



scottish
schools
education
research
centre

The Modern Science Teacher

A guide for new and recently
qualified science teachers

Jim Stafford



Acknowledgements

This guide is published by SSERC, a registered educational charity and a company limited by guarantee the corporate members of which are the thirty two Scottish Education Authorities.

SSERC's science, technology and safety services are provided for the elected members, officers, teachers and technicians of those Local Authorities and its other members.

Jim Stafford is a Senior Associate with SSERC working in the area of leadership in science education on a part time basis. Previously he has been a Principal Teacher of Biology, a Local Authority Science Adviser and Quality Improvement Officer. During his career Jim has also worked on a number of areas of science education on a part time basis and on secondment including leadership training, health and safety guidance and the development of national qualifications in biology.

Foreword

Successive generations of Scots have recognised and valued the vital role that education plays in their lives: as individuals, as citizens and as workers.

The twenty-first century educated Scot is no different. He or she will engage with enticing possibilities, exciting developments and enormous challenges throughout their lives, much of which will be driven by the impact of science, engineering and technology on how they live, learn and work. Twenty-first century living will increasingly require an ability to engage constructively with complex issues. Responsible citizenship requires an ability to discriminate between well-grounded evidence and well-packaged opinion. Citizens must have levels of scientific understanding which allow them to contribute effectively to major ethical debates such as are already being generated by developments in genetics and climate change, for example. The theories which underpin such issues will change in response to emerging evidence, as will the issues themselves. Our young people, therefore, cannot simply master an extant body of knowledge. During their time in school they must acquire the foundations for lifelong engagement with science.

Science and technology are also at the heart of economic success and wellbeing. Scotland will continue to need the kinds of scientists of all disciplines, increasingly as part of multi-disciplinary teams, who have made and continue to make such powerful contributions to scientific progress, nationally and internationally throughout recent history.

What does this mean for science education?

The first and most important point is that, as the OECD said in their 2005 report, 'Teachers Matter' [1]. The evidence that high quality teachers lead to high quality learning is powerful. Not only do young people enjoy greater success in measured outcomes, but they can also be inspired to enjoy learning for its own sake. Sparking and sustaining a passion for science starts from teachers who capitalise on the curiosity of young people from their earliest years and develop the kind of satisfaction in learning which comes from meeting real intellectual challenge throughout a school career and beyond. However, high quality teachers do not just appear. Sustained high quality teaching comes from a lifelong personal commitment to professional growth. Changes in the curriculum and in pedagogy are most likely to take root if those who are implementing change are also at least co-authors of that change. Teachers who routinely take part in critical reflection on the effectiveness of existing practice together with openness to new ideas will be central to the kinds of stimulating and effective practice which science education will demand now and in the future.

"The Modern Science Teacher" is designed to help make that culture of professional growth a reality. It is relevant for all science teachers, irrespective of whether they have recently qualified or have been teaching for many years. It supports the reflective and enquiring culture which should increasingly characterise all Scotland's schools and learning communities. Each section explores key aspects of science education. It provides philosophical and practical advice covering the 'why?' and the 'how?' of teaching and assessment. It also sets science education in its important, pivotal, position within the wider policy and professional environment of modern Scottish education. It should be seen not just as an invaluable resource for all teachers of science but also as an important point of reference for those whose decisions will set the context for the kind of high quality science education which Scotland's young people need and deserve.

Professor Graham Donaldson CB, *University of Glasgow*

Preface

Although this guide is intended for new and recently qualified science teachers, it should also be useful to those who support, supervise and manage new and recently qualified science teachers. Much of it may also be of use or interest to longer established teachers who wish to refresh their thinking about science education and to science teachers returning to the profession. Although set firmly in the context of the Scottish education system much of what is covered in this guide deals with fundamental issues of science education that will also be relevant to science teachers wherever they practice.

This guide attempts to address modern thinking on science education generally as well as current educational developments in Scotland. In developing the guide the views of probationer science teachers attending SSERC in-service courses were also sought and taken into account.

As part of Curriculum for Excellence science teachers now have the freedom and responsibility to devise a science curriculum appropriate to the needs and aspirations of their learners and to employ approaches to learning and teaching suited to their learners. This guide does not attempt to describe such approaches nor does it describe what a science curriculum should contain. It seeks to provide a ready reference point on the key issues that have to be taken into account when devising science courses for the 21st century. It also considers issues associated with the organisation of the science teaching laboratory including working with technicians and health and safety. Like all science teachers the new or recently qualified science teacher will wish to continue to develop professionally and so there are sections on CPD, action research and self evaluation. Finally there is a section on the involvement the new or recently qualified science teacher may have in school self evaluation and school inspection.

