desk in the correct order before transferring any materials. It is well worth considering a “practice run” of transferring without including the actual material to be transferred.

Some equipment and materials may be very delicate and should be treated with great care, whilst some may be more resilient and require firm handling. Be confident in your handling technique, demonstrating safe and appropriate handling of all glassware by holding with both hands for larger pieces of equipment.

Precision instruments will need further care when handling, to avoid possible damage to delicate springs in a top-pan balance or sensors and probes, for example. Unnecessary damage during the investigation stage is both costly in financial terms and time. You don't want to postpone your investigative project after putting in so much work during the planning phase.

When transferring biological material, in particular bacteria and other microorganisms, the procedure to be followed is necessarily detailed and must be followed exactly. This will ensure that no possible contamination of your culture occurs. This process of transfer is termed 'aseptic techniques' and will involve such procedures as sterilising inoculating loops used to transfer microorganisms (by passing the metal loop through a Bunsen burner flame), for example.

Use of equipment

Notes and diagrams from your planning stage are now ready to be put into practice with the setting up of apparatus. Your tutor and/or technician will need to observe your use of equipment for the assessment of your practical skills. You should ensure:

- ▶ that you have complete awareness of health and safety issues
- ▶ that you can demonstrate competence in your assembly of equipment
- ▶ that you have the ability to manipulate the equipment to obtain results
- ▶ that you have skills in observation and record keeping practices

- ▶ that you adhere to **good laboratory practice** (GLP)
- ▶ that you can take measurements with **accuracy** and **precision**.

Key terms

Good laboratory practice – a system of regulation which ensures that tests carried out in non-clinical laboratories are well planned, reliable and have hazards suitably assessed to reduce risks to the public and environment.

Accuracy – the closeness of the readings to the actual value.

Precision – the degree of uncertainty of a measurement linked to the size of the measured unit.

The way in which you use the equipment available needs to be well practised and suitable for the laboratory environment. Mistakes at this stage will have serious effects on your results and render the investigation invalid because the conclusions drawn will be meaningless.

Repeat readings to obtain useful **means** of the results and conduct preliminary tests if the investigation is suitable. Use the correct 'base' and 'derived' units in all your measurements with the correct symbols. Keep a clean and well-organised record of notes and diagrams in a laboratory note book.

Key term

Mean – the average of all the numbers within a set of results. It is obtained by totalling the results and then dividing the total by the number of results.

- ▶ **Table 6.4** How to take measurements and use instruments and sensors accurately

Taking measurements	Instruments and sensors
Pour liquids into test tubes and measuring cylinders slowly and at eye level.	Check or recalibrate any sensors or instruments which have not been used often.
Use wash bottles to ensure all solid residue is used.	Carry out test readings to get familiar with values expected.
Hold thermometers at the top and rotate gently in the liquid.	Don't underestimate the importance of analogue instruments or rely totally on digital forms.
Repeat readings using digital and analogue meters to establish those results to be discarded.	Double check electrical meters. There can be considerable differences in voltage and current readings using a variety of instruments.

► **Table 6.4** Continued

Taking measurements	Instruments and sensors
Gently shake test tubes when heating liquids until desired temperature is reached.	Ensure that probes are clean.
Check top-pan balances carefully before measuring masses.	Record the readings of more than one power supply to identify any which may be providing inaccurate results.
Read liquid volume measurements at the bottom of the meniscus.	Take repeat readings to confirm instrument or sensor results.
Perfect your use of pipettes.	Handle all sensors according to the manufacturer's strict guidelines.

Observation skills

Good observational skills in the laboratory are essential if you are to successfully identify and interpret a range of reactions, phenomena or other details to draw meaningful conclusions from your studies. During your studies you may observe fluids, tissue sections, cellular specimens, colour changes, consistency changes, meter readings and other physical changes. In some instances it is useful to have a reference chart to compare things to when making observations. For example, if you are observing a colour change you could have a colour chart to help you to make accurate judgements.

Many of these observations will be easily seen but others may only be observed through a microscope, and you need to give yourself the time needed to observe such science related aspects so that your results can be more firmly based on sound evidence.

Becoming a good observer requires training. The more scientific observations you make, the better at observing you will become. When asked to draw what they see on a slide of onion cells, the differences shown by two students can be quite significant.

Discussion

In pairs, give yourselves 60 seconds and count the number of 'red' words in this colourful sentence.

'First of all, I would redefine the concept of the green synthesis, because I don't want to reduce this to an obvious statement and swear that black is white.'

If your observational skills are good, you should arrive at 10.

Adherence to relevant legislation

Good Laboratory Practice (GLP)

The principles of GLP were first developed in the USA in 1978 and later adopted by the European Community. Sections of the regulations are updated when necessary.

In the wider context, GLP ensures that tests carried out in non-clinical working laboratories are reliable and well regulated, assessing the hazards and risks to the public and the environment.

Industries using these principles include:

- industrial chemicals
- food and food additives
- pharmaceuticals
- cosmetic chemicals
- agrochemicals (used in agriculture, for example, pesticides or fertilisers)
- veterinary medicine.

In the context of your school or college, GLP relates to the general, well-established principles of carrying out a practical investigation using safe procedures and suitable scientific techniques.

The general guidelines are set out below. You may already be fully aware of many of those listed.

- Produce a detailed risk assessment.
- Tie back long hair securely.
- Wear goggles always and a laboratory coat where relevant.
- Wash hands before and after the investigation procedures.
- Wear waterproof dressings on existing wounds.
- Do not take food or drink into the laboratory.
- Regularly monitor electrical equipment.
- Use a Bunsen burner safety flame when not in constant use.
- Handle glassware with care and caution.
- Prevent liquid spills on electrical appliances.
- Identify areas where firefighting equipment is kept.
- Identify eye washing facilities.
- Identify the gas and electricity emergency cut-offs.

Good Manufacturing Practice (GMP)

Good manufacturing practice (GMP) is 'that part of quality assurance which ensures that medicinal products are consistently produced and controlled to the quality standards appropriate to their intended use and as required by the marketing authorisation (MA) or product specification. GMP is concerned with both production and

quality control' (source: www.mhra.gov.uk, a government agency set up to regulate quality and safety in the manufacture of medicines and medical devices).

Key term

Good manufacturing practice – a system of quality assurance to ensure that medicines and medical products are manufactured to the highest quality standards.

The agency is committed to ensuring:

- ▶ benefits to the public justify the risks taken
- ▶ availability of information
- ▶ quicker access to medical products and treatments
- ▶ thorough investigation of defective medicines and appliances.

Good Clinical Practice (GCP)

Good clinical practice (GCP) is 'a standard for the design, conduct, performance, monitoring, auditing, recording, analyses, and reporting of clinical trials that provides assurance that the data and reported results are credible and accurate, and that the rights, integrity, and confidentiality of trial subjects are protected' (source: www.ct-toolkit.ac.uk, Department of Health and Medical Research Council, 2004).

Key term

Good clinical practice – a set of quality standards for studies involving human beings.

In general, GCP is a quality standard for studies involving humans. It became effective from 1997 in the European Union, Japan and USA, setting down the principles of sound ethics, conduct and record keeping. It helps to ensure that clinical trials are reliable, confidential and safe.

Collect, collate and analyse data

Recording results

The way in which you record data obtained during a scientific investigation is important and is a fundamental part of your method. If your results tables do not show clarity and organisation, you can easily lose sight of the general patterns which may be available in the data.

Collecting the data must be completed with a high degree of 'Integrity', which means that you must record the results exactly as they are found and not as you expect or would

like to see. Record your data with 'Precision', to the correct number of decimal places based on the equipment used.

In science, there is generally more than one outcome or result from an experiment and there may be many repeats necessary, depending on the type of investigation undertaken. Tabulated recording of results is the most suitable in most cases and even where one outcome is to be recorded, the principle of repeat experiments to check the validity of your results determines the need for you to produce a table. Of course, in many cases you will need to devise your own tables in accordance with the investigation you are performing.

Here are some examples of tables for different experimental results.

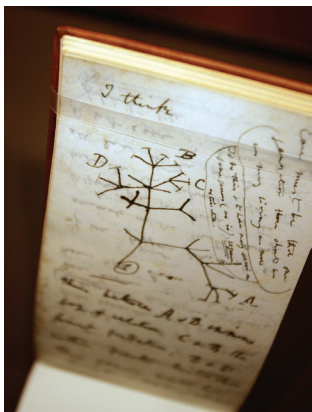
Length (m)	Current (A)	Voltage (V)	Resistance (Ω)

Load (or tension) (N)	Extension (mm)

Water-soluble compound	Acidic, alkaline or neutral solution?
Small-chain aliphatic acids	Strongly acid, pH < 7
Small-chain alcohols	Neutral pH = water pH
Small-chain aldehydes	Neutral or slightly acid due to oxidation
Small-chain ketones	Neutral pH = water pH
Small-chain amines	Weakly alkaline, pH > 7

Maintenance of laboratory notebook

Completing a laboratory notebook is considered a lost art, but nevertheless a very important document which shows the work carried out during investigations. Many well-known scientists have had their work interpreted and analysed later from notebook recordings which they completed during practical investigations (the photograph on the next page shows an extract from Charles Darwin's notebook).



► Charles Darwin's notebook used during his voyage on the 'Beagle'.

To use a laboratory notebook successfully, follow these guidance points.

