Unit 3: Scientific Investigation

Unit code: K/502/5543
QCF Level 3: BTEC National
Credit value: 10
Guided learning hours: 60

Aim and purpose

The aim of this unit is to enable learners to explore the protocols associated with scientific investigations. The unit is based around working as a research scientist, setting up an idea, testing it and then reporting the findings.

Unit introduction

In many research and development, analytical and pilot scale laboratories technicians are employed to safely carry out new practical investigations following prescribed laboratory procedures and repeating them to ensure consistent results are obtained.

This science practical investigation unit is designed to allow learners to develop and demonstrate their science knowledge, practical and project management skills. The investigation should be carried out in stages where learners should discuss with their tutor how they will plan, carry out and analyse the results of their experiment and present it as a scientific report. Learners may be asked to carry out a practical investigation that has been designed by somebody else or to suggest their own design.

The topic chosen for the scientific investigation will depend on the course pathway the learner is following and the resources and equipment available. This unit places an emphasis on Health and Safety issues and on the learner's ability to plan, implement their ideas, collect and use data and draw conclusions from the results of the investigation. One investigation should be used to cover all the outcomes, although the experiment may be repeated on several occasions to ensure that the results are correct and accurate.

It is not intended that learners should use skills, techniques and information gained from other units. This unit may be linked with many other units in the programme but it is intended that the investigation used is *chosen specifically for this unit.*

Learning outcomes

On completion of this unit a learner should:

1 Be able to plan an investigation relevant to the area of study

2 Be able to undertake the planned investigation, using appropriate scientific principles

3 Be able to collect, collate and analyse the results from the investigation

4 Be able to draw conclusions from the investigation.

Unit content

1 Be able to plan an investigation relevant to the area of study

Nature of the investigation: statement about experimental research, eg laboratory, fieldwork, sports facility

Information resources: identification, location and extraction of relevant information sources; use of recognised protocol for recording the sources, eg Harvard system; assessment of reliability and validity of information researched

Principles of design of investigations: details of experimental design and controls; formulation of hypothesis; statement of proposed analytical techniques to be used; assessment of possible errors in practical work.

Health and safety: risk assessment; elimination/minimisation of identified risks; availability of physical resources

Project plan: hypothesis; objectives; milestones; resources

2 Be able to undertake the planned investigation, using appropriate scientific principles

Experimental techniques: assembly of relevant equipment and materials; adherence to Health and Safety requirements during the practical investigation; manipulative skills; appropriate use of instruments and techniques for taking measurements; observational skills; recording results, accuracy, integrity, precision; maintenance of working laboratory logbooks and record keeping; Good Laboratory Practice (GLP), Good Manufacturing Practice (GMP), Good Clinical Practice (GCP), relevant legislation

3 Be able to collect, collate and analyse the results from the investigation

Practical data: organisation of data, eg class intervals, tallying; methods of data processing and analysis, eg mean, standard deviation, learner's t-test; correct units of experimental quantities used; assessment of experimental accuracy and precision

Validation of method and results: fitness for purpose of methods used; repeatability; sources and magnitudes of errors in reading taken

Assessment of information sources used: relevance to investigation; use of relevant, researched information to support/not support experimental work

4 Be able to draw conclusions from the investigation

Scientific report of the experiment: correct scientific protocol used for report, eg structure and format, use of correct scientific terminology including use of third person, past tense; references and bibliography correctly written and included in appendix

Data presentation: range of appropriate data presentation used; choice of data presentation explained; correct presentation of chosen data format explained

Scientific evaluation of findings: evaluation of results; conclusions drawn using scientific principles; experimental and literature investigations; evaluation of proof or otherwise of the hypothesis stated

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 state the objectives and hypothesis relating to the investigation	**M1** analyse the research information and discuss its relevance to the planned experiment	**D1** evaluate the different approaches considered for the investigation, justifying the hypothesis chosen
P2 produce a list of relevant research resources using a recognised protocol for recording them		
P3 produce a realistic working plan for the experiment including health and safety assessments [IE 1-6; CT 1-6; RL 2,3,6; SM 2-4]		
P4 demonstrate the required manipulative skills to assemble relevant equipment and materials	**M2** justify the choice of experimental techniques (and their modification if any) as a means of increasing accuracy, reliability and validity	**D2** evaluate the effectiveness of the investigative procedures, suggesting how these could be improved
P5 safely carry out the planned investigation [IE 1-6; CT 1-6; RL 2,3,6; SM 2-4]	**M3** justify the statistical techniques used by relating them to the validity of their findings	
P6 demonstrate the ability to accurately record the results obtained, using scientific protocols		
P7 analyse the results obtained using appropriate statistical techniques [IE 1-6; CT 1-6; RL 2,3,6; SM 2-4]		
P8 explain the conclusions gained from the investigation	**M4** justify the conclusions made, drawing on primary and secondary research data.	**D3** using scientific protocols evaluate the outcomes of your investigation.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P9 present the conclusions in a format that uses accepted scientific protocol and language. [IE 1-6; CT 1-6; RL 2,3,6; SM 2-4]		

