Quality Assuring a Science Curriculum

Jim Stafford

Acknowledgement

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Foreword

I am delighted to introduce Quality Assuring a Science Curriculum from SSERC. As the Director of Education in Glasgow and a former HM Inspector of Education, I know how important it is for teachers and science curriculum leaders to be constantly reflecting on the quality of both the learning and teaching of science and the curriculum being delivered.

Local authorities work very effectively with SSERC. We are grateful for the high standards of professional learning which SSERC deliver which is helping to raise the bar for the delivery of learning and teaching in science. Their professional learning gives teachers, particularly those primary colleagues who do not have a science degree, the confidence, knowledge and skills to deliver exciting, creative learning developing our children to be curious confident learners.

The purpose of this document is to support science teachers and science curriculum leaders in developing approaches to quality assuring the science curriculum they provide. There is no specific Scottish guidance on quality assuring a science curriculum nor is there an agreed consensus on what constitutes a quality science curriculum internationally.

Given that, this document does not attempt to provide a definitive method of quality assuring a science curriculum; rather it considers the elements that could be found in a quality science curriculum and provides resources from which science teachers and science departments could construct their own systems of quality assurance.

Quality Assuring a Science Curriculum should be seen as complementary to the well-established systems of quality assurance and self-evaluation provided by Education Scotland.

Scotland needs young people with high quality scientific skills and knowledge. Employers continue to report a skills gap for STEM careers. Therefore, it is critical that we have the highest expectations for the children and young people we teach and for the teachers and curriculum leaders who are delivering science.

High quality learning and teaching does not just happen, it requires us all to be working together with the shared common purpose of only the best will do.

Maureen McKenna
Executive Director of Education, Education Services Glasgow City Council

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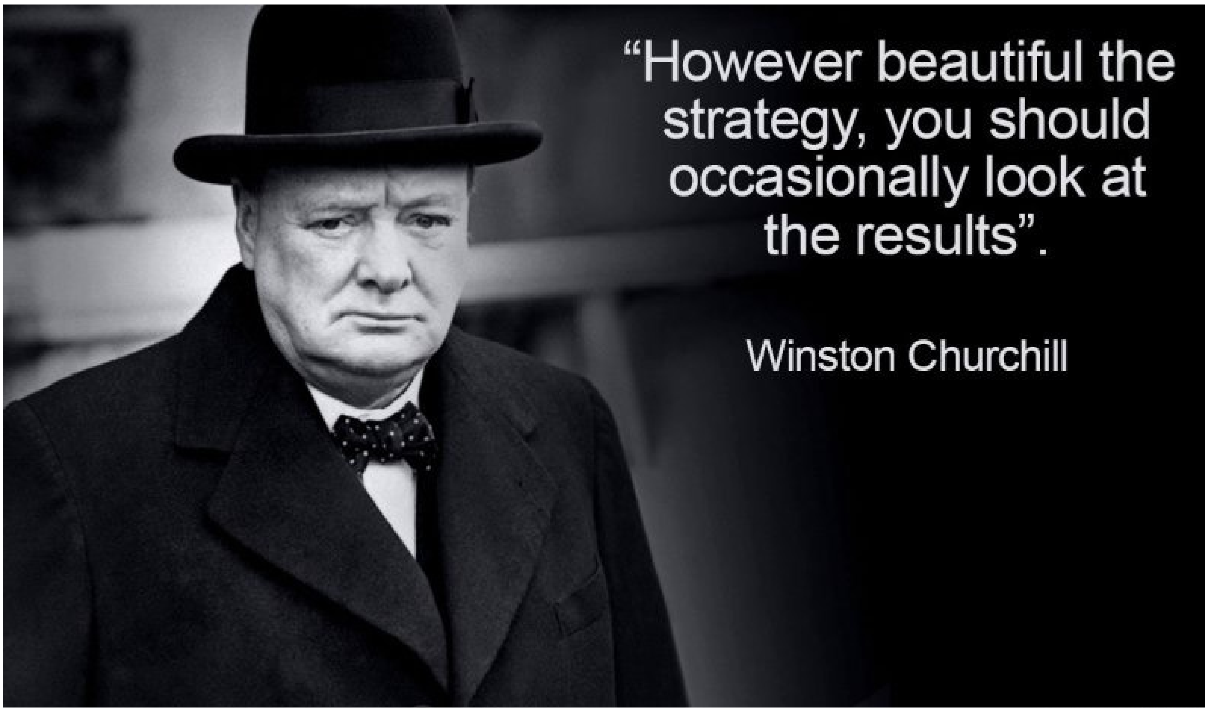
Introduction

The purpose of this document is to support science teachers and science curriculum leaders in developing approaches to quality assuring the science curriculum they provide.



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What follows should not be seen as an alternative to the well established systems of quality assurance and self evaluation provided by HMI. Rather these are a supplement to these measures and should be complementary to them in the specific context of science education.

Scientific literacy and Curriculum for Excellence

1

THE CONTEXTS FOR QUALITY ASSURANCE OF A SCIENCE CURRICULUM

1.1 SCIENTIFIC LITERACY

The aim of a science curriculum should be to develop scientifically literate citizens with a lifelong interest in science. It should also provide a foundation for more advanced learning in science and for future careers in science and technology. These components should not be at odds with each other. Although historically school science was seen as a preparation for further learning in science, more recent curriculum developments have in addition sought to provide science learning that is relevant to the everyday life of citizens in the 21st century and to provide pathways relevant to employment. When we ask the question 'To what extent does our science course develop scientific literacy?' we should be able to find evidence of meeting all of these aims.

Scientific literacy can be considered to comprise of three elements. They are:
1) Acquiring scientific knowledge that enables learners to develop understanding and provide explanations - the 'understanding how things work' of science.
2) Using scientific methodology to explore questions and solve problems - the practical work of 'doing science'.
3) Making personal decisions based on scientific evidence - the application of 'using science in everyday life'.

Scientific knowledge
There is a problem in identifying the knowledge to include in a science curriculum - there is a huge amount of scientific knowledge and it is growing exponentially. Thus the knowledge content of a science curriculum cannot remain static; it has to be updated in terms of new knowledge and new ways of thinking about existing knowledge. As a consequence a rationale is required for selecting the knowledge to include and a mechanism for keeping it up to date. Rather than a body of facts and theories the curriculum should be a smooth progression of planned understanding that leads to the big ideas of science that will enable learners to understand events and phenomena relevant to their lives and to take part in decisions as informed citizens. Identifying these big ideas and the progression of the key concepts that underlie them is the challenge to be met by curriculum designers to create a science curriculum that is important and powerful to learn. Successive 'fresh starts' should be avoided as they often lead to misconceptions and misunderstanding that have to be unlearned. Rather the end points of the school science curriculum should be identified and then pathways to those end points planned. In constructivist models of curriculum development this is referred to as 'deep learning' as opposed to recall based 'superficial' or 'surface learning'.