- Protect your lab book with a cover.
- Use a dark coloured ink, not a pencil.
- Don't rip pages out or use correction fluid for mistakes. Cross out mistakes with a single straight ruled line through the error.
- Make good notes on safety issues.
- Put the title, task outline and date in your book.
- Start each task on a clean page.
- Label drawings well.
- Produce drawings of specialised equipment, not essential items such as small pipettes or beakers.
- Use bullet points for notable points and comments.
- Clearly label tables and graphs.
- Show relevant calculations where useful.
- Highlight general conclusions and link them to the hypothesis.

Organisation of data

In many scientific investigations, a large amount of data in the form of numerical figures can be generated and so must be organised in such a way that you can analyse the data.

The following example shows the steps needed to organise data for analysis.

'Consider a class set of 20 agar plates showing bacterial colony counts in identical conditions after 24 hours.'

1, 2, 4, 3, 6, 7, 6, 8, 3, 9, 6, 7, 7, 6, 5, 4, 5, 6, 5, 8

Using the first set of figures for the 20 agar plates of bacterial colonies after 24 hours, the mean is 5.3.

Table 6.5 gives the **frequencies** for the data.

► Table 6.5 Frequency table

Score	Tally	Frequency
1	I	1
2	I	1
3	II	2
4	II	2
5	III	3
6	IIII I	5
7	III	3
8	II	2
9	I	1
		20

The figure that occurs most often is 6, so the **mode** is 6.

Key terms

Frequency – how often a particular value occurs within a set of values.

Mode – the data value that occurs the most often in a set of values.

When the data values are much larger, it is more useful to group the figures into ranges of values which are called class intervals.

In this example, the same agar plates were kept in suitable conditions for a further 24 hours. The colonies grew in number and were counted again:

30, 46, 45, 43, 53, 42, 51, 55, 61, 44, 50,
52, 35, 37, 54, 62, 68, 58, 56, 46

The range is from 30 to 68 (a full range of 38). A suitable class interval width is 5 for this value, so you need $38/5 = 7.6$ (rounded up to 8) class intervals.

► Table 6.6 Class intervals

Class interval	Tally	Frequency
30–34	I	1
35–39	II	2
40–44	III	3
45–49	III	3
50–54	IIII I	5
55–59	III	3
60–64	II	2
65–69	I	1
		20

From Table 6.6, we can see that the modal class interval is 50–54.

This tells us that most bacterial colonies grow to 50–54 in these conditions over a 48-hour period.

Methods and uses of data processing and analysis

Figure 6.7 sets out a standard deviation on a normal distribution curve of agar plates/bacterial colonies.

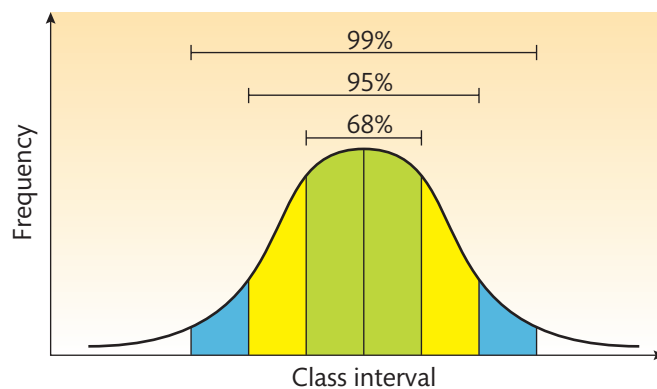


Figure 6.7 Standard deviation graph of agar plates/bacterial colonies. Generally, about 68 per cent of data lies within 1 standard deviation, 95 per cent within 2 standard deviations and 99 per cent within 3 standard deviations.

Link

Go to *Unit 3: Science Investigation Skills* for more on methods of data processing and analysis.

Theory into practice

Calculating standard deviation (using the formula in the worked example).

- Calculate the mean.
- Subtract the mean from each of your datum values to get the standard deviation.
- Square these numbers and add them all together.
- Divide this figure by one less than your sample number.
- The standard deviation is the square root of this value.

Worked Example

You are working in a horticultural laboratory which is testing a mixture of nutrients on the growth of tomato plants. Having measured 10 of the plants, you must now determine their standard deviation. Results (cm): 10.2, 10.4, 10.3, 10.5, 10.4, 10.8, 10.6, 10.9, 10.6, 10.6

Step 1: Calculate the mean (\bar{x})

$$\bar{x} = (10.2 + 10.4 + 10.3 + 10.5 + 10.4 + 10.8 + 10.6 + 10.9 + 10.6 + 10.6) / 10 = 10.53$$

Step 2: Produce a table that shows all the figures at a glance.

A	B	C
Height	$x - \bar{x}$	$(x - \bar{x})^2$
10.2	-0.33	0.1089
10.4	-0.13	0.0169
10.3	-0.23	0.0529
10.5	-0.03	0.0009
10.4	-0.13	0.0169
10.8	0.27	0.0729
10.6	0.07	0.0049
10.9	0.37	0.1369
10.6	0.07	0.0049
10.6	0.07	0.0049

Adding column 'C', $\Sigma(x - \bar{x}) = 0.421$

Standard deviation: $s = \sqrt{\frac{(x - \bar{x})^2}{n - 1}} = \sqrt{\frac{0.421}{9}} = 0.22$

The standard deviation for the height of the tomato plants is 0.2 cm and is given to the same number of decimal places as the original set of data.

Theory into practice

As part of a statistical analysis of the flight distance of honey bees on one day from the main colony, a tiny transmitter was carefully attached to a selection of 20 bees and the following set of data has been found.

Maximum distance of bee from the main colony (km):

1.2, 1.4, 1.6, 2.4, 3.5, 5.7, 6.3, 5.4, 3.2, 4.1, 4.2, 5.2, 3.7, 1.4, 1.5, 6.2, 4.2, 1.8, 2.3, 3.8

Calculate the standard deviation.

Student t-test

This statistical method is used to compare the means of two samples and is effectively an indication of how separate two sets of data are. The final figure is then checked in t-tables (see Table 6.7) to determine the percentage probability in terms of how significant the differences in means are. There are two types:

- ▶ unmatched pairs (two separate groups are used in the study, e.g. two selected groups of people given a new pharmaceutical for testing blood pressure)
- ▶ matched pairs (e.g. one group of people tested for their reflexes before being given a new stimulant and then after being given the new stimulant).

Link

See *Unit 3: Science Investigation Skills* for more information on the t-test.

▶ **Table 6.7** The t-test table

Degrees of freedom	Significance level					
	20%	10%	5%	2%	1%	0.1%
1	3.078	6.314	12.706	31.821	63.657	636.619
2	1.886	2.920	4.303	6.965	9.925	31.598
3	1.638	2.353	3.182	4.541	5.841	12.941
4	1.533	2.132	2.776	3.747	4.604	8.610
5	1.476	2.015	2.571	3.365	4.032	6.859
6	1.440	1.943	2.447	3.143	3.707	5.959
7	1.415	1.895	2.365	2.998	3.499	5.405
8	1.397	1.860	2.306	2.896	3.355	5.041
9	1.383	1.833	2.262	2.821	3.250	4.781
10	1.372	1.812	2.228	2.764	3.169	4.587
11	1.363	1.796	2.201	2.718	3.106	4.437
12	1.356	1.782	2.179	2.681	3.055	4.318
13	1.350	1.771	2.160	2.650	3.012	4.221
14	1.345	1.761	2.145	2.624	2.977	4.140
15	1.341	1.753	2.131	2.602	2.947	4.073
16	1.337	1.746	2.120	2.583	2.921	4.015
17	1.333	1.740	2.110	2.567	2.898	3.965
18	1.330	1.734	2.101	2.552	2.878	3.922
19	1.328	1.729	2.093	2.539	2.861	3.883
20	1.325	1.725	2.086	2.528	2.845	3.850
21	1.323	1.721	2.080	2.518	2.831	3.819
22	1.321	1.717	2.074	2.508	2.819	3.792
23	1.319	1.714	2.069	2.500	2.807	3.767
24	1.318	1.711	2.064	2.492	2.797	3.745
25	1.316	1.708	2.060	2.485	2.787	3.725
26	1.315	1.706	2.056	2.479	2.779	3.707
27	1.314	1.703	2.052	2.473	2.771	3.690
28	1.313	1.701	2.048	2.467	2.763	3.674
29	1.311	1.699	2.045	2.462	2.756	3.659
30	1.310	1.697	2.042	2.457	2.750	3.646
40	1.303	1.684	2.021	2.423	2.704	3.551
60	1.296	1.671	2.000	2.390	2.660	3.460
120	1.289	1.658	1.980	2.358	2.617	3.373
∞	1.282	1.645	1.960	2.326	2.576	3.291

The following worked example calculation is for unmatched pairs.

Worked Example

From microscopic analysis, the heart rates of two sets of water fleas (daphnia) were recorded in cool river water, group A and group B. Caffeine solution of 0.01 per cent concentration was also added to the water for group A. There were 10 fleas in each sample group. (n = number of sample, i.e. 10.)

Heart rate A	Heart rate B
113	68
111	56
136	62
121	78
108	82
109	64
117	66
122	78
132	77
116	81

Key term

Degrees of freedom – number of variables that are used to make a calculation.