PLTS: This summary references where applicable, in the square brackets, the elements of the personal, learning and thinking skills applicable in the pass criteria. It identifies opportunities for learners to demonstrate effective application of the referenced elements of the skills.

Key	IE – independent enquirers	RL – reflective learners	SM – self-managers
	CT – creative thinkers	TW – team workers	EP – effective participators

Essential guidance for tutors

Delivery

Formal input will be needed at the start of this unit so that learners are quite clear about the scientific protocols associated with a science investigation. The investigation carried out by the learner is not expected to be original but it should be new to the learner concerned. The opportunity is provided in this extended science project for learners to show their ability to do meaningful investigative work using standard operating procedures expected of technicians in the workplace. Individual or group work is permissible as is the pooling of results, but each learner must be able to prove that all the outcomes and grading criteria are covered by their own work.

Health and safety issues relating to this work must be emphasised and safe working practices adhered to. Risk assessments, the use of COSSH and other regulations must be followed and the learners should be supervised by qualified members of staff in the laboratory.

The use of laboratory logbooks and careful record keeping should be emphasised along with following the codes for good laboratory/manufacturing/clinical practice (GLP, GMP, GCP). This links to the requirements of industry and the Sector Skills Council (SSC).

Learning outcome 1 covers the ability to plan an investigation. Formal input will probably be needed initially and then tutorial support as learners research their area of interest, set up a hypothesis and plan the practical work to test it. Tutorial guidance is essential as learners will be limited in their choice of topic by the facilities and equipment available. At this stage learners will need to discuss what analytical methods they will use for learning outcome 3. This is necessary as very small sets of results often cannot be statistically analysed and learners must be aware of this. The choice of topic for investigation should be vocationally relevant and chosen specifically for this unit.

Learning outcome 2 has laboratory work as its major component. The assessor must observe each learner assembling the equipment needed and safely carrying out the practical work. The assessor should make it clear to the learner what skills they will be assessed on eg manipulation, observation, dexterity, use of correct equipment etc. The recording of their data in a working laboratory logbook with accuracy and integrity should also be observed.

Learning outcome 3 requires learners to organise their data using conventional methods and then apply statistical techniques. Formal input will be needed in helping them choose and use the statistical techniques that are dealt with in the numeracy unit. Learners should be validating their methods and results and making reference to their research to support or otherwise their findings. Negative results are as valid as positive ones if the learner can explain what has happened and why. Tutor support will be needed throughout this outcome especially in choosing and applying the analytical techniques.

Learning outcome 4 requires a written report which follows standard scientific protocol for reporting investigations. The end result should be in a form which any science supervisor would accept as an account of a laboratory investigation. Learners need to use references within their text and compile a reference list and bibliography using accepted methods. This report will be expected to include text, graphical data, data collection charts and evidence of statistical techniques. A conclusion should be given and a statement saying clearly whether the hypothesis has been proved or not and why.

Outline learning plan

The outline learning plan has been included in this unit as guidance and can be used in conjunction with the programme of suggested assignments.

The outline learning plan demonstrates one way in planning the delivery and assessment of this unit.