Reprint of the first edition (2018)

Information on SQA qualifications and HMI inspection procedures has been updated in this reprint to take account of changes since the first edition was published in 2013.

Contents

INTRODUCTION

1

PART 1 MAKING A START

1.1 Starting Your Teaching Career 3

1.2 The Teaching Laboratory 4

1.2.1 Laboratory organisation 4

1.2.2 Behaviour management 4

1.2.3 Laboratory maintenance 5

1.2.4 Working with technicians 5

1.3 Health and Safety in Science Education 5

1.3.1 The legal position 5

1.3.2 Safe practice 6

1.3.3 First aid and emergency treatment 7

1.3.4 Guidance on health and safety 7

1.3.5 Risk assessment 8

PART 2 DEVELOPING SCIENCE LEARNING AND TEACHING

2.1 Learning and Teaching in Science 9

2.1.1 The culture of science 9

2.1.2 Practical work 9

2.1.3 Progression in key concepts and skills 11

2.1.4 Learning intentions and success criteria 13

2.1.5 Homework 15

2.1.6 Learner motivation 15

2.2 Assessment 16

2.2.1 Purposes of assessment 16

2.2.2 Using test questions to support learning 18

2.2.3 Evidence of achievement 18

2.2.4 Breadth, challenge and application 20

2.2.5 Moderation activities 21

2.2.6 Assessment and SQA 22

2.2.7 Reporting 23

PART 3
CONTINUING TO MAKE PROGRESS

IN CONCLUSION

REFERENCES

2.3	Developing the Science Curriculum	24
2.3.1	Developing a curriculum framework for science	24
2.3.2	Developing scientific literacy	26
2.3.3	Developing health and wellbeing, literacy and numeracy through science	29
2.3.4	Developing skills for learning, life and work through science	32
2.4	Drawing the Curriculum, Learning and Teaching and Assessment Together	33
2.4.1	The misconception (or alternative conception)	33
2.4.2	The learning	33
2.4.3	Breadth, challenge and application	34
2.4.4	The curriculum design	35
2.4.5	The assessment	35
2.4.6	Action research and self evaluation	35
3.1	Continuing Professional Development	36
3.1.1	The impact of CPD on teaching practice	36
3.1.2	Keeping subject knowledge up to date	37
3.1.3	The GTC standard for full registration	37
3.1.4	CPD and the school improvement plan	38
3.1.5	SSERC and CPD	38
3.1.6	Education Scotland	39
3.1.7	SQA and CPD	39
3.2	Action Research	40
3.2.1	Carrying out action research	41
3.3	School Self Evaluation and Inspection	41
3.3.1	School self evaluation	41
3.3.2	Self evaluating your own work	42
3.3.3	School inspections	43
	IN CONCLUSION	45
	REFERENCES	46

INFORMATION BOXES

1) Expectations placed on the Modern Science Teacher	2
2) Laboratory Safety Rules	6
3) Some Common Science Misconceptions	12
4) Big Ideas in Science	13
5) Example of a Report to Parents of a Learner in S1 Science	24
6) Purposes of Learning in the Sciences (from Curriculum for Excellence Principles and Practice)	25
7) SQA Framework for Knowledge, Understanding and Skills in CfE Higher Sciences	26
8) Nuffield Foundation Definition of Science Literacy	27
9) The Framework for Science Reasoning from the Trends in Mathematics and Science Study (TIMSS) Survey	28
10) The Four Capacities of Curriculum for Excellence	31
11) SQA Framework of Skills for Learning, Life and Work	33
12) Key Features of Action Research	40

Introduction

This booklet is designed to support the modern science teacher in starting to address the expectations on him or her by providing a ready reference point on key issues. It does not attempt to be a complete manual on the teaching of science. As the expectations placed on the modern science teacher (Box 1) indicate, building the capacity to become a professional science teacher is a continuous career long process for which the individual science teacher has to take personal responsibility. This booklet represents the early stages of that process for new and recently qualified science teachers.