Means [$\bar{x} = \sum x/n$]: A = 118.5 B = 71.2
The sum of the squares of each value in each table [$\sum x^2$]: A = 141 225 B = 51 438
The squares of the totals ($\sum x$)²: A = 1 404 225 B = 506 944
($\sum x$)²/ n : A = 140 422.5 B = 50 694.4
 $\sum d^2$ using [$\sum x^2 - (\sum x)^2/n$]: A = 802.5 B = 743.6
Standard deviation (σ^2) using [$\sum d^2/n - 1$]: A = 89.2 B = 82.6
Variance of difference between means (σd^2) using [$\sigma 1/n1 + \sigma 2/n2$]:
A = 8.92 B = 8.26 Answer = 17.18
 $\sum d$ using [$\sqrt{\sigma d^2}$]: $\sqrt{17.18} = 4.14$
t = **11.43**

Looking at t-tables with sample number of 2, the value obtained is much higher than even the 99.9 per cent probability (**0.1 per cent significance**) which shows as **3.92** in the t-tables.
The heart rates of daphnia in group A are much higher than those of group B, which can be linked in this case to caffeine.

II PAUSE POINT

The following sets of data were recorded by a student who tested the impact of light on photosynthesis for a water plant ‘cambomba’. He used 10 plant stems in total, five were subject to light from a 100 W lamp and five subject to light from a 40 W lamp. He counted the bubbles produced for each plant. Determine if there is any significant difference between the samples.

- Set A – 37, 42, 39, 50, 48
- Set B – 26, 29, 31, 23, 30

- Hint Use t-test for unmatched pairs and also quote your ‘null hypothesis’ for the experiment.
- Extend Suggest some possible next steps in the investigation to confirm your findings.

Chi-square test (χ^2)

This statistical test is used to test or support a particular scientific hypothesis or to identify a relationship between two quantities. Chi-squared is used to compare observed data to expected data. It allows you to see if there is any significant difference or whether the difference is due to chance alone.

Link

The full procedure and explanation of how to perform the chi-square test is provided on pages 159–161 of *Unit 3: Science Investigation Skills*, Student Book 1.

Using the tables for confidence levels at 5 per cent and 1 per cent shown in Table 6.8, you can determine the ‘degrees of freedom’ for all columns of data from an investigation.

Table 6.8 Degrees of freedom

		<i>p</i>	
		0.05	0.01
Degrees of freedom	1	3.841	6.635
	2	5.991	9.210
	3	7.815	11.345
	4	9.488	13.277
	5	11.070	15.086
	6	12.592	16.812
	7	14.067	18.475
	8	15.507	20.090
	9	16.919	21.666
	10	18.307	23.209
	11	19.675	24.725
	12	21.026	26.217
	13	22.362	27.688
	14	23.685	29.141
	15	24.996	30.578

II PAUSE POINT

In a conservation woodland analysis, species of four birds native to the UK woodland were observed visiting a carefully constructed feeding station and photographed for identification. Given their similar dietary requirements, sizes and other characteristics, it was expected that there would be approximately equal numbers of each bird type observed. The results over a weekly period were recorded.

chaffinch – 37; house sparrow – 52; great tit – 44; robin – 14

The null hypothesis states that there is no difference between the observed and expected frequency of birds. From the tables, at 3 degrees of freedom ($n - 1$), a confidence level of 5 per cent is 7.82.

Use a chi-square test to determine if the null hypothesis should be accepted or rejected.

Hint

Produce a suitable table for $(O - E)^2/E$ for each bird type. Find a value for χ^2 . Is this value larger or smaller than the critical value for a 5 per cent confidence level? Should you reject or accept the null hypothesis?

Extend

If another survey were carried out in other, similar woodlands, would you expect to find equal numbers of the same types of birds?

Correct units

We come into contact with units in all aspects of life. A supermarket with an offer on potatoes, for example, always provides the units. This is important because there is a considerable difference between selling potatoes at £1.00 per kilogram (kg) and £1.00 per pound (lb).

In all your measurements and calculations for science, you should begin to use the correct and appropriate units associated with the numerical figure as soon as possible.

It is a common mistake to leave units out when performing calculations or making brief notes but this can cause confusion when you are writing your final reports from lab notes and also when work is being assessed.

Using the appropriate sub-unit of measurement is equally important. The distance between cities is obviously measured in kilometres (km), not centimetres (cm), even though they are both units of distance measurement. Table 6.9 lists some units of measurement.

► Table 6.9 Common units of measurement

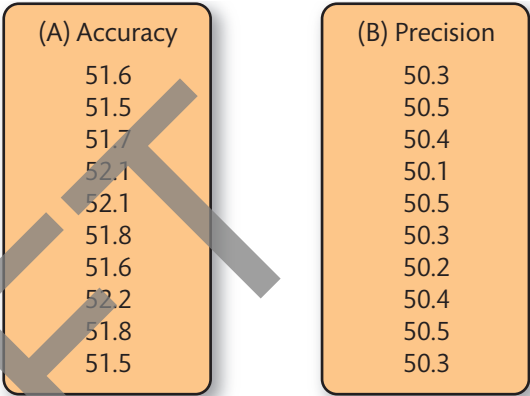
Standard International (SI) base units	Derived units	Commonly used SI derived units	Common prefixes
<ul style="list-style-type: none">• Second (s)• Kilogram (kg)• Metre (m)• Ampere (A)• Mole (mol)• Kelvin (K)• Candela (cd)	<ul style="list-style-type: none">• Force (N)• Acceleration (m/s²)• Volt (V)• Speed (m/s)• Energy (J)• Charge (C)• Pascal (Pa)	<ul style="list-style-type: none">• Volume – litres (dm³), millilitres (ml)• Area – m², cm², mm²• Electrical resistance – Ohms• Density – kg/m³• Frequency – Hz	<ul style="list-style-type: none">• Nano – (10⁻⁹)• Micro – (10⁻⁶)• Milli – (10⁻³)• Kilo – (10³)• Mega – (10⁶)

Assessment of accuracy, reliability and precision

Your investigation findings should now be assessed in terms of the accuracy of results and precision of readings or measurements. A section in your final report will be devoted to your explanation of dealing with accuracy and precision and so the way in which you ensure that both these aspects are in place should be clearly shown in your laboratory note book.

Link

Guidance on understanding the difference between accuracy and precision has been given on page 148 of *Unit 3: Science Investigation Skills* Student Book 1.



► Figure 6.8 Accuracy versus precision of measurements

Figure 6.8 gives a useful recap of the main points using separate measurements of a verified 52.0 g mass on a top pan balance.

The figures shown in (A) have a range from 51.5 g to 52.2 g, a total range of 0.7 g. All 10 readings are very close to the actual value of 52.0 g, whilst the reading furthest from the actual value is 0.7 g. These reading are very accurate as they are close to the true value.

Figures shown in (B) have a much smaller range of values, from 50.1 g to 50.5 g – a total range of 0.4 g. This range of readings is much lower than those in (A) but is much further from the actual measured value of 52.0 g. These readings are precise as they are close together.

The degree to which the measurements can be depended upon is an important factor when you are trying to determine the accuracy and precision of your results. For data to be reliable, there must be a small variation within the values, even though there is always some variation in any set of measurements.

II PAUSE POINT

The two data sets were obtained by two students from different titration experiments. This involved neutralising an unknown concentration of hydrochloric acid (HCl) and a 1.0 mol dm⁻³ concentration of 25.0 cm³ sodium hydroxide (NaOH). The actual concentration of the acid was tested by a technician and known to be 1.1 mol dm⁻³. Which are:

a) most accurate b) most precise?

Data Set 1: Volume of titre (cm³) – 24.7, 25.0, 24.8

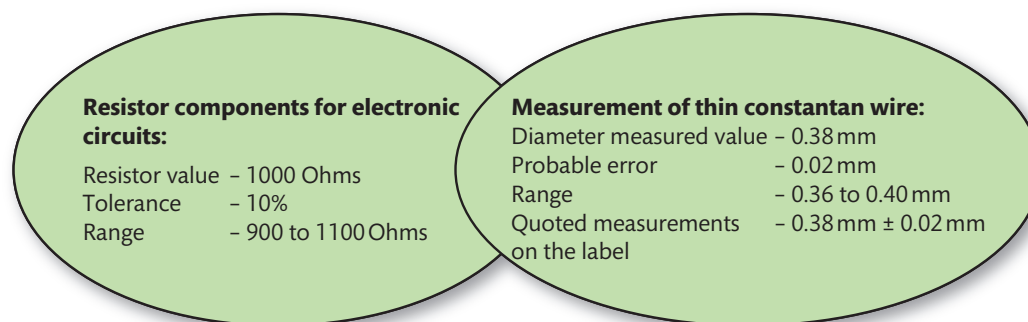
Data Set 2: Volume of titre (cm³) – 23.6, 24.1, 23.8

Hint

Calculate the individual values of concentration, average them and present them to three significant figures.

Extend

Find the average titre value which would provide a concentration of 1.1 to two significant figures.



► **Figure 6.9** Examples of probable error

Validation of method and results

The scientific method is meant to be a logical set of steps that need to be followed carefully so that you can draw conclusions about an area of study. It is a valuable means to ensure that you are able to organise your thoughts and scientific procedures.

The scientific method you have used should have been well designed and well planned. If this is the case, experimental errors or bias can be greatly reduced or eliminated and your overall confidence in the activity and its results can be high. To establish whether the method used is fit for purpose, you must ask yourself, 'Did the method allow me to fully investigate the hypothesis?' and 'Could I have made any improvements?'