Topic and suggested assignments/activities and/assessment
Introduction to unit and programme of learning. Input from tutor using DVDs etc to show how science laboratories work. Learners use internet to research on laboratory work, how experiments are conducted, consideration of GLP. Discussion with tutor about findings.
Visit to industrial/medical laboratory. Follow-up discussion about laboratory protocols, safe working.
Discussion on how to carry out a scientific investigation (assignment) including possible topics, methods, how to propose a hypothesis. Learners begin to choose topics and research them. Tutorial with learners to discuss their work so far. **Stage 1: Choosing a Topic (P2, M1)**
Individual tutorials on topics chosen and research done so far. Learners begin to set up a hypothesis and outline plan of investigation, consulting with tutor and technician re equipment, laboratory space etc depending on type of experiment chosen. (If field work or work placement is being used, amend accordingly.)
Stage 2: Hypothesising and Planning (P1, P3, D1) Learners finalise hypothesis in discussions with tutor in individual tutorials. Learners finish planning practical work in detail. Learners consult with tutor/technician if necessary, obtain final approval to go ahead with the work proposed. **Stage 3: Trial Run and Planning Result Collection and Analysis (M2, D2)** – preliminary experiment
Learners discuss trial run of work with supervisor and agree adjustments if needed. They plan what results will need to be collected and statistical techniques to use – discuss with supervisor.
Learners carry out practical work under supervision, and record results in laboratory book. **Stage 4: Practical Work (P4, P5)** Learners discuss the outcomes with tutor.
Further practical work, possibly repeating experiment. Learners record results in laboratory book.
Stage 5: Collecting, Recording and Analysing data (P6, P7, M3) Learners complete laboratory work, assemble results, begin analysis.
Learners continue analysis of results and compare with research results found earlier.
Stage 6: Conclusions (P8, P9 M4, D3) Learners write up results, conclusions – consult with tutor.
Learners finish writing up experiment in protocol accepted by the scientific community.
Learners hand in written work.
Review of unit and results of investigations.

Assessment

All the pass grade criteria must be met in order for a learners to achieve this unit..

The learner must present a realistic working plan for the experiment with enough detail for the assessor to follow the practical work planned. A risk assessment should be carried out to comply with existing health and safety rules in the laboratory.

For P2, learners are expected to give a comprehensive bibliography and list of references using a standard protocol such as the Harvard system. At this level learners should realise that the bibliography is recommended reading and the references are sources they have referred to in the text or from which they have taken information. Assessors should look for material taken from another source to be acknowledged as such. Assessors should also look for more than one source being used to confirm a statement being made by the learner. For M1 the assessor will look for evidence of the research material being analysed. Learners need to show they can use the research material to help them plan their work and indicate its relevance to what practical work they have in mind. It is expected that this analysis will influence their hypothesis and the experimental plan.

To achieve P1 the learner must present objectives which will explain the purpose of the work. A clear hypothesis must also be given which is relevant to the practical work planned. The hypothesis(es) must be stated in a way that makes them testable by the practical work. For P3, the realistic working plan should be such that the tutor/assessor could follow the information and carry out the experiment without reference to the learner. The assessor must assure themselves that correct health and safety risk assessments have been carried out. For D1, learners need to show they have considered in detail more than one approach and the problems raised. Having settled on their plan they should justify their choice and the hypothesis they are going to test.

The next two criteria can be observed during the trial run. For M2, justification for the experimental techniques used could be elicited by questioning but there must be evidence for this so it can be verified internally and externally. Similarly, learners may refine their experimental technique but it must be recorded in some way so it can be assessed and verified. For D2, the observation is carried out by the assessor although the learner may have modified their practical procedure whilst not being observed. Either way the alterations need to be documented so verification is possible. The review of the experimental procedure and its progress may end in a decision to start again, modify something, repeat the whole procedure or even carry on as originally intended. Whatever, learners must record their review procedures and explain and justify their decisions.

Learners are expected to demonstrate accuracy in their observational skills, eg reading liquid levels by showing awareness of the meniscus, positioning themselves correctly to read the level in a burette/measuring cylinder etc. Recording the results in an appropriate format is required, including noting approximations, decimal point accuracy etc. Learners must justify for example, why an approximation was used, why only two decimal points were recorded etc. This should enable the assessor to judge if the learner has understood that experimental techniques can affect accuracy, reliability and the validity of results.

For P4, learners must be observed in the laboratory assembling the equipment and materials and carrying out the experiment safely. An expert witness such as the laboratory technician may be used to judge the effectiveness of assembling the equipment and working safely.

For P5, the assessor will be looking at how well the practical is carried out and the accuracy with which the learner records their results in the laboratory logbook. The assessor may devise a list of factors which the learners must meet in order to satisfy the grading criteria for P4 and P5. If such a list is used, learners must be aware, in advance, of what they will be judged against. The assessor must also assure themselves that all health and safety regulations have been complied with before any work is started and that they are followed throughout the practical work sessions.

For P6, the assessor should regularly check the laboratory logbook of each learner and sign and date the section seen. In this way the learner is made aware of the importance of these logbooks as a record of what they are doing. Assessors should check that the protocols expected when using logbooks are followed such as pages are not removed and correcting fluid is not used.