Scientific methodology
The curriculum should provide first-hand experience of science practical work in the laboratory and in the field. The processes and techniques of practical work should appear regularly in the curriculum to develop competence. Practical work should be at an appropriate level of demand for the curriculum. By increasing the complexity of a task, by for example by having an experiment with more variables or by generating complex data to be analysed, a level of demand appropriate to the curriculum can be achieved. Even straight-forward experiments, with some thought, can be moved intellectually 'up-market' to be at an appropriate level of demand. That is scientific methodology should require thought and intellectual engagement rather than only instruction following to see an effect or demonstrate a phenomenon - the 'minds on' as well as the 'hands on' of practical work in science. Practical work in science can provide a number of learning outcomes. It can be used to:

- Illustrate theoretical knowledge to help develop understanding.
- Develop skills of experimental design.
- Develop skills of planning and carrying out scientific experiments and investigations.
- Develop skills of data analysis.
- Develop competence in laboratory and fieldwork techniques.
- Provide opportunities to identify hazards, assess risks and implement control measures.

Scientific decision making
This is the important life skill of making decisions based on evidence. The curriculum should include science that is relevant to the lives of learners and their communities. It should equip them with knowledge they can use to understand the scientific world in which they live and with the skills to seek out the evidence they need to make decisions important to them. Learners should be able to:

- Process raw data so that trends, patterns and relationships can be readily seen.
- Interpret tables, graphs, diagrams and other forms of representing data.
- Perform calculations and to use formulae and equations in real life situations.
- Recognise a fair test.
- evaluate the validity of experimental designs and the reliability of recorded data.
- Draw valid conclusions.
- Source, read and understand articles about science in the media and comment on the validity of the conclusions.
- Comment on and discuss the impact of science and technology on everyday life.

To be scientifically literate means that you use science skills and knowledge in everyday life.

The Four Capacities of *Curriculum for Excellence*

successful learners

with
- enthusiasm and motivation for learning
- determination to reach high standards of achievement
- openess to new thinking and ideas

and able to
- use literacy, communication and numeracy skills
- use technology for learning
- think creatively and independently
- learn independently and as part of a group
- make reasonal evaluations
- link and apply different kinds of learning in new situations

confident individuals

with
- self respect
- a sense of physical, mental and emotional wellbeing
- secure values and beliefs
- ambition

and able to
- relate to others and manage themselves
- pursue a healthy and active lifestyle
- be self aware
- develop and communicate their own beliefs and view of the world
- live as independently as they can
- assess risk and take informed decisions
- achieve success in different areas of activity

TO ENABLE ALL YOUNG PEOPLE TO BECOME

responsible citizens

with
- respect for others
- commitment to participate responsibly in political, economic social and cultural life

and able to
- develop knowledge and understanding of the world and Scotland's place in it
- understand different beliefs and cultures
- make informal choices and decisions
- evaluate envirionmental, scientific and technological issues
- develop informed, ethical views of complex issues

effective contributors

with
- an enterprising attitude
- resilience
- self-reliance

and able to
- communicate in different ways and in different settings
- work in partnership and in teams
- take the initiative and lead
- apply critical thinking in new contexts
- create and develop
- solve problems

Figure 1 - The Four Capacities of Curriculum for Excellence.

1.2 CURRICULUM FOR EXCELLENCE

In recent years *Curriculum for Excellence* (*CfE*) has set the context for curriculum developments in Scotland. Although curriculum initiatives come and go, the principles of *CfE* are likely to remain as part of the curriculum.

CfE is centred around the Four Capacities. Each capacity details the characteristics (the 'with') of learners and the capabilities (the 'and able to') that they should acquire. In terms of QA it is the capabilities that we should focus on and consider how a science curriculum can contribute to their delivery. A science curriculum should not be required to deliver all the capabilities; that is the responsibility of the whole curriculum (Figure 1 above).

As well as the capabilities associated with the Four Capacities, *CfE* is expected to deliver Higher Order Thinking Skills. These skills have their origin in Bloom's Revised Taxonomy (Figure 2). Bloom's Revised Taxonomy can be viewed as a ladder of hierarchical skills. In science we may take issue with the order these skills are presented in the ladder. For example in science because we put particular emphasis on analysing information and data, students are often accomplished in these areas. Consequently we may view these skills as being lower in the ladder. Scientific ideas by comparison are often abstract and can be counter-intuitive making understanding them challenging and perhaps worthy of a higher position.

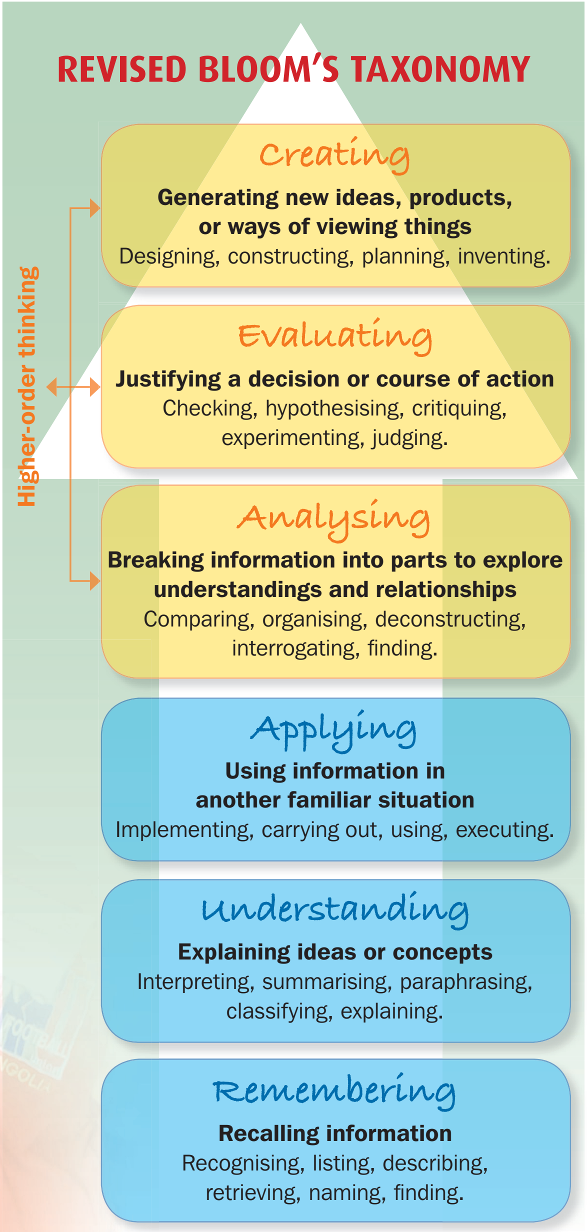
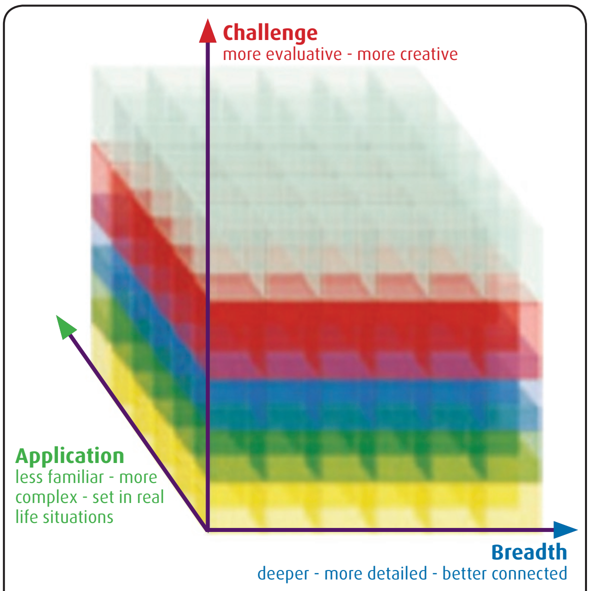


Figure 2 - Revised Bloom's Taxonomy.