If someone else can reproduce your method and results almost exactly at a later date, then your investigation is **repeatable**. If the data is similar after many repeats, then you can be confident that the results are reliable. This is the basis of scientific work. You can then build on your

theories until they are firmly established. To establish whether a science investigation is valid, you need to ask, 'Will someone else be able to repeat my investigation to get the same or similar results?'

Key term

Repeatable – the consistency of a set of results.

When measurements are taken, you need to take into account the possible error value in the reading, particularly when dealing with smaller scales of measurement.

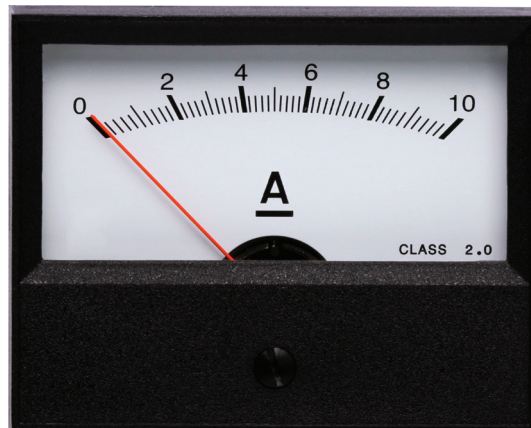
In most cases, the probable error in measurement is quoted so that the value obtained can fall within a range of values and still be acceptable in science (see Figure 6.9).

Sources and magnitudes of errors in readings taken

It is common practice to estimate the probable error using the precision of the scale from which your readings are to be taken. Here are some examples which show the measurements and the probable error.



► Pipette scaled in ml (± 0.5 ml)



► Analogue DC ammeter scaled in 10mA (± 5 mA)



► A typical Celsius/Fahrenheit thermometer scaled in 2 °F (± 1 °F) and 1 °C (± 0.5 °C)

Top-pan balances and other pieces of technical precision instrumentation are thoroughly checked for operational capability in manufacture and subjected to calibration before dispatched to customers. Most will need to be re-calibrated during their lifetime. A top-pan balance that has a 0.1 g error for a considerable length of time will transfer this error to all readings taken with it. This becomes a systematic error and may be difficult to detect. If the operation of a top-pan balance is suspect, the balance needs to be re-calibrated by comparing a set of mass readings against a known standard weight. Adjustments can then be made to the balance.

If doubts are raised during scientific investigation, check the measurements with an identical or similar form of equipment or analyse your measuring technique thoroughly. Remember that repeat readings cannot eliminate systematic errors.

Errors that may occur as a result of reading analogue meters or imprecise scales can be reduced if the following important points are noted.

- ▶ Ensure that you fully understand the principles involved in your investigative project.
- ▶ View glass measuring devices, meters and gauges at 90°.
- ▶ Make repeat readings where appropriate.
- ▶ Accept that digital meters are no more reliable than analogue versions.
- ▶ Check the calibration of equipment where appropriate to avoid systematic errors.
- ▶ If in doubt, check readings with a second meter to avoid further systematic errors.

Data presentation

Expert professional evidence and an array of academic studies have concluded that graphs, tables and numerical displays play a vital part in enhancing the overall quality of the scientific report. It is generally accepted that visual displays of data will provide valuable information to the reader in a much shorter time scale, provided the displays are kept brief, contain the essential information intended and are produced with clarity.

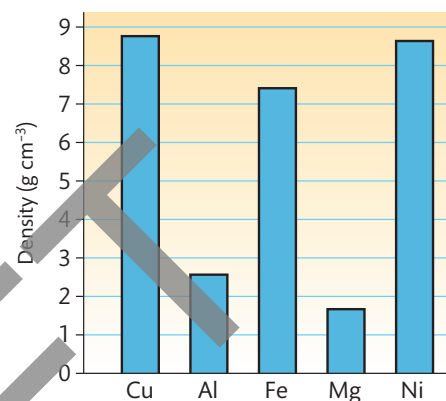
Range of data presentation

Wherever possible, you should use a number of different ways of displaying the data obtained from a scientific investigation to help visualise the information provided and to 'bring out' the relationships or comparisons which are present. Options include:

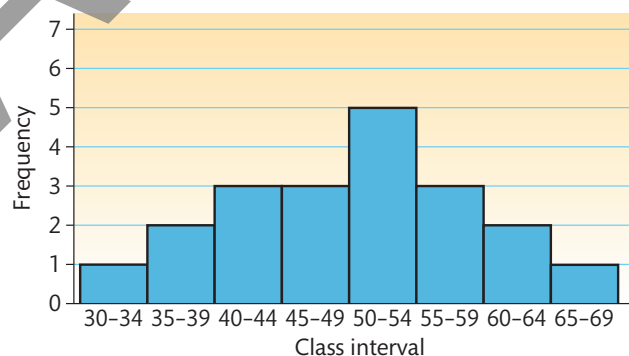
- ▶ graphs
- ▶ tables
- ▶ charts
- ▶ photo/video.
- ▶ sketches

Choosing the correct and most appropriate graph for the data obtained is important both in the context of the ease with which the information can be understood by the reader and also the need to display the relevant information with a sufficient degree of accuracy.

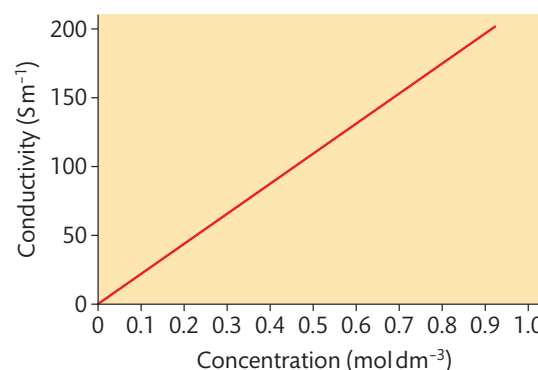
The most common method to display data is using graphs (see Figures 6.10–6.13). The type of graph used is based on the kind of data that is to be displayed, as shown in Table 6.10.



▶ **Figure 6.10** Bar chart showing densities of metals (g/cm³)



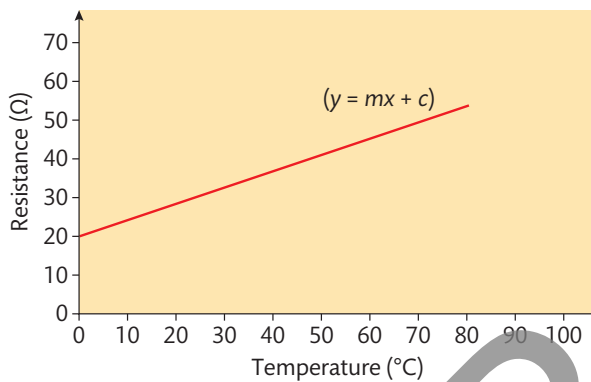
▶ **Figure 6.11** Histogram of bacteria growth in class intervals



▶ **Figure 6.12** Line graph showing conductivity/concentration for HCl

► **Table 6.10** Types of data

Type of data	Description	Examples
Discrete data	<ul style="list-style-type: none">• Also referred to as 'discontinuous'• Labels on axes are for measured values and whole numbers for count or other aspects• Pie chart or bar chart typically used	<ul style="list-style-type: none">• Number of masses added• Number of layers of insulation used
Continuous data	<ul style="list-style-type: none">• Horizontal axis scale from appropriate values• Usually a histogram or line graph• Histogram bars touch to show continuation of values	<ul style="list-style-type: none">• Temperature• Mass• Length• Time• Volume
Categoric data	<ul style="list-style-type: none">• Specific word labels such as 'Animals – Dogs, Cats, Horses . . .' Axes labelled the same as for discrete charts• Bar charts are typically used	<ul style="list-style-type: none">• Names of metals• Names of plants• Names of compounds• Names of animals



► **Figure 6.13** Line graph of $y = mx + c$ showing that the y-axis is intercepted at a point above zero. In this case it indicates that the wire coil has significant resistance at 0 °C.

Theory into practice

Producing appropriate graphs from sets of information and data is an important part of many employment positions in the science industry. Unless you have the ability to present the information in a format that can be easily visualised by others and that makes the data clear to understand, an employer will limit your tasks to more mundane activities.

In your role as a junior member of the technicians' team in a large city college, you have been asked to put together suitable graphs of the following two sets of data which are to be included in a PowerPoint presentation by the Head of Department during an open evening for the college.

The data sets are to illustrate some of the activities and research that are undertaken by the college's Science department:

- a) resistivity testing of conductive wires
- b) levels of CO₂ recorded between 1950 and 2000.

a)

Metal	Resistivity Ωm
Copper (Cu)	1.7×10^{-8}
Constantan	4.9×10^{-7}
Aluminium (Al)	2.8×10^{-8}
Silver (Ag)	1.6×10^{-8}

b)

Year	CO ₂ levels (ppm)
1950	310
1960	325
1970	340
1980	350
1990	365
2000	275

Graphs should be able to stand alone in your report. This means that the information about the investigation, such as the title and other important factors, should be placed with the results on the same document.

Including the following aspects will ensure that the focus of your investigation can be viewed immediately from your graph document.

- **Heading** – the title of the investigation and the variables plotted.
- **Labelled axes** – this should include the correct units and scales of measurement.
- **y axis non-zero indicator** – sometimes, the scale on the y-axis does not start from zero. A 'zigzag' is usually placed between the origin and the first scale point so that the proportions are viewed correctly.
- **Error bars** – these show the maximum variations in measurements on the x-axis, y-axis or both axes on the same graph. The length of the bar represents the error or uncertainty in a measured value.