For P7, learners must analyse the results of their practical work. The statistical techniques chosen by the learner should be appropriate to the results obtained and it is to be expected that a lot of tutor help will be needed to achieve this assessment criteria.

For M3, learners should apply at least one appropriate statistical technique to the data collected and record the method involved even if a computer program did the calculations. Learners should relate the outcomes of the analysis to the research data found in P2 and M2 and show the validity (or not) of their own findings.

For P8, learners are drawing together the results of their work, stating if their original objective or hypothesis has been met and explaining their conclusions. The report for P9 requires the learner to write more formally using accepted scientific language and protocols, eg impersonal, third party, past tense.

For M4, the learners should be bringing together the results of their work by justifying the conclusions they have drawn. In doing so they should be in a position to support (or not) their original hypothesis and justify their opinion based on both their data and the researched material, ie primary and secondary data.

The D3 criterion requires learners to review the information obtained from their practical work and research, decide on its validity and whether the original hypothesis has been met. They should include evaluation of alternative experimental approaches, the modification or rewriting of their hypothesis and the strengths and weaknesses if alternative approaches were used. Learner should also evaluate the effectiveness of their choice of statistical methods. The validity and usefulness of their researched data should be evaluated and how their experimental data compares to published information. It is expected that at this level correct scientific protocols are observed throughout the project.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P2, M1	Choosing a Topic	Working as a research scientist, set up a hypothesis, research and test your hypothesis and then report your findings.	Written report.
P1, P3, D1	Hypothesising and Planning		Written report.
M2, D2	Trial Run		Observation by tutor.
	Planning Result Collection and Analysis		Written report/discussion with tutor.
P4, P5	Practical Work		Observation by tutor.
P6, P7, M3	Collecting, Recording and Analysing Data		Observation by tutor/written report.
P8, P9, M4, D3	Conclusions		Written report.

Links to National Occupational Standards, other BTEC units, other BTEC qualifications and other relevant units and qualifications

This unit forms part of the BTEC in Applied Science sector suite. This unit has particular links with all units in the Applied Science suite of qualifications but it is intended that the investigation performed is chosen specifically for this unit.

Essential resources

To deliver this unit, laboratory space equipped for advanced level work is required. The facilities needed should include access to equipment that will enable the learner to carry out an experiment of their choosing. The choice of experiment will be negotiated with the tutor but it must be practically based, probably in the laboratory, and could cover any of the three sciences or a combination of them. Therefore the centre will be expected to have the normal range of equipment and materials to carry out advanced level practical work in physics, chemistry and biology.

Research facilities should include access to computers, CD ROMs and suitable texts. Learners should have access to science and maths packages to help them present their data in the most appropriate way.

Suitably experienced and qualified staff will be needed to supervise the practical work and the assessments carried out in the laboratory. Similarly, suitable staff will be required for the assessment of the writing up of a scientific report using standard scientific protocol.

Employer engagement and vocational contexts

Learners should visit/experience laboratories in a range of industries, eg research, pharmaceutical, industrial, forensic, manufacturing. Employers could provide speakers/input/materials about procedures, especially the use of laboratory logbooks, record keeping and good laboratory practice. For tutors the type of supervision within commercial laboratories should be noted.

Indicative reading for learners

Textbooks

Foale S, Hocking S, Llewellyn R, Musa I, Patrick E, Rhodes P and Sorensen J – *BTEC Level 3 in Applied Science Student Book* (Pearson, 2010) ISBN 9781846906800

Coyne G S – *The Laboratory Companion: A Practical Guide to Materials, Equipment and Technique* (John Wiley & Sons, 2005) ISBN 9780471780861

Dean J R et al – *Practical Skills in Chemistry* (Prentice Hall, 2001) ISBN 9780130280022

Dean J R et al – *Practical Skills in Forensic Science* (Prentice Hall, 2005) ISBN 9780131144002

Derenzo S E – *Practical Interfacing in the Laboratory: Using a PC for Instrumentation, Data Analysis and Control* (Cambridge University Press, 2003) ISBN 9780521815277

Hutchings K – *Classic Chemistry Experiments* (The Royal Society of Chemistry, 2000) ISBN 9780854049196

Jones A et al – *Practical Skills in Biology, 4th Edition* (Benjamin Cummings, 2007) ISBN 9780131755093

Lintern M – *Laboratory Skills for Science and Medicine: An Introduction* (Radcliffe Medical Press, 2006) ISBN 9781846190162

Morgan S – *Advanced Level Practical Work for Biology* (Hodder Murray, 2002) ISBN 9780340847121