In *CfE* the Higher Order Thinking Skills associated with the breadth, challenge and application of the curriculum are presented as being more like a climbing frame than a ladder (Figure 3).

Breadth encompasses acquiring new knowledge, acquiring greater depth to existing knowledge and the ability to make connections between areas of knowledge and from existing knowledge to new knowledge. It involves the learner in processing their knowledge into categories and hierarchies, improving their ability to recall knowledge and to use it to develop understanding and to provide explanations.

Challenge is associated with applying science skills and knowledge in situations that are unfamiliar and more complex. In science, challenge can be achieved through the critical evaluation of reports of scientific research and by learners creating their own experimental designs and investigations. Complexity can be achieved by using analytical skills in situations that involve a wider range of information or by increasing the number and type of variables being considered.



The three dimensions of breadth, challenge and application that apply to assessment, the curriculum and learning representing their simultaneous advance as learners make progress.

Figure 3 - Higher Order Thinking Skills.

Application is about using science knowledge and skills in new situations. It can involve interpreting new scientific information to draw conclusions, support explanations or to make predictions and generalisations. It can involve devising questions and hypotheses to solve problems through designing experiments and investigations and making decisions about how to process and present data. It is of direct relevance to learners in appreciating the impact of science and technology on everyday life and in making and justifying decisions about things that involve science.

Tools for quality assuring a science curriculum

2

2.1 SELF EVALUATION OF LEARNING EXPERIENCES - APPENDICES FROM *THE EXCELLENT SCIENCE DEPARTMENT*

The SSERC publication *The Excellent Science Department* [1] deals with leadership and self evaluation. Appendices 7 to 11 deal with aspects of science curriculum provision. Appendix 7 deals with the teaching process, appendices 8 to 10 deal with learning experiences (the curriculum) and appendix 11 deals with meeting learning needs. Appendices 8 to 10 (with some reference to appendices 7 and 11) could be used to give structure to and form the basis of a collaborative discussion on the quality of a school's science curriculum. These appendices are shown below.

Self evaluation of the teaching process (Appendix 7)

- Share the aims of lessons with learners.
- Take account of prior learning from previous lessons.
- Use a variety of approaches to make lessons stimulating.
- Set an appropriate pace for learning.
- Provide clear explanations and instructions.
- Use ICT to enhance learning experiences.
- Organise appropriate and sufficient resources for practical activity.
- Ensure safe practice is being observed.
- Use questioning to check learners' understanding and to develop their thinking.
- Use praise effectively to encourage and build learners' self esteem.
- Consolidate new information or skills at the end of the lesson.
- Set regular homework that is appropriate and well linked to class work.

Self evaluation of learning experiences - learning and teaching approaches for knowledge and understanding (Appendix 8)

- Making use of artefacts, visual aids and models in teacher expositions and explanations.
- Using data projectors and interactive whiteboards to enhance presentations and teacher expositions.
- Using peer teaching and peer presentations to develop knowledge and understanding.
- Discussing current scientific issues in the media.
- Discussing the social, moral and ethical implications of scientific developments.
- Providing opportunities for further reading and research.
- Using resource based learning where it is appropriate.

Self evaluation of learning experiences - problem solving skills (Appendix 9)

- Devising hypotheses.
- Planning and designing investigations.
- Organising and carrying out practical tasks.
- Deciding on how to record results.
- Analysing recorded data.
- Drawing conclusions from recorded data.
- Evaluating experimental designs for validity and reliability.
- Evaluating results for accuracy and errors.
- Evaluating conclusions in light of known knowledge.
- Writing scientific reports.
- Making predictions and generalisations based on evidence.

[1] http://www.sserc.org.uk/images/Leadership/ESD_book%202014%20web.pdf.

Self evaluation of learning experiences - types and purposes of practical work (Appendix 10)
- Illustrating science concepts as an aid to understanding.
- Developing competence in practical techniques.
- Generating data for subsequent analysis.
- Testing hypotheses and drawing conclusions.
- Developing skills of experimental design.
- Developing knowledge through planned sequences of experiments.
- Developing problem solving skills such as critical thinking, planning and organising, reviewing and evaluating.

Self evaluation of meeting learning needs (Appendix 11)
- Make use of information on learners' prior knowledge and attainment.
- Make use of known misconceptions in science when designing tasks and activities.
- Provide helpful feedback on learners' work and encourage them to be involved in monitoring their own progress.
- Make use of comment only marking to provide feedback and encourage improvement.
- Match tasks and activities to the needs of individual learners.
- Make use of tasks and activities that can be differentiated by outcome.
- Ensure the pace of learning is sufficiently challenging for all learners.
- Use classroom assistants and SEN auxiliaries to provide appropriate levels of support to meet the needs of all learners.

2.2 CURRICULUM FOR EXCELLENCE CHARACTERISTICS SHOWN BY LEARNERS IN SCIENCE - HMIE REPORT *SCIENCE - A PORTRAIT OF CURRENT PRACTICE IN SCOTTISH SCHOOLS*

The HMIe Science Portrait report [2] describes the characteristics often shown by learners for each of the four capacities of *CfE* based on evidence from school inspections. A science curriculum could be compared to the signposts for each capacity to see if the curriculum provides learners with the opportunities to develop these characteristics. The signposts for each capacity are shown below.

Characteristics of successful learners

They:
- are motivated and enthusiastic about learning which in turn impacts positively on their wellbeing;
- provide explanations supported by evidence or justifications;
- make reasoned evaluations based on the strength of evidence available;
- apply knowledge to evidence from observations, experiments, inquiries and investigations to formulate hypotheses, draw conclusions and make predictions and generalisations;
- think creatively and independently by designing procedures and carrying out experiments to investigate and solve problems;
- link and apply different kinds of learning to a range of issues arising from the application of science in society at local, national and global levels;
- are aware of the pace and significance of developments in science and can evaluate the impact of these;
- use science as a means of developing and using a range of skills in critical thinking as well as literacy, numeracy and information and communications technology (ICT).

[2] This document can be downloaded from the Leadership pages of the SSERC website at http://www.sserc.org.uk/979-leadership/4240-science-portrait.

Characteristics of confident individuals

They:

- relate to others and manage themselves by working on a wide range of science inquiries, investigations and projects;
- demonstrate self-awareness by reflecting on the impact of new scientific evidence on their own understanding and views;
- assess risk and benefit in order to make informed decisions;
- achieve success in practical and research tasks, problem solving, data analysis and evaluation, discussion and debate;
- can express and justify their views on science-based issues of importance to society.