Data format explained

We are all different in our perception of numerical data and how we identify key points in a set of data. For this reason, it is useful that you provide a variety of displays for presentation of the data and to outline the reason for your chosen presentation.

You may wish to incorporate data into the main body of the text, use the data to produce a graph or chart, or present the data in a suitable table. Your ultimate choice will depend on:

- ▶ the amount of data or numbers that you are attempting to present
- ▶ the complexity of the data (significant figures, for example)
- ▶ the ease with which your data can be visually interpreted
- ▶ whether you can describe the information in a few words in your table/graph titles and labels.

Assessment practice 6.3

C.P4

C.P5

C.M4

CD.D3

A competent technician needs to make the correct choices for instrumentation and apparatus, using them with a high degree of precision and care. In your studies for this qualification, you will probably have many practice attempts at science investigation for many different units. Your skills and knowledge will almost certainly improve.

Browse over some previous practical activities that you have completed:

- 1 Explain the function of the equipment and instruments that you have used.
- 2 Outline your accuracy and precision arrangements.
- 3 Comment on your evaluations for the activities. You should find that you are able to make many improvements on earlier versions.

Plan

- What is the task? What am I being asked to do?
- How confident do I feel in my own abilities to complete this task? Are there any areas I think I may struggle with?

Do

- I know what it is I'm doing and what I want to achieve.
- I can identify when I've gone wrong and adjust my thinking/approach to get myself back on course.

Review

- I can explain the results obtained from the task.
- I can apply the activity to other situations.

D Review the investigative project using correct scientific principles

Your literature review and research have given you a suitable area of study and your planning stage has ensured that all the work undertaken (experimentation, results gathering, observational and data analysis) has been carried out to the best of your ability. Now you must produce a coherent and comprehensive report based on your work.

Your scientific report will encompass all that you have achieved during your investigative project and identify areas where you have particular strengths. It will also identify aspects in the investigation where you may have certain weaknesses. Your report should be well-written, have a logical structure and be appropriately referenced. Results must be evaluated and suitable conclusions drawn. You must consider areas that could be improved if the investigation were to be repeated sometime in the future, and link your findings clearly to the hypothesis.

Scientific report for the vocational investigative project

Correct scientific principles

The following list sets out a standard structure used in scientific investigative reporting. There may be some slight variations in use, dependent on differences in some scientific establishments and the investigation type.

- ▶ **Title:** The name of the investigation.
- ▶ **Abstract:** A summary of the whole investigation, to be completed last and should include the summary of the results as well as what was done to produce them.
- ▶ **Introduction:** The whole purpose of the investigation with some background. The hypothesis should be explained here.

- ▶ **Method:** A step-by-step procedure on how to complete the investigation. It should include the sizes and numbers of the pieces of equipment.
- ▶ **Results:** Identifying comments and tables with figures/observations.
- ▶ **Accuracy:** An in-depth account of how you ensured accuracy in your results.
- ▶ **Discussion:** Detailed comments on your findings, graphs, problems that you encountered, **reliability**, validity.
- ▶ **Conclusions:** General statements of what your investigation was able to show with proposed areas for further study.
- ▶ **References:** A correct list of research sources that directly contributed to your investigation.
- ▶ **Bibliography:** A full list of all research sources that may or may not have been used in your investigation.

Key terms

Reliability – how well a set of experiments, tests or measurements is able to be repeated with similar results.

Bibliography – generally regarded as a list of sources that may or may not have been found useful in providing information for an activity.

Video and photographic evidence will need to be referenced within the report and made easily available.

Terminology

Using the correct words to describe an item or procedure in science is vital to make sure that the whole scientific community is able to understand what you are communicating and so that others will have confidence in the science that you are trying to convey.

Many words used in science are particular to science and will not transfer easily to everyday language, so be careful in their use. Instruments, processes and all items of apparatus in science will have specific words, names or titles which you need to understand and use correctly when in conversation or when completing reports.

Research

Learn and use words for the following:

- glassware
- instruments
- sensors, probes and meters
- scales
- measurements in scientific procedures
- scientific processes
- chemicals
- specific biology/physics/chemistry terms.

Collate your rough notes and experimental diagrams from your laboratory notebook and decide which are most useful to include in your final report. Set out your report in the structure shown above, using the sub-headings shown. It is advisable to begin a new page for each section of the report, although not always necessary. Consider the format of your report from the list below:

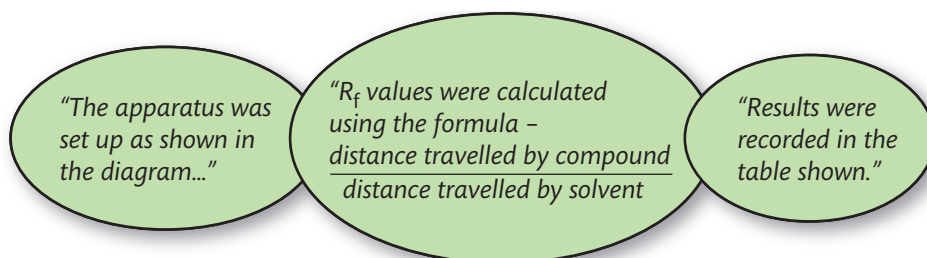
- ▶ handwritten bound report
- ▶ word-processed report on suitable electronic storage device or printed bound report
- ▶ PowerPoint presentation, if accepted by your tutor in support of your main report.

Past tense

Since your report has been fully completed after the work has been done, your sentences need to reflect this. All sentences should be in the past tense, as shown in Figure 6.14.

Third person

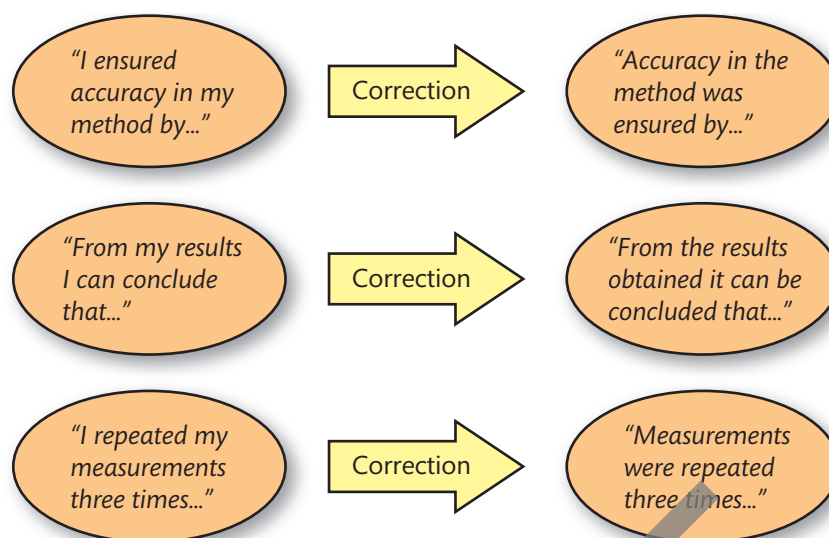
Reports in science are always written in the **third person** so that there is no use of 'I', 'we', 'you', 'our group', etc. If you do not already use this style of writing, it may take some practice before you automatically use it in your scientific reports. Some examples of statements made in first person and their third person corrections are shown in Figure 6.15.



Key term

Third person – a means of writing an account of an activity without referring to anyone who performed the activity.

▶ **Figure 6.14** Examples of the past tense



► **Figure 6.15** Correcting from first person to third person



PAUSE POINT

Convert the following scientific passage to third person.

'Our percentage yield of 73 per cent was not as we had expected from our research and preliminary tests. We can assume that some of the loss of yield was caused by the number of transfers we made during our investigation.'

Hint

Identify all the words that relate to the investigators.

Extend

Rewrite the information in third person, adding changes to the sentences where appropriate and making the passage more fluid and understandable, but not altering the essential meaning.

Remember

To write a good report, you should:

- check your spelling
- check your grammar
- explain abbreviations and acronyms
- use past tense
- use third person.

References and bibliography

When carrying out research which may help you in developing your investigative project, the sources you use must be clearly listed in your completed report to acknowledge that the information is not your own and to provide recognition of the work carried out by the original author(s). The references that you produce can then be located by the reader of your report so that they are able to confirm the details that you have included.

The Harvard referencing system is the most widely used method of identifying the source of information that has contributed to a report. The information taken is cited

from sources, which are usually shown at the end of a report or possibly within the actual text and are called in-text citations.

Examples of both forms of referencing are shown below together with the generalised definition of the bibliography. Both references and bibliography must appear in the **appendix** of your report – the supplementary section at the end.

Key term

Appendix – a list of subsidiary material at the end of a report.

Harvard referencing should be in the following format:

► Publication

A. Fothergill, V. Berlowitz, 2011, Frozen Planet, London, Ebury Publ. BBC Books, Page 205

► Online

J. Clarke, 2007 (modified 2016), [online], Page 1 available at: Paper Chromatography, <http://www.chemguide.co.uk/analysis/chromatography/paper.html>. (accessed 20/09/2016)

A bibliography should:

- ▶ list all sources browsed and/or used
- ▶ be listed alphabetically by author(s)
- ▶ be written in the same format as the 'references'
- ▶ appear after the 'references' section in the report.