The booklet is designed to provide a point of reference on key issues and is organised into three parts. Part 1 *Making a Start* deals with establishing yourself in a science department, setting up your teaching laboratory and being aware of the health and safety issues of science teaching. Part 2 *Developing Science Learning and Teaching* looks at developing your craft as a science teacher. This is the most demanding part of this booklet. In recent times a great deal of educational research has been carried out on how children learn ideas about science, the impact of assessment and how science learning should be constructed. It is using that research evidence to inform and influence your teaching practice that is the great challenge to science teachers in the early part of the 21st century - what has simply been referred to as 'the hard stuff' of teaching. This expectation on science teachers to continually review and improve their teaching will become a career long process. This part of the booklet aims to draw together and summarise all the key information that will support your journey through that process. Part 3 *Continuing to Make Progress* deals with interacting with and contributing towards other sources and agencies with whom science teachers may become involved as they pursue their career.

Because this booklet is intended to be used as a point of reference there are occasions where issues are referred to in more than one section. Although this may appear repetitious to a reader who reads it through in its entirety, it is hoped that the benefits of this when used as a point of reference outweighs any inconvenience.



BOX 1

Expectations placed on the Modern Science Teacher

Scottish education requires 21st century professionals for 21st century learning. As well as combating social disadvantage, the Scottish education system is expected to deliver:

- raised levels of achievement;
- stronger literacy and numeracy skills in order to ensure that all children can progress in their learning and development;
- more challenging and interesting learning;
- a stronger and more consistent broad general education before young people embark on qualifications.

For a modern science teacher to contribute to meeting these expectations they will be expected to:

- have expertise in their science subject(s), pedagogy and educational theory that they keep up to date throughout their career;
- take responsibility for their own professional development and progress;
- contribute to the development of other teachers;
- engage in innovation and change that is based on research, thought through and well planned;
- evaluate the impact of what they do in relation to the improvement of children's learning.

Science teachers who wish to learn more about the issues facing Scottish education and consider their contribution to national endeavours in education should read the Donaldson report - *Teaching Scotland's Future* [2].

Making a start

1.1 Starting your teaching career

The new or recently qualified science teacher, or indeed any newly appointed teacher, will become part of a department where hopefully there will be an established learning and teaching programme. This means that the teacher will be able to develop their own approaches to learning and teaching in a supportive environment which has established learning strategies and resources. Blending in with an existing department is important as there is much to learn from experienced practitioners. Equally experienced practitioners have much to gain from the fresh eye of the new or recently qualified teacher. Learners often have a view and expectations of a particular subject or department and where these are positive it is good to be perceived by the learners as being part of that team. It is of course vitally important, whatever the circumstances, that the new or recently qualified teacher establishes them self (and their teaching) as a positive figure in the school community.

Where the subject or department is not supportive it is important not to become isolated and overwhelmed. Supportive relationships can be built with like minded individuals within a department, from other departments or from other schools to discuss, develop and share ideas, approaches and materials. Where there is little in the way of learning and teaching materials or the materials are poor, you will still have to comply with what is expected of you as well as having to develop your own materials and approaches to learning. It is important to do this in a way that is planned and achievable. Making use of what is to hand or can be obtained from others to fill the gaps, although not ideal, can help you to survive. Within that, the new or recently qualified teacher should develop a proportion of lessons of the quality to which they aspire. Then over time a suitable programme of learning and teaching materials can be built up. This is what good teachers in good departments do in any event (albeit from a higher base line) as part of a culture of continuous improvement. The lessons the new or recently qualified teacher builds up, whatever the situation, should be shared and made available to others in a spirit of collaboration.



1.2 The Teaching Laboratory

Hopefully the new or recently qualified science teacher will be allocated their own teaching laboratory rather than moving between laboratories. Establishing good teaching practices is more challenging where a teacher does not have their own laboratory. Where teachers are moving between laboratories it is vital that laboratories are equipped to a common standard with everyday apparatus and materials stored to a common pattern so that they are readily accessible in the same way in every laboratory. This assists learners as well as teachers in getting to know where things are. Once that is established the teacher can then go on to develop the individual character of their own laboratory.

1.2.1 Laboratory organisation

New or recently qualified science teachers are more likely to inherit a teaching laboratory rather than to get the opportunity to be involved in the design of a new laboratory. Scope for altering the layout of a laboratory may well be limited by fixed furniture and services. However where the opportunity for alteration to the layout exists a few key principles should be borne in mind. Areas for practical work are best separated from areas for written and other general classroom work. This may be difficult to achieve in terms of the available space so teachers will often have to organise the same space for both types of activity at separate times. This will involve teachers thinking about the timetabling and sequencing of activities during class time and establishing with learners the necessary routines for changing the work space for different types of activity.