Characteristics of responsible citizens

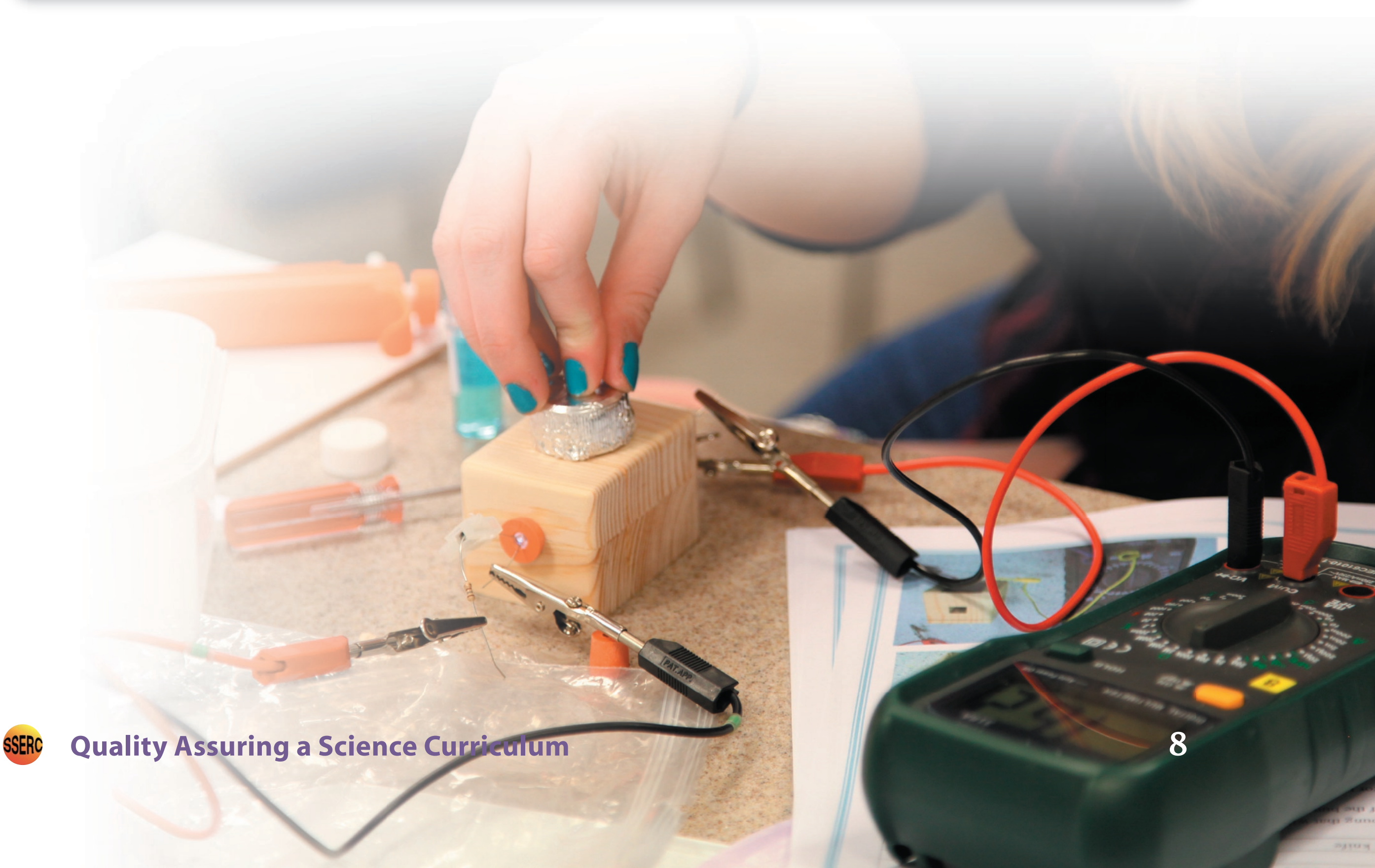
They:

- develop the scientific values of respect for living things and the environment, respect for evidence and the opinions of others, honesty in collecting and presenting data and openness to new ideas;
- understand the cultural significance and importance of science;
- make informed choices and decisions on issues relating to the impact of science in society;
- evaluate environmental, scientific and technological issues, based on their knowledge, understanding and analysis of evidence;
- develop informed, ethical views of complex scientific issues.

Characteristics of effective contributors

They:

- have an enthusiasm for collaborative learning and group tasks;
- listen and respond to others and build on others' suggestions and ideas;
- collaborate effectively in teams during inquiry and investigation tasks and discussions;
- take the initiative and lead in developing strategies to solve problems and experiment;
- apply critical thinking to interpret data, make deductions and draw conclusions based on reliable scientific evidence;
- communicate effectively in a range of ways including orally and through scientific report writing;
- solve scientific problems and challenges.



2.3 PURPOSES OF LEARNING IN THE SCIENCES - CURRICULUM FOR EXCELLENCE, *SCIENCES PRINCIPLES AND PRACTICE*

The Sciences Principles and Practice [3] paper from Curriculum for Excellence emphasises that learners develop an interest in and understanding of science through engaging in a wide range of collaborative investigative tasks that develop the skills to engage in the scientific and technological world of the 21st century. The purposes of science learning for *CfE* from Principles and Practice are shown below.

Children and young people participating in the experiences and outcomes in the sciences will:

- Develop a curiosity and understanding of their environment and their place in the living, material and physical world.
- Demonstrate a secure knowledge and understanding of the big ideas and concepts of the sciences.
- Develop skills for learning, life and work.
- Develop skills of scientific inquiry and investigation using practical techniques.
- Develop skills in the accurate use of scientific language, formulae and equations.
- Recognise the role of creativity and inventiveness in the development of the sciences.
- Apply safety measures and take necessary actions to control risk and hazards.
- Recognise the impact the sciences make on their lives, the lives of others, the environment and on society.
- Develop an understanding of the Earth's resources and the need for responsible use of them.
- Express opinions and make decisions on social, moral, ethical, economic and environmental issues based upon sound understanding.
- Develop as scientifically literate citizens with a lifelong interest in the sciences.
- Establish the foundation for more advanced learning and, for some, future careers in the sciences and the technologies.

2.4 NUFFIELD FOUNDATION DEFINITION OF SCIENCE LITERACY

The Nuffield Definition of Science Literacy [4] shown below describes how a scientifically literate person would use science in everyday life. As such it could be used as a suitable quality assurance tool for areas of the curriculum intended to develop that particular aspect of scientific literacy.

A scientifically literate person would be expected to be able to:

- Appreciate and understand the impact of science and technology on everyday life, on economic and social change and on the environment.
- Take informed personal decisions about things that involve science, such as health, diet, use of energy resources.
- Read and understand the essential points of media reports about matters that involve science.
- Reflect critically on the information included in, and (often more important) omitted from such reports and hence make some estimate as to its reliability and significance.
- Take part confidently in discussions with others about issues involving science.
- Know something of the ways in which new scientific knowledge is created and how processes within the scientific community aim to ensure the reliability of new knowledge.

[3] https://education.gov.scot/Documents/sciences-pp.pdf.
[4] http://www.nuffieldfoundation.org/science-society/scientific-literacy.

2.5 EFFECTIVENESS OF PRACTICAL WORK

Millar and Abrahams outline a model for evaluating the effectiveness of school science practical activities in their paper *Practical Work: making it more effective* [5]. They have also produced a quality assurance tool associated with this - *The Practical Activity Analysis Inventory* [6]. They classify practical activities into three categories according to their main learning objectives:

- Illustrating ideas.
- Practising procedures.
- Enquiry processes.