An example of in-text referencing is as follows:

Whenever energy is transferred, there is usually some form of unwanted energy. *'We often refer to these unwanted forms as "wasted" energy.'* (Pearson, 2002)

Scientific evaluation of findings

Evaluation of statistical results

You will need to scrutinise your data processing and analysis of results obtained during the practical aspect of your scientific investigation so that you can assess the overall quality and value of the data in relation to the full investigation. This is your evaluation. At this point you will need to identify whether there are any links or correlation between the variables you have tested and so you will need to look closely at what your statistical analysis tells you about the data.

Remember

The null hypothesis can be regarded as the opposite of what you are asking in the investigative project. A *null hypothesis* would state that there is no relationship. By disproving the null hypothesis, you provide support for your hypothesis, i.e. there is a relationship between the variables.

The t-test: this will help you to establish if there is a correlation between the sets of data you have collected. If the means of the two sets of data are statistically the same, then there is no great difference between them. An example of this would be to establish a correlation between gender and height in a non-paired population study. Having calculated the relevant significance level from the sample, if the t-test indicates a value equal to or less than this, we can reject the null hypothesis.

The chi-square test: this will allow you to determine if there is a difference between the values you expect from a quantity and the number you observe. In an example of the general population to determine if there is a correlation between gender and colour blindness, the null hypothesis would state that there is no difference between the occurrence of colour blindness in males and females.

If the chi-square value is less than the critical value, then the null hypothesis can be accepted. If the value of the chi-square test is greater than the critical value, then the null hypothesis can be rejected.

Conclusions drawn

This section is the point at which you can bring your investigative planning, experimental technique and data records together and you must now take your statistical analysis, errors, uncertainty and other data into consideration when drawing your conclusions. Assuming that you have maintained correct and appropriate scientific principles throughout, you will need to review your **primary data** and **secondary data** with a view to developing conclusions and include this into your evaluation of data.

Key terms

Primary data – information that you have collected directly during your investigation.

Secondary data – information collected by someone else that you have used in your investigation.

It is easy to ignore the importance of the final conclusions and evaluation of your investigation after conducting such an extensive, time consuming and practically demanding study. However, this section represents the culmination of your efforts and, if it were reported on in a scientific article, would form the focus of the first statement.

Some focus questions to produce your conclusions and aid in your evaluation are as follows.

▶ Is there a link or relationship between the variables?

No correlation – no obvious pattern between the data.

Weak correlation – points of data are not too close to the line of best fit.

Strong correlation – most points of data are close to line of best fit.

Positive correlation – as the value of x increases, so does the value of y (a positive slope).

Negative correlation – as the value of x increases, the value of y decreases (a negative slope).

▶ Do the results support the hypothesis?

If your method was followed closely and correctly, you may not necessarily have results that support the hypothesis.

▶ Have you identified errors in your investigation?

Identify anomalous readings and errors and make a valid comment on how you have dealt with them.

► **Were there any experimental problems?**

Make valid comments on the difficulties of measurement or suitability of the equipment if you feel they were significant.

► **Can you outline improvements?**

Perfect investigations do not exist. There will always be something that can be improved. Make a comment which tries to link your work to the context.

Limitations of investigation

This section of your report should be your chance to identify the strengths and weaknesses in your investigative project. In science activities, the need to measure particular objects or events with great precision and/or accuracy can sometimes be impossible with the type and the limits of the equipment available.

In measuring bacterial colonies under a high power microscope, for example, we can only measure the two-dimensional area of the bacteria, even though the volume of the bacteria may be necessary for us to report on. In this example, the microscope itself introduces certain limitations in the investigation.

Investigation limitations are generally identifiable in three areas:

- investigation design
- instrument limits
- practical considerations not identified.

To deal with investigation limitations, you should:

- Identify the limitations: Ask whether your findings show quality in your work and whether you were able to answer your hypothesis. If 'yes' then your limitations (practical skills, instruments, measurements etc) may not be too important. Try to reduce this point to those areas that you feel would have had the most impact on your work.
- Explain the nature of the limitations: In your sampling method, for example, you can explain the limitations in numerical terms. Were there enough samples? Did you repeat the investigation enough times? Was there other, more suitable apparatus available? Were there alternative samples in a qualitative study? Can you justify your choices?
- Suggest how to reduce limitations: This section is a chance to describe what can be done to overcome the limitations that you have identified. As a result, this work will be preparation for your decisions on recommendations for further research.

Assessment and relevance of information sources

The literature review that you completed for learning aim A has been used to help you develop an understanding and a working plan for the subject area for which you have recently completed an investigative project. At this point in your final report, you must now look back at the information gathered from your list of references and decide whether the information taken was valuable for the purpose of the investigation.

- Were your sources reliable and do they reflect current knowledge?
- Was your information taken from a reputable publication such as a scientific journal or independent source?
- Is there a clear indication that your information was written by informed experts in the field?
- Were any of your other sources, such as newspaper or non-technical magazines, also useful?

Your report will now contain a substantial word count and a lot of relevant information that will form the culmination of your accrued knowledge and experience.

Reflect

Read your report thoroughly and identify, in bullet points, all those areas in your work that can also be identified in your research notes from the literature review.

Are the number or points quite extensive and do you have confidence in the information provided from your initial literature review? Identify all sources that provided relevance to your investigation findings.

Evaluation of proof of hypothesis

As a scientist, you should not discuss your hypothesis in terms of being 'right' or 'wrong', but look at whether or not your data and evidence support your hypothesis. A single investigation is never usually enough to provide a categorical answer. You should not rely on this, because the data may be misleading unless other independent investigations are carried out and are in agreement with your initial findings.

If the evidence you have collected does not support your hypothesis, make this clear in your report and look closely at your experimental data to ensure that you have reached the correct decision. Remember that in science your evaluation of the hypothesis will be judged by the quality of the overall investigation and not simply the final decisions that you have made.

'Form a hypothesis and try to prove it wrong, not right! Then perhaps formulate a new hypothesis based on your results.'

In summary, ask yourself what the 'strengths are in your hypothesis?'

- ▶ Does it encompass exactly what you set out to test?
- ▶ Does it fit with the assignment brief?
- ▶ Can the hypothesis be interpreted in a different way by someone else?
- ▶ Does it match with your initial assumption of the experimental outcomes?
- ▶ Was your hypothesis suitable or does the evidence suggest that another hypothesis could have been used?

Remember to include in your abstract:

- ▶ your hypothesis statement
- ▶ whether the evidence supports it
- ▶ how significant your findings are to the hypothesis.

Recommendations for further research

Finally, consider what you would do to improve or change aspects of your investigative project if you were able to repeat it. You should not necessarily aim this section of your report at yourself, but could address the points to other learners who may be able to continue your work. Set your ideas out into a clear list of formal recommendations that are firmly supported by your study. Remember that further research in this context does not mean 'more of the same' but rather alternative areas that could be explored that are linked to the investigative project which you have carried out.

Assessment practice 6.4

D.P6

D.M5

CD.D3

At this stage of the process, your full investigative project is now coming to an end. This is now the opportunity to compile all your work into a clearly organised set of headings to provide a means from which your work can be assessed.

Use this as a checklist for the final completion of your report. Make sure that all points are included:

- correct structure and format
- correct terminology
- written in third person, past tense
- correct referencing and bibliography
- evaluation of statistical analysis
- conclusions
- assessment of information sources
- evaluation of your hypothesis
- recommendations for further research.

Plan

- What is the task? What am I being asked to do?
- How confident do I feel in my own abilities to complete this task? Are there any areas I think I may struggle with?

Do

- I know what it is I'm doing and what I want to achieve.
- I can identify when I've gone wrong and adjust my thinking/approach to get myself back on course.

Review

- I can explain the results obtained from the task.
- I can apply the activity to other situations.

Skill development within project work

Your final report is now complete and it's time to ask yourself *'What have I learned and what skills have I used and developed over the course of completing my project?'*

For many, the identification of their personal skills does not come readily. It is more usual that the answers are provided by an individual following direct questioning from another person, such as your tutor at school or college or supervisor in a working context. Becoming confident with critical self-appraisal and questioning of

abilities is an important part of the development of all of us, because in order to develop our abilities further and to make progress in any forthcoming endeavours we need to be realistic in our acceptance of personal abilities and understand our limitations. In short – know your strengths and weaknesses!

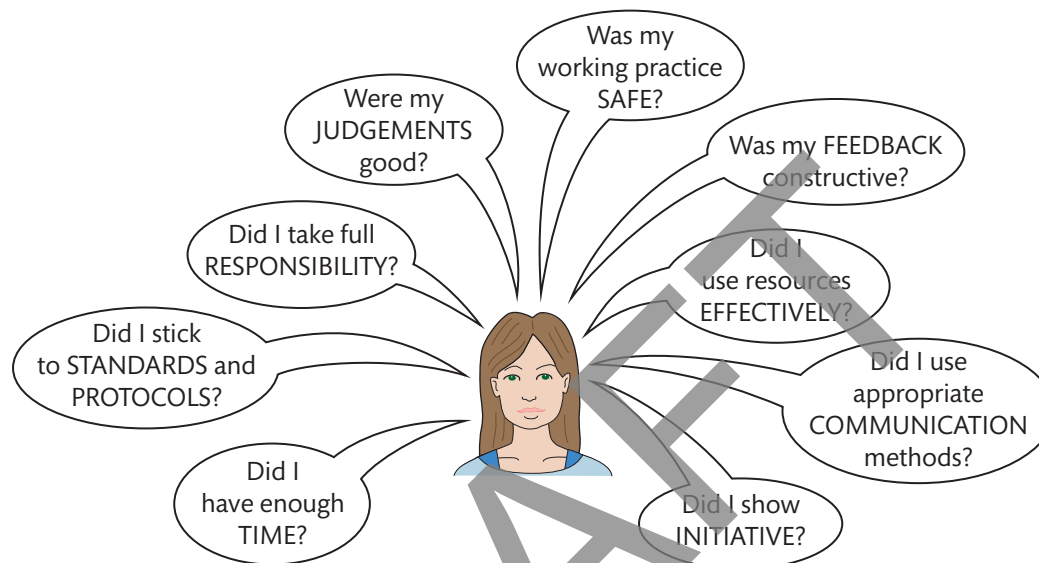
Time management and organisation

Think back over the course of your investigative project to the very start of your literature review. Estimate how much time you have spent on the project in total, covering both formal and informal input into the activity. Was it more or less than you had anticipated?