Prichard E and Lawn R – *Practical Laboratory Skills Training Guide: Measurement of pH* (The Royal Society of Chemistry, 2003) ISBN 9780854044733

Prichard E and Lawn R – *Practical Laboratory Skills Training Guide: Measurement of Volume* (The Royal Society of Chemistry, 2003) ISBN 9780854044689

Reed R et al – *Practical Skills in Biomolecular Science, 3rd Edition* (Benjamin Cummings, 2007) ISBN 9780132391153

Journals

Nature

New Scientist

Scientific American

Websites

www.chemistry-react.org	Ideas for practical investigations
www.mhra.gov.uk	Information on good practice in laboratories, clinical practice and manufacturing (pharmacy)
www.opsi.gov.uk	Statutory instruments which govern all aspects of laboratory practice (aimed at tutors)

It is also worth looking at some university websites as they issue protocols to their students doing practical work.

Delivery of personal, learning and thinking skills

The table below identifies the opportunities for personal, learning and thinking skills (PLTS) that have been included within the pass assessment criteria of this unit.

Skill	When learners are ...
Independent enquirers	[IE1-6] carrying out research for their chosen topic
Creative thinkers	[CT1-6] designing, setting up their objectives and hypotheses
Reflective learners	[RL2,3,6] reviewing and evaluating practical work and preparing work using scientific protocols
Self-managers	[SM2-4] organising laboratory time, dealing with pressure of experimental procedures and time/equipment constraints, seeking advice from tutor.

Although PLTS are identified within this unit as an inherent part of the assessment criteria, there are further opportunities to develop a range of PLTS through various approaches to teaching and learning.

Skill	When learners are ...
Independent enquirers	carrying out research as part of P2
Creative thinkers	setting up a hypothesis (P1, D1), comparing work (M3, D2), coming to conclusion (D3, D4)
Reflective learners	comparing results to published work, coming to conclusions M3, D2
Team workers	working with others in practical work, sharing ideas and equipment, discussing with tutor the work planned and undertaken
Self-managers	carrying out practical work (P4, P5, P6), writing up experiments, the whole unit
Effective participators	in discussion groups at beginning of unit and as a result of visits.

Functional Skills – Level 2

Skill	When learners are ...
ICT – Use ICT systems	
Select, interact with and use ICT systems independently for a complex task to meet a variety of needs	analysing data from the practical work carried out writing up experiments as a result of the practical work researching order to compare their results with published material and to gain background information about possible topics to follow up
Use ICT to effectively plan work and evaluate the effectiveness of the ICT system they have used	analysing (statistically) practical results and comparing with other work
Manage information storage to enable efficient retrieval	scoring results, analysing results, writing up experiment using computer programmes for analysis, graphs plus spreadsheets for the data collected
Follow and understand the need for safety and security practices	backing up all information stored, using password to protect data etc
Troubleshoot	retrieving information if lost when up or downloading
ICT – Find and select information	
Select and use a variety of sources of information independently for a complex task	researching using the internet, books, journals which are often available online doing statistical analysis using programmes
ICT – Develop, present and communicate information	
Enter, develop and format information independently to suit its meaning and purpose including: • text and tables • images • numbers • records	recording results and conclusions on spreadsheets and analysing to show the information as tables, graphs or lists of figures
Bring together information to suit content and purpose	researching to choose a topic, then to find out information to back up their ideas and finally to compare their results with those that have been published
Present information in ways that are fit for purpose and audience	writing up investigative report as a whole which will be aimed at an audience with some science knowledge
Evaluate the selection and use of ICT tools and facilities used to present information	presenting statistical analysis of practical work

Skill	When learners are ...
Mathematics	
Identify the situation or problem and the mathematical methods needed to tackle it	using statistical methods to find out if the data collected is viable and can be used to draw conclusions from
Select and apply a range of skills to find solutions	using statistical methods to find out if the data collected is viable and can be used to draw conclusions from
Use appropriate checking procedures and evaluate their effectiveness at each stage	analysing raw data and choosing appropriate statistical methods
Draw conclusions and provide mathematical justifications	using statistical methods and results. This relies on the fact that correct statistical analyses has been carried out by choosing the most appropriate technique
English	
Reading – compare, select, read and understand texts and use them to gather information, ideas, arguments and opinions	carrying out research
Writing – write documents, including extended writing pieces, communicating information, ideas and opinions, effectively and persuasively	writing up investigation using scientific protocol and formal, specialised language.