These broad learning objectives are then further divided into more specific learning objectives in the inventory mentioned above. Their research suggests that we need to increase the 'minds on' rather than the 'hands on' aspects of practical work if we are to be more effective in developing learners' understanding of scientific ideas.

Probably too many of our practicals are of the' illustrating ideas' type which aim to allow learners to see, and remember, scientific phenomena. We need to develop these practicals so that learners use ideas to make sense of what they do, leading to a deeper understanding of scientific ideas that may be implicit in the practical work rather than directly observable. The excitement of a science practical activity is often what goes on in the student's head rather than what they directly observe (the 'minds on' as well as the 'hands on').

When 'practising procedures' as well as aiming for competence learners should be challenged to think creatively about how equipment and procedures could be used in new and unfamiliar situations (for example in project work) and to consider improvements and refinements that could be made to the methods used.

Often practicals that involve 'enquiry processes' have been reserved for assessment, for example the former Standard Grade Investigations and the current National Qualifications Assignments. Too often the focus of such lessons can become the achievement of assessment criteria rather than developing the higher order skills of scientific investigation. Millar and Abrahams identify the following aspects of scientific enquiry:

- Identifying a good investigation question.
- Planning a strategy for collecting data to address the question.
- Choosing the equipment for an investigation.
- Presenting data clearly.
- Analysing data to reveal or display patterns.
- Drawing and presenting conclusions based on evidence.
- Assessing how confident you can be that a conclusion is correct.

Attempting to assess all of these aspects in the one practical activity can result in a contrived enquiry where higher order thinking skills become lost and the outcomes become trivial - the jumping through hoops of assessment. It is better to focus on one or a few aspects of scientific enquiry that a practical activity lends itself to developing. Then the challenge for teachers is to cover a range of practicals that will cover all of the aspects of scientific enquiry well rather than one practical activity that covers them all poorly. As students develop their skills then the challenge of more open-ended practical projects can be introduced.

In scientific practical work the thinking should be as important as the doing, so that learning becomes about constructing meaning from experience. Millar and Abrahams' documents referred to above are powerful tools in developing meaningful practical work in science and are highly recommended.

[5] *Practical Work: making it more effective*, Robin Millar and Ian Abrahams, School Science Review 91 (334), 2009. http://www.gettingpractical.org.uk/documents/RobinSSR.pdf.

[6] *Analysing Practical Science Activities to assess and improve their effectiveness*, Robin Millar, The Association for Science Education, 2010. https://www.rsc.org/cpd/teachers/content/filerepository/frg/pdf/ResearchbyMillar.pdf.

2.6 SQA COURSE ASSESSMENT SPECIFICATIONS - SKILLS, KNOWLEDGE AND UNDERSTANDING

The SQA Course Assessment Specifications for Biology, Chemistry and Physics [7] give details of a set of capabilities for knowledge and understanding and the skills of scientific experimentation, investigation and enquiry that are common to all science courses. These capabilities could be used as a quality assurance tool to ensure that a science curriculum delivers all of these capabilities. The capabilities are shown below.

SQA sciences course skills, knowledge and understanding

- Demonstrating knowledge and understanding by making statements, describing information, providing explanations and integrating knowledge.
- Applying knowledge to new situations, analysing information and solving problems.
- Planning and designing experiments/practical investigations to test given hypotheses or to illustrate particular effects.
- Carrying out experiments/practical investigations safely, recording detailed observations and collecting data.
- Selecting information from a variety of sources.
- Presenting information appropriately in a variety of forms.
- Processing information (using calculations and units, where appropriate).
- Making predictions and generalisations from evidence/information.
- Drawing valid conclusions and giving explanations supported by evidence/justification.
- Evaluating experiments/practical investigations and suggesting improvements.
- Communicating findings/information effectively.

The Course and Unit Support Notes for SQA qualifications in Biology [8] provide a more detailed breakdown for these broad capabilities of knowledge and understanding and science skills. Although specified for Higher Biology these could be readily amended or adapted for chemistry, physics and science more generally. Used as a quality assurance tool they would provide a more detailed and comprehensive approach. These capabilities are shown below.

Skills of scientific experimentation, investigation and enquiry

Selecting information

Select and analyse relevant information from texts, tables, charts, keys, graphs and/or diagrams. The study of biology involves dealing with written and visual information. Learners will often deal with more complex information than they can produce. Learners should be able to:

- Work with quantitative and qualitative data, discrete and continuous data and sampled data.
- Deal with experimental data presented in tables, pie and bar charts, line graphs, lines of best fit, graphs with semi-logarithmic scales, graphs with error bars and information presented as box plots.
- Analyse and interpret typically two interconnected tables, charts, keys, graphs or diagrams or a single source of graphical information with two to three patterns, trends, conditions, variables or sets of results.
- Deal with statistical concepts such as the mean, range and standard deviation of data and statistically significant differences (as shown by error bars in graphs and plus and minus values in tables of results).
- Deal with text to analyse its content, select appropriate information, identify and evaluate evidence, explain relationships, draw conclusions and display related knowledge.
- Use computers and software applications to search and retrieve relevant information.

[7] http://www.sqa.org.uk/sqa/45625.html.
[8] http://www.sqa.org.uk/files_ccc/CfE_CourseUnitSupportNotes_Higher_Sciences_Biology.pdf.

Presenting information
Present information appropriately in a variety of forms, including summaries and extended text, flow charts, keys, diagrams, tables and/or graphs.

(a) Representing data. Learners should be able to:
- Present variables from experimental or other data in an appropriate form including tables, charts, keys, graphs and diagrams.
- Distinguish between dependent and independent variables.

(b) Communication. Learners should be able to:
- Select, organise and present relevant information, including presenting alternative points of view, on a biological issue.
- Produce scientific reports which describe experimental procedures, record relevant observations and measurements, analyse and present results, draw conclusions and evaluate procedures with supporting argument.
- Produce extended text presenting relevant ideas clearly, coherently and logically using specialist vocabulary where appropriate.
- Use word processing and graphics packages, spreadsheets and other data handling software.

(c) Oral communication. Through discussion and presentations learners should be able to:
- Convey information clearly and logically using specialist vocabulary where appropriate.
- Use images including charts, models, graphs, diagrams, illustrations or video in conveying information.
- Respond to others by answering questions, clarifying points, contributing points of view and asking questions to clarify or explore in greater depth.

Processing information
Process information accurately using calculations where appropriate. Learners should be able to:
- Perform calculations involving whole numbers, decimals and fractions.
- Calculate ratios and percentages including percentage increase and decrease.
- Round answers to an appropriate degree of accuracy (e.g. to two decimal places or three significant figures).
- Deal with a range of units in accordance with Society of Biology recommendations. Learners will be expected to be able to convert between, for example, μg and mg.
- Deal with calculations involving negative numbers, numbers represented by symbols and scientific notation.
- Work with data to find the mean and range of the data.
- Calculate genetic ratios based on probability.
- Substitute numerical values into equations and changing the subject of an equation.
- Use software packages to carry out statistical and other data handling processes.