For each of the stages outlined below, identify if it took a longer or shorter time than expected and note any aspects during each stage which could have accounted for the difference (e.g. you needed to change your hypothesis following consultation with your tutor or working partner):

- ▶ literature review
- ▶ investigative project proposal
- ▶ schedule

- ▶ plan
- ▶ health and safety and ethical considerations
- ▶ experimental procedures and techniques
- ▶ collect, collate and analyse data
- ▶ data presentation
- ▶ scientific report for the vocational investigative project
- ▶ scientific evaluation of findings.



▶ **Figure 6.16** What skills have you learnt and what skills have you used over the course of your project?

Discussion

How much time difference have you been able to account for? Which stages were the most difficult to determine in terms of the length of time needed? Where could you have saved time and where was time wasted?

Adhering to and following appropriate standards and protocols

At this stage in the completion of this unit, you should have a very good idea about the standards in scientific investigation and the need to adhere to the general procedural method so that you were able to complete your investigative project successfully and, hopefully, without incident.

Irrespective of the subject of your investigation, the protocols followed would have been developed over a very long period of time and have been fine-tuned by generations of scientists to ensure that all eventualities have been taken into account. This scientific practice takes time to develop. We are not born with the natural ability to foresee everything!

The following questions provide some guidance for you to consider in order to complete your self-appraisal

concerned with adherence to science standards and protocols during your investigative project work:

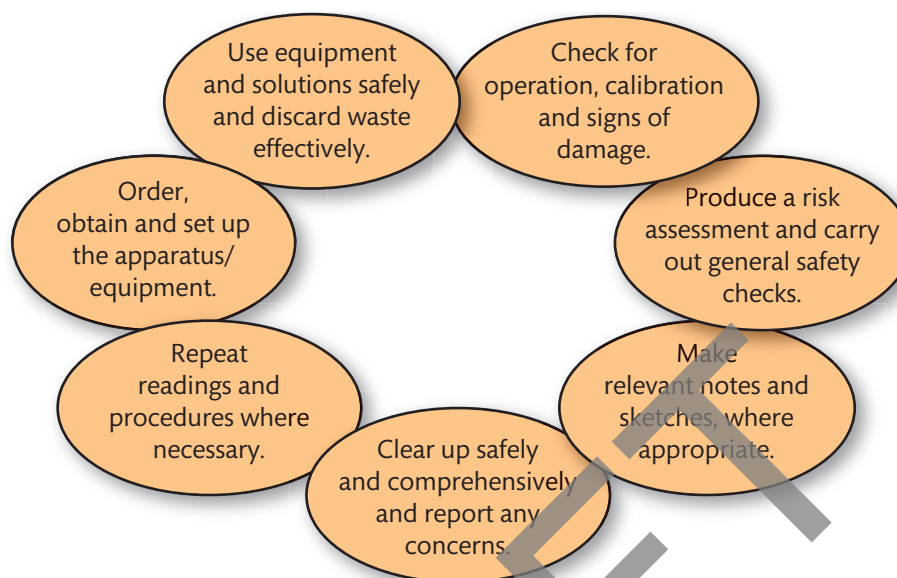
- ▶ Was my equipment choice appropriate?
- ▶ Was my equipment handling good at all times?
- ▶ Did I consult relevant documentation, such as procedures and Health and Safety, during the procedure?
- ▶ Did I follow my plan closely or adapt correctly when necessary?
- ▶ Was my attitude mature and professional at all times?
- ▶ Did I encounter problems and deal with them appropriately using contingency planning?
- ▶ Was my laboratory notebook used correctly?

Taking responsibility for completing tasks/procedures

Whether working individually, in pairs or even within a group, all of us must take responsibility for the individual tasks that we are performing. This does not simply imply that we are to carry out the activity, make a few notes and 'wash our hands'.

Committing to a science investigation is an important undertaking and must always be given the utmost consideration and attention during the planning and

experimental stages. It does not matter what your particular responsibilities were in the overall activity, what matters is the manner in which you completed it.



► **Figure 6.17** Questions to ask of yourself

If you have worked alone on the investigative project, then you alone must bear the full responsibility of the tasks that you performed. Ask yourself 'Did I...?':

Making judgements within defined parameters

Working in the discipline of science involves a greater degree of personal responsibility than in other subject disciplines which do not involve the need to be extra vigilant with equipment. You will generally be expected to undertake work with a higher level of complexity, linking physical and chemical apparatus and equipment to the subject information to determine a satisfactory outcome under strict scientific conditions.

Working independently or within small groups means that you make more decisions when carrying out your work. The judgements you make will have important influences on the eventual outcome of your investigation. You must be clear about the scope of your investigation at the start so that you can work within the measurable limits (defined parameters) of what you were finding out.

It is important that you were able to identify what the defined parameters were, how they were to be measured and what, or how, you needed to observe in order to measure them.

For the purpose of assessing your skills development, it is useful to list these parameters, record the judgements you made and comment on your performance. Are there any judgements or decisions you made with a low level of confidence? Are there any you made with a high level of confidence?

Application of safe working practice

With the very best of intentions and the most careful planning considerations, it is still true to say that not all safe working practices are followed ALL of the time.

The breadth and detail of safe working practices you have applied will depend on the type of investigation you have completed. With hindsight, you should now be in a very good position to appraise critically your safe working practice based on your pre-investigative planning. Correct and honest identification of those safe practices you fully observed and those which you 'let slip' from time to time, will help you to establish a firm knowledge base for future investigative work and may well protect you from a possible dangerous incident.

Your completion of a risk assessment, identification of hazards, use of suitable PPE and adherence to COSHH regulations may have fulfilled the requirements set down in health and safety legislation, but your thoughtful consideration of safe working practices which you did not perform consistently can determine whether you have seriously learned from this activity.



PAUSE POINT

Look back over your health and safety considerations in your project plan. Identify those which you adhered to and those which you did not.

Hint

Were there times when you removed your goggles and delayed putting them back on? Did you carry out some practical work alone for any given time? Did you carry delicate glassware appropriately?

Extend

How could you ensure that all those working in a laboratory environment adhered strictly to high standards of safe working practice? Would you change or add to 'Notices'? Could you introduce sanctions, perhaps?

Give and receive constructive feedback

The manner in which we are able to provide feedback to others and to receive it ourselves will eventually determine the extent of our own future improvement and the degree of personal development in both practices and understanding. Remember, 'feedback' is not simply advice. It is information given freely in an attempt to identify what went well and what went not so well, so that improvements can be made.

When offered correctly, and from an objective point of view, the feedback can be very constructive, leading to

sound improvements in practices and understanding. It is this form of feedback which is supplied by the trained professionals in your school or college and should be accepted positively. In a similar manner, feedback which you provide to your investigation partner should also be objective and developmental, explaining the reasons behind your comments and giving guidance to the way forward in an activity. When you provide feedback to your tutor or technician about your investigation, you should also adhere to objective statements in a manner befitting the professional environment you are working in.

Case study

Tamelia is a second year sixth form student in a very successful urban college of further education. She has been performing many science investigations in her time at the college and has produced some outstanding reports based on biological, chemical and physical scientific investigations. Her most recent investigation involved a study into the effects of pollution from acid rain on the germination of cress seeds for which she needed to produce standard solutions and titrations to determine the concentrations used.

During and following her practical activity, she was given feedback from a supply tutor about her investigative procedure: "How on earth did you break that beaker!? You haven't used enough seeds in each dish and your acid concentrations weren't accurate. Don't ever scoop the broken glass into the paper bin and why weren't you wearing goggles at all times? Where's your risk assessment? Shanice was supposed to be with you but you did it all - why? Your notes are very poor. Hasn't Mr. Evans shown you how to carry out science practicals before? I want it done again, only right, this time!"

Check your understanding

- 1 Re-write the feedback comments to reflect a more professional tone.
- 2 Tamelia was at fault in some aspects of the investigation. Identify them.