Thought may also be given to having some learners engaged in practical activity while others are involved in other non practical activity. This can be more difficult to manage and here the key consideration is to avoid parallel activities that have a high demand for teacher involvement or supervision. If one of the activities can be relatively self directing then the success of the mixture of activities is more likely. From time to time an experiment may have to be left set up until a class returns. In such a case consideration will have to be given as to the best place to leave such apparatus so as to avoid conflict with the activities of other classes.

1.2.2 Behaviour management

Behaviour management can be an issue when carrying out practical work at the laboratory bench. In addition to laboratory rules and having a more general classroom code of conduct for learners there are specific practical measures that science teachers can take to reduce the potential of difficulties arising. Strategies to increase space for practical work and minimise movement can help. The distribution of gas, electricity and water services will limit the spacing of learners at the bench. However learners working in pairs or groups at a work station can help, although then issues of the allocation of tasks in a pair or group have to be addressed. Where learners are working at the bench individually it may be helpful to have an alternate non practical activity so that a rotation can be employed. Not only does space between learners help to avoid issues arising it also eases the movement of the teacher among the learners which has a calming effect. Movement of learners to collect apparatus and materials can be reduced by a number of class management strategies. If basic equipment that is used frequently at a work station (Bunsen, tripod, beaker, test tubes for example) is stored as a set adjacent to the work station then it will reduce the number of movements to a central collection point. Alternatively equipment can be set out prior to the lesson or at the start of the lesson. Tray systems with all the materials required for a particular activity will avoid several collections. Having multiple sets of solutions etc. is easier to manage than one solution which has to be accessed by all. Solutions in a class set of dropping bottles can be easier to manage than decanting from beakers. In general, class sets of

equipment help in reducing movement and waiting time. For example, consider a laboratory with one Bunsen lighter as opposed to one with three or more. Clearly there is a role for school science technicians in doing the necessary background work to help teachers achieve these aims.

1.2.3 Laboratory maintenance

Science teachers should take responsibility for the management of their own laboratory with the support of technicians and within the policies and practices of the science department. Equipment should be checked after use, maintained in a serviceable condition and replaced where necessary. Departments should have systems in place to ensure that happens. Equipment and materials used regularly for the delivery of courses should be in class sets where appropriate, be well organised, kept up to date and be readily available in the laboratory. Quantities of chemicals and consumable materials in the teaching laboratory should only be sufficient for class use, stocks should be stored elsewhere. Specialised equipment and materials for specific experiments are best stored centrally (often on a tray system) managed by technicians. Wall displays should celebrate learners work and relate to the work of classes. Wall displays should be changed regularly to maintain interest. Learners can be involved in that process. Science laboratories should be secure and thought given to secure storage within the laboratory as well as making the laboratory secure when no one is there.

1.2.4 Working with technicians

Effective technicians provide invaluable support to science teachers. Science technicians are key players in providing a quality science learning experience in schools. Schools should have systems in place where the roles and responsibilities of science technicians in supporting learning in science are clear. Technicians will manage the central storage, maintenance and repair/replacement of apparatus and equipment. In partnership with teachers they will do the same for teaching laboratories. They will also manage the central storage, maintenance and stock control of chemicals, radioactive substances, micro-organisms and other science consumables. They will prepare equipment and materials for science lessons through an established ordering system. Science technicians will have a programme for the on-going testing and servicing of laboratory equipment. Testing and servicing of equipment such as microscope servicing, fume cupboard testing and portable appliance testing (PAT testing) of electrical equipment is often scheduled during school holidays. Teachers and technicians should collaborate together in developing, devising and trialing new practical work for science lessons. Technicians can research, trial and refine experimental protocols to ensure that experiments are reliable and show results within a known time scale. Technicians can also devise and build simple laboratory apparatus and equipment for practical work.

1.3 Health and Safety in Science Education

1.3.1 The legal position

Health and safety in science education is the responsibility of the employing authority. Employers are required to provide safe working conditions, health and safety information and training for teachers and technicians and a Health and Safety Policy. They also have a duty of care for learners as non employees. Although the employer can delegate tasks and functions relating to health and safety to teachers and technicians, responsibility in the event of an accident remains with the employer unless there is gross negligence or disregard for instructions on the part of the teacher or technician. Fortunately very few serious accidents occur in school laboratories. It is a tribute to teachers that their practice is usually safe.



1.3.2 Safe practice

It is an important part of science education that learners are taught to work safely and responsibly. Learners are more likely to follow health and safety instructions if they understand why they are necessary. A