Planning, designing and carrying out
Plan, design and carry out experimental procedures to test given hypotheses or to illustrate particular effects. This could include identification of variables, controls and measurements or observations required.

(a) Planning and designing. Learners should be able to:
- State the aim of an investigation.
- Suggest a hypothesis for investigation based on observation of biological phenomena.
- Plan experimental procedures and select appropriate techniques.
- Suggest suitable variables that could be investigated in a given experimental set up identify dependent and independent variables in an investigation.
- Decide on the experimental designs required to ensure the validity of experimental procedures.
- Decide on the measurements and observations required to ensure reliable results.
- Modify procedures in the light of experience.

(b) Carrying out. Learners should be able to:

- Identify component tasks in practical work and plan a procedure (to include timings and allocation of tasks where appropriate) identify, obtain and organise the resources required for practical work.
- Carry out work in a methodical and organised way with due regard for safety and with appropriate consideration for the well-being of organisms and the environment where appropriate.
- Follow procedures accurately.
- Make and record observations and measurements accurately.
- Capture experimental data electronically using a range of devices.
- Modify procedures and respond to sources of error.

Evaluating experimental procedures

Evaluate experimental procedures by commenting on the purpose or approach, the suitability and effectiveness of procedures, the control of variables, the limitations of equipment, possible sources of error and/or suggestions for improvement. Learners should be able to:

- Identify and comment on variables that are not controlled in experimental situations and distinguish between dependent and independent variables.
- Identify sources of error in measurements and observations.
- Identify and comment on the reliability of results.
- Identify and comment on the validity of experimental designs.
- Suggest possible improvements to experimental set ups.
- Use observations and collected data to make suggestions for further work.

Drawing conclusions

Draw valid conclusions and give explanations supported by evidence or justification. Conclusions should include reference to the aim of the experiment, overall pattern to readings or observations, trends in results or comment on the connection between variables and controls. Learners should be able to:

- Analyse and interpret experimental data to select relevant information from which conclusions can be drawn.
- State the results of the investigation.
- Draw conclusions on the relationships between the dependent and independent variables.
- Take account of controls when drawing conclusions.
- Analyse and interpret experimental data to identify patterns, trends and rates of change.

Making predictions and generalisations

Make predictions and generalisations based on available evidence. Learners should be able to:

- Predict the outcome in experimental situations from supplied information.
- Make generalisations from a range of biological information.
- Use modelling and simulation software to test predictions and answer questions related to biological and experimental phenomena.
- Use evidence to support a personal decision or point of view on a current scientific, technological, environmental or health issue.

2.7 FRAMEWORK FOR SCIENCE REASONING - *TRENDS IN MATHEMATICS AND SCIENCE STUDY (TIMSS)*

The Trends in Mathematics and Science Study (TIMSS) [9] compares students' educational achievement in maths and science across a diverse range of educational systems worldwide. Students are assessed at the equivalents of P5 and S2. The study is carried out every four years and Scotland has not participated since 2007, although England has participated in all the studies from 1995 to 2015. Reasoning is one of the cognitive domains assessed, the others are Knowing and Applying. The assessment domains do not alter greatly from study to study to allow comparisons over time as well as comparisons between countries. The Framework for Scientific Reasoning from the 2011 study [10] is shown below. The 2011 study was chosen as the framework is presented in a bulleted list format which makes using it as a quality assurance tool more straightforward.

1) Analyse/solve problems
- Analyse problems to determine the relevant relationships, concepts, and problem-solving steps.
- Develop and explain problem-solving strategies.

2) Integrate/synthesise
- Provide solutions to problems that require consideration of a number of different factors or related concepts.
- Make associations or connections between concepts in different areas of science.
- Demonstrate understanding of unified concepts and themes across the domains of science.
- Integrate mathematical concepts or procedures in the solutions to science problems.

3) Hypothesise/predict
- Combine knowledge of science concepts with information from experience or observation to formulate questions that can be answered by investigation.
- Formulate hypotheses as testable assumptions using knowledge from observation and/or analysis of scientific information and conceptual understanding.
- Make predictions about the effects of changes in biological or physical conditions in light of evidence and scientific understanding.

4) Design/plan
- Design or plan investigations appropriate for answering scientific questions or testing hypotheses.
- Describe or recognise the characteristics of well-designed investigations in terms of variables to be measured and controlled and cause-and effect relationships.
- Make decisions about measurements or procedures to use in conducting investigations.

5) Draw conclusions
- Detect patterns in data, describe or summarise data trends, and interpolate or extrapolate from data or given information.
- Make valid inferences on the basis of evidence and/or understanding of science concepts.
- Draw appropriate conclusions that address questions or hypotheses, and demonstrate understanding of cause and effect.

6) Generalise
- Make general conclusions that go beyond the experimental or given conditions, and apply conclusions to new situations.
- Determine general formulas for expressing physical relationships.

7) Evaluate
- Weigh advantages and disadvantages to make decisions about alternative processes, materials, and sources.
- Consider scientific and social factors to evaluate the impact of science and technology on biological and physical systems.
- Evaluate alternative explanations and problem-solving strategies and solutions.
- Evaluate results of investigations with respect to sufficiency of data to support conclusions.

[9] http://timssandpirls.bc.edu/.
[10] http://timssandpirls.bc.edu/timss2011/downloads/TIMSS2011_Frameworks.pdf.

2.8 SCIENTIFIC COMPETENCIES - *PROGRAMME FOR INTERNATIONAL STUDENT ASSESSMENT (PISA)*

The Programme for International Assessment (PISA) [11] evaluates education systems worldwide by assessing the skills and knowledge of 15 year olds in reading, mathematics and science. The assessments take place every three years and in 2015 science was the main focus for assessment. Scotland has participated in all PISA survey since their inception in 2000. The scientific competencies from the 2015 survey [12] are shown below.

Explain phenomena scientifically

Recognise, offer and evaluate explanations for a range of natural and technological phenomena demonstrating the ability to:

- Recall and apply appropriate scientific knowledge.
- Identify, use and generate explanatory models and representations.
- Make and justify appropriate predictions.
- Offer explanatory hypotheses.
- Explain the potential implications of scientific knowledge for society.

Evaluate and design scientific enquiry

Describe and appraise scientific investigations and propose ways of addressing questions scientifically demonstrating the ability to:

- Identify the question explored in a given scientific study.
- Distinguish questions that are possible to investigate scientifically.
- Propose a way of exploring a given question scientifically.
- Evaluate ways of exploring a given question scientifically.
- Describe and evaluate a range of ways that scientists use to ensure the reliability of data and the objectivity and generalisability of explanations.

Interpret data and evidence scientifically

Analyse and evaluate scientific data, claims and arguments in a variety of representations and draw appropriate conclusions demonstrating the ability to:

- Transform data from one representation to another.
- Analyse and interpret data and draw appropriate conclusions.
- Identify the assumptions, evidence and reasoning in science-related texts.
- Distinguish between arguments which are based on scientific evidence and theory and those based on other considerations.
- Evaluate scientific arguments and evidence from different sources (e.g. newspaper, internet, journals).

[11] http://www.oecd.org/pisa/aboutpisa/.
[12] https://www.oecd.org/pisa/test/PISA2015-Released-FT-Cognitive-Items.pdf.