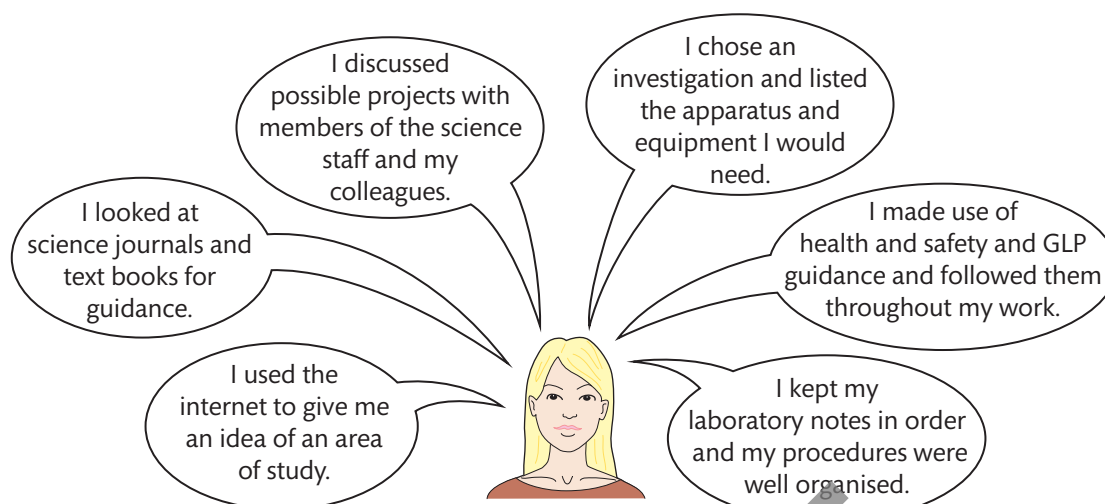
Identify, organise and use resources effectively to complete tasks

So, what were the resources at your disposal and did you use them in a suitable manner to complete the investigation? (See Figure 6.18.)

Utilising channels of communication

By what means do we communicate in science, before, during and after completion of an investigative project?

Consider the effectiveness of your overall communication to others in your work. How well did you explain what was needed and how well was your communication received? Identify areas where there may have been misinterpretation with colleagues or staff and times when communication was simply lacking between you and those around you. What would you have communicated differently? Did you use all available communication channels (see Figure 6.19)? How could your procedural communication be improved? Did you need to re-phrase anything to anyone?



► **Figure 6.18** What resources did you use?

Communication channels

Verbal (questions, equipment orders etc)
Written in pen (lab. notes, equipment orders etc)
Word processed/e-mail/texting (project plan, equipment orders, guidance from staff etc.)
Physical gesturing (simple thumbs-up when level of solution has been reached, perhaps)

► **Figure 6.19** What communication channels did you use?

Being resourceful and using initiative

Being resourceful is an attribute which some people have naturally and others may acquire over a long period of time, given the guidance and tuition. It is the difference between completing a project to a satisfactory standard and completing one to a high standard, using an abundance of materials, resources and innovative ways to incorporate them into your work.

When working on a task, whether individually or within a group, it is usually apparent who has the greatest level of resourcefulness and the initiative to put their plans into action.

Review your entire investigative project and ask yourself the following questions. It will help you to learn about the general failings in the way that you performed the work, but also help to provide valuable information about **YOU** and the way in which you will be able to improve your performance for the tasks awaiting you in future years.

- Did I realise immediately who the expert in the subject was and use their abilities from the start? (This is

important in providing you with the fundamentals of the investigation and also objective and additional information which may steer you in a slightly different direction.)

- Were there other ways I could have achieved the result and did I pursue them? (This may depend largely on the extent and depth of your initial literature research which can be underestimated in its importance to providing comprehensive information on the subject material.)
- Was I content with confirming what the outcome was going to be or did I try to find something different? (Most scientific investigations in school or college are based on tried and tested methods and so will usually produce the established results – but there may be some which produce results that do not always conform.)
- If you worked in a group or partnership, did you adopt a culture of listening and encouraging all possible thoughts and initiatives? (Many ideas we share or keep to ourselves may not be particularly useful or correct, but sometimes even the most unusual ideas can be beneficial to a given problem and should always be considered.)

Remember

When something is important to us, we are all capable of achieving a solution to our problem.
 Resourcefulness is a product of necessity and our creativity and persistence.

Further reading and resources**Websites**

www.sop-standard-operating-procedure.com website which provides information on standard operating procedures in a laboratory

www.rsc.org/learn-chemistry resources to assist tutors and learners in chemistry related topics

www.hse.gov.uk website of the regulation authority for health and safety

www.npl.co.uk National Physics Laboratory website for ionising radiation and ultrasound

www.physicsclassroom.com a virtual physics classroom with a variety of resources at different levels

DRAFT

THINK ▶ FUTURE



Richard Young Science technician

I work in the science section of a very busy urban college on the outskirts of one of the largest cities in England and have been working as a science technician for about 7 years. I am currently studying for my Higher National Diploma whilst working in the college on a full-time basis.

My role involves dealing with the needs of all laboratories in the science department, but I specialise in the chemistry section. The daily routine can be very changeable because of having to respond quickly to the demands of the individual science disciplines. Much of my time is taken up with the Biology and Chemistry sections of the department, but there are also opportunities to cross over to the purpose-built wing that houses the specialist Physics equipment. As an experienced science technician, I am now called upon to produce annual notes for the department. These are added to the departmental report sent to the Head of Centre.

A typical day in the science department begins with a general check on the maintenance of the laboratory equipment, particularly if it was used late in the previous day. Some maintenance forms part of the daily and weekly specific routines: equipment calibrations, glassware, electrical checks and checking of biological equipment such as microscopes. It is my responsibility to ensure that all junior technical staff are

supervised and are able to perform their duties in the science sections to which they are allocated. I also provide induction and continued training for technical staff as required by the senior departmental manager. Much of my time, however, is spent tending to the needs of the science lecturers and making sure that they have all the equipment and apparatus necessary to perform the investigations and demonstrations required for teaching and student project purposes. I find that I am regularly called upon to test a new method of performing a particular experiment or an alternative experiment sometimes devised by the lecturers themselves. This is one of the more interesting aspects to my role, since it also tests my understanding of the subject material and demands more engagement on my part. My work is overseen by the Head of Department and Senior Manager, who check on my continued professional progress and understanding of procedures.

At present, I am increasing my qualification status by studying software applications in technical sciences at the college part-time in the evenings and hope to enrol onto a full degree programme if this is successful. I am also developing my skills with people, communicating more effectively in writing and face to face conversations.

Focusing on Skills

Think carefully about the role of a science technician in your school or college.

- 1 What scientific knowledge will you need and what additional skills are required to perform your tasks successfully? Can you identify what skills you currently have?
- 2 What sort of tasks will you be carrying out on a daily basis and which ones will be carried out less often?
- 3 Who will you be working with and how will you support them in their roles?
- 4 What can you do to improve your knowledge and skills in the science laboratory? Are there likely to be good opportunities for further education or experiences?

Getting ready for assessment

Corey is working towards his BTEC National Diploma in Applied Science. His first assignment was based on producing a literature review that would be used to develop his investigative project proposal. The title of the assignment was 'What am I interested in?' The assignment expects learners to research areas of science with a view to finding a topic of interest that can be investigated independently. A full range of resources is to be used and recorded in the appropriate referencing manner. Once the topic for investigation has been decided, Corey will be expected to write a rationale for his area of study in a report that will be added to during his investigative project proposal. The report must include the following: identification of sources of information used, what type of study is proposed, e.g. field work, laboratory work etc., why he chose the area of study and the background to the topic, a hypothesis based on his research and a set of aims or objectives.

Corey shares his experience below.

How I got started

First I made sure that my laboratory notebook was available and that I had a clear understanding of what I needed to do. I discussed the type of research with my tutor and science technician so that I had sound advice and began a general search on the internet and in reference books on areas of science which I find interesting. I had already decided that I would like to use my centre's new sports facilities, so that the limitations of my project were reduced, and was then able to focus my investigative project into physiological aspects of testing. This was important because I then had a clear direction and was able to research the subject in greater depth. Having taken relevant notes from the research sites and listing them as possible reference sources, I began to fill in a table to list them.

How I brought it all together

Writing the rationale for my proposal was quite straight forward since I had a particular interest in sport and keeping fit. I began to find further background information on my proposed topic so that I could focus my investigation into an area that could be tested. At this point, I needed to identify exactly what I would be testing and if it was measureable. My tutor reminded me that, if other learners were used to provide the data for my project, then I would need their permission. I came up with three possibilities for my proposal.

After considerable thought and further research, I decided upon the effect of exercise on a person's reaction times because of the data that would be generated. Producing a hypothesis such as 'exercise increases a person's reaction times' gave me a clear direction for my study and resulted in a simple null hypothesis: 'there is no difference in a person's reaction times observed after exercise'.

My aims and objectives followed from my proposal and I needed to identify the issues regarding use of people in

the sample, the length of time that would be needed for the testing and the availability of the physical equipment especially since the fitness room is a very popular area for most learners and staff.

What I learned from the experience

I became very involved with the project proposal and the information that I was beginning to find from research sources. I was surprised to discover that I had a very keen interest in the science behind the subject area. I was nervous when asking a group of other learners to take part because I was a little unsure as to what I needed to tell them. My tutor provided additional and important guidance on this.

Finding relevant information was easy and there were many similar web pages that gave information on my project proposal with some providing an actual method. I learned how to use the Harvard referencing system, although this needed a lot of practice at first. The background information available was staggering. Much of it was a little beyond my understanding, but I was able to narrow down the information to the basics I needed to help me focus on the direction of the project. By proposing to use the centre's fitness equipment, I was able to decide which pieces of equipment my 'subjects' would be using and also book these in well in advance.

Think about it

- ▶ Have you decided how many sources of information you intend to use and where they are from?
- ▶ What age of sources are you going to use and which type are you going to exclude?
- ▶ What is the nature of your study?
- ▶ Have you clearly referenced sources from a wide variety?
- ▶ Can you demonstrate a good understanding of your project proposal and the subject involved?

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