Designing your own science quality assurance tool

3

Quality assuring a science curriculum can be a mammoth task. Remember you have a full-time day job. It is better to make quality assurance a relatively small but regular part of your work routine than a one-off large scale exercise. The purpose of quality assuring a science curriculum should be to improve the quality of the curriculum.

Identify the areas you need to address and then prioritise targets and tasks to improve the curriculum you provide. You can draw on the tools in Part 2 to help you. For example if you were interested in the quality of your practical work and the contribution it actually makes to learning you could use the tools devised by Millar and Abrahams in 2.5 *Effectiveness of Practical Work*. Their work is highly recommended for all science departments as their research indicates that often the practical work we do in science is too much 'hands on' and not enough 'minds on'. Or if you were concerned about the curriculum providing opportunities for pupils to see the relevance of science to everyday life you might want to draw on 2.4 *The Nuffield Foundation Definition of Science Literacy*. Or if you were concerned about developing pupils' data analysis skills you might want to draw from the SQA, TIMSS and/or PISA skills. Or if you wanted to ensure you were contributing to the principles of *CfE* you might want to draw on the Four Capacities (Figure 1, page 3) or the characteristics from 2.2 *HMIe Science Portrait*. Or if you wanted to take a brief overview (say in discussion at a departmental meeting) you might want to use the appendices from *The Excellent Science Department*.

Alternatively you could devise your own QA instrument by drawing on some or all of the QA tools mentioned in part 2. An example of how this could be done for Scientific Literacy is shown below.

3.1 QUALITY ASSURING SCIENTIFIC LITERACY

Area of scientific literacy	What we do	Notes/required action/evidence
Scientific knowledge Understanding science is the goal of acquiring knowledge and of our science teaching.	To develop understanding we focus on scientific knowledge that is important and powerful to learn.	
	We have identified the areas of scientific understanding that we want our learners to achieve.	

Area of scientific literacy	What we do	Notes/required action/evidence
Scientific knowledge Understanding science is the goal of acquiring knowledge and of our science teaching.	We expect learners to be able to use their understanding to explain phenomena, to form generalisations and to make predictions.	
	We have identified the key concepts that underpin the big ideas of science that will lead to understanding.	
	We organise the teaching of key concepts into progressive pathways that will lead to understanding and where learning is not linear we collect concepts together so that learners can make the necessary connections that will lead to understanding.	
* A case study focuses on just one particular area of interest or concern. This can then provide a theme or context through which the learner gains insight to the underlying science. That is the case study provides the vehicle for a study that illuminates the general principles of science by examining a particular example of scientific endeavour. For example in Higher Biology a case study on cancer could provide a context within which to study DNA, gene expression and genomics.	We challenge our learners to research instances and examples of key concepts through a case study approach* to deepen their understanding and to provide personalisation and choice in their learning.	

Area of scientific literacy	What we do	Notes/required action/evidence
Scientific knowledge Understanding science is the goal of acquiring knowledge and of our science teaching.	We challenge learners to apply their knowledge to new situations and to make connections between knowledge from different areas of science (including from other science subjects, mathematics and computing science). As teachers we are aware of the learning in other subjects that relates to our teaching of science.	
	We are aware of common misconceptions in science and check for their occurrence in learners both before and after learning.	
	We challenge misconceptions through the presentation of experimental evidence that contradicts the misconception and through discussion of alternative conceptions (e.g. presented as concept cartoons and/or as questions with multiple responses).	
Scientific methodology Providing opportunities to participate in the practical work of doing science is a major part of our science teaching.	We provide our learners with a wide range of first-hand experiences of laboratory and field based practical work.	

Area of scientific literacy	What we do	Notes/required action/evidence
Scientific methodology Providing opportunities to participate in the practical work of doing science is a major part of our science teaching.	We aim to develop competence in the use of common scientific equipment and techniques by providing every learner with regular planned opportunities in their use.	
	In planning practical work we identify the learning we seek students to achieve and make the purpose of the practical work clear to learners.	
	As well as practising individual skills, we challenge learners to work collaboratively in designing and carrying out scientific investigations, in discussing the evaluation of collected data and in reporting and presenting their findings.	
	In planning practical work for our learners, we ensure that the level of demand is appropriate to the student and the level of course.	

Area of scientific literacy	What we do	Notes/required action/evidence
Scientific methodology Providing opportunities to participate in the practical work of doing science is a major part of our science teaching.	We challenge learners to use their data analysis skills to make decisions on how to process raw data so that they can make the most of their results.	
	We expect learners to write scientific reports on their practical work.	
Scientific decision making Recognising that science impinges on everyday life and being able to make personal decisions based on scientific evidence is an important life skill and a goal of our science teaching.	We include scientific knowledge in our curriculum that is relevant to the lives of our learners.	

Area of scientific literacy	What we do	Notes/required action/evidence
Scientific decision making Recognising that science impinges on everyday life and being able to make personal decisions based on scientific evidence is an important life skill and a goal of our science teaching. * A case study focuses on just one particular area of interest or concern. This can then provide a theme or context through which the learner gains insight to the underlying science. That is the case study provides the vehicle for a study that illuminates the general principles of science by examining a particular example of scientific endeavour. For example in Higher Biology a case study on cancer could provide a context within which to study DNA, gene expression and genomics.	We provide learners with opportunities for personal choice in the case studies* they research for scientific evidence.	
	We challenge learners to make decisions relevant to themselves, their communities and globally based on scientific evidence.	
	We expect learners to use evidence to make a case that supports a point of view while accommodating the views of others.	
	We develop our learners' ability to recognise hazards, manage risks and devise control measures that will keep themselves and others safe.	

Area of scientific literacy	What we do	Notes/required action/evidence
Scientific decision making Recognising that science impinges on everyday life and being able to make personal decisions based on scientific evidence is an important life skill and a goal of our science teaching.	We expect learners to be able to interpret, draw conclusions from and critically evaluate scientific data presented in a variety of forms.	
	We challenge learners to discuss the validity and reliability of experimental designs and reports of science (and non-science) in the media.	
	We expect our learners to have an appreciation of the impact science and technology has on everyday life.	

Below is an example where a group of teachers [13] used the QA instrument for scientific literacy for a mixture of self evaluation evidence and as a guide for future action.

Area of scientific literacy	What we do	Notes *(N)*/required action *(RA)*/ evidence *(E)*
Scientific knowledge Understanding science is the goal of acquiring knowledge and of our science teaching.	To develop understanding we focus on scientific knowledge that is important and powerful to learn.	*Notice board and word walls are used to highlight 'important science'.(E)*
	We have identified the areas of scientific understanding that we want out learners to achieve.	*Course content is tied to Es & Os, SAoL and benchmarks.(E)* *We need to look at the demands of H/AH and plan progression in the earlier stages to better prepare learners.(RA)*
	We expect learners to be able to use their understanding to explain phenomena, to form generalisations and to make predictions.	*In investigation reports, the discussion section requires learners to draw on their knowledge as well as experimental results.(N)* *Open ended questions do this, although we need to develop 'hints and tips' sheets to support learners.(E/RA)* *Prediction and generalisation questions are identified in past paper revision.(N)*
	We have identified the key concepts that underpin the big ideas of science that will lead to understanding.	*BGE topics are developed around a big idea in science and its underlying concepts and put it in a context relevant to pupils lives.(N)* *'Guided discovery' and 'thematic learning' are used to organise concepts into a progression.(N)* *Summative and formative tasks are used to track and monitor understanding of key concepts.(E)* *Does level 4 follow on / link to level 3?(RA)*

[13] The contribution of teacher participants in the SSERC course *Leading for Excellence in Science* to the development of these materials is gratefully acknowledged.

Area of scientific literacy	What we do	Notes *(N)*/required action *(RA)*/ evidence *(E)*
Scientific knowledge Understanding science is the goal of acquiring knowledge and of our science teaching.	We organise the teaching of key concepts into progressive pathways that will lead to understanding and where learning is not linear we collect concepts together so that learners can make the necessary connections that will lead to understanding.	*Traditional science topics that show a strong progression in key concepts have been retained.(N)*
	We challenge our learners to research instances and examples of key concepts through a case study approach* to deepen their understanding and to provide personalisation and choice in their learning.	*Science reporter of the week.(E)* *Choice of research topics linked to common key concepts.(E)* *Peer review and evaluation of research tasks.(N)*
	We challenge learners to apply their knowledge to new situations and to make connections between knowledge from different areas of science (including from other science subjects, mathematics and computing science). As teachers we are aware of the learning in other subjects that relates to our teaching of science.	*Happy with learners ability in handling information skills but less confident of their ability to transfer numeracy and calculation skills from maths to science.(N)* *Contribute to school IDL projects but don't see evidence of skills transfer to science learning.(N)* *Working to develop use of ICT throughout science courses.(RA)*
	We are aware of common misconceptions in science and check for their occurrence in learners both before and after learning.	*A member of staff is carrying out a research project on 'science misconceptions'. This research is discussed at DMs and potential pitfalls identified.(N)*
* A case study focuses on just one particular area of interest or concern. This can then provide a theme or context through which the learner gains insight to the underlying science. That is the case study provides the vehicle for a study that illuminates the general principles of science by examining a particular example of scientific endeavour. For example in Higher Biology a case study on cancer could provide a context within which to study DNA, gene expression and genomics.	We challenge misconceptions through the presentation of experimental evidence that contradicts the misconception and through discussion of alternative conceptions (e.g. presented as concept cartoons and/or as questions with multiple responses).	*Concept cartoons [14] are used and evaluated using pre and post assessment.(E)*

[14] http://www.millgatehouse.co.uk/product/science-concept-cartoons-set-2/.

Area of scientific literacy	**What we do**	**Notes *(N)*/required action *(RA)*/ evidence *(E)***
Scientific methodology Providing opportunities to participate in the practical work of doing science is a major part of our science teaching.	We provide our learners with a wide range of first-hand experiences of laboratory and field based practical work.	*Need to develop more field based practical work.(RA)* *Check that all teachers give classes the same (or similar) practical work by checking the use of equipment and materials through technicians.(E)*
	We aim to develop competence in the use of common scientific equipment and techniques by providing every learner with regular planned opportunities in their use.	*Introductory science skills unit.(E)* *Assess competence in skills from time to time during class practicals.(RA)* *Teachers demonstrate new or unfamiliar techniques.(N)*
	In planning practical work we identify the learning we seek students to achieve and make the purpose of the practical work clear to learners.	*In experiments, focus on the parts of the scientific method that is best suited to development in that experiment.(RA)* *Carry out a 'Practical Activity Analysis Inventory'.(RA)*
	As well as practising individual skills, we challenge learners to work collaboratively in designing and carrying out scientific investigations, in discussing the evaluation of collected data and in reporting and presenting their findings.	*Teams of learners are presented with real life tasks, situations or problems and challenged to design an investigation to solve the problem that is appropriate to their prior learning.(N)*
	In planning practical work for our learners, we ensure that the level of demand is appropriate to the student and the level of course.	*Review each practical to look at what different outcomes are possible as a basis for 'differentiation by outcome'.(RA)*
	We challenge learners to use their data analysis skills to make decisions on how to process raw data so that they can make the most of their results.	*Data analysis problem solving exercises that require learners to process and present given raw data.(N)*
	We expect learners to write scientific reports on their practical work.	*Do our investigation booklets hamper skills development at the expense of assessment?(RA)* *Develop poster style presentations to report experimental and investigative findings.(RA)*

Area of scientific literacy	What we do	Notes *(N)*/required action *(RA)*/ evidence *(E)*
Scientific decision making Recognising that science impinges on everyday life and being able to make personal decisions based on scientific evidence is an important life skill and a goal of our science teaching.	We include scientific knowledge in our curriculum that is relevant to the lives of our learners.	*Outdoor learning in locality examines indicator species.(E)* *Pupil voice contributes to curricular design.(N)*
	We provide learners with opportunities for personal choice in the case studies* they research for scientific evidence.	*Choice of related research topics (e.g. stem cell research topics include a range of conditions for which stem cell therapy may have a role).(N)* *CREST [15] awards are a curriculum elective.(E)*
	We challenge learners to make decisions relevant to themselves, their communities and globally based on scientific evidence.	*Decision making tasks require fully referenced sources.(E)* *Short (5 min.) informal 'so what do you think' sessions based on lessons or topical science news items.(N)*
	We expect learners to use evidence to make a case that supports a point of view while accommodating the views of others.	*Build on the debates, discussions and discursive essays we have been trying out. Liaise with the English Dept to consider their approaches while maintaining science outcomes.(RA)*
	We develop our learners' ability to recognise hazards, manage risks and devise control measures that will keep themselves and others safe.	*Introductory science lessons.(E)* *Discussion prior to practical work.(N)* *Present real life examples of hazard and risk and challenge learners to devise sensible and proportionate control measures.(RA)*
* A case study focuses on just one particular area of interest or concern. This can then provide a theme or context through which the learner gains insight to the underlying science. That is the case study provides the vehicle for a study that illuminates the general principles of science by examining a particular example of scientific endeavour. For example in Higher Biology a case study on cancer could provide a context within which to study DNA, gene expression and genomics.	We expect learners to be able to interpret, draw conclusions from and critically evaluate scientific data presented in a variety of forms.	*Revision past paper questions.(N)* *Exams require students to interpret more complex data than they are expected to produce. Students to process more complex data in class to improve their interpretation skills.(RA)*

[15] http://www.crestawards.org/.

Area of scientific literacy	What we do	Notes *(N)*/required action *(RA)*/ evidence *(E)*
Scientific decision making Recognising that science impinges on everyday life and being able to make personal decisions based on scientific evidence is an important life skill and a goal of our science teaching.	We challenge learners to discuss the validity and reliability of experimental designs and reports of science (and non-science) in the media.	*Download and use the learning materials based on Ben Goldacre's 'Bad Science'.(RA) [16]* *Develop materials similar to the Unit assessment for AH Biology Unit 3 for lower levels.(RA)*
	We expect our learners to have an appreciation of the impact science and technology has on everyday life.	*Weekly 'Science in the News' notice board.(N)*

[16] https://collins.co.uk/page/Bad+Science?

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ISBN 978-0-9933282-1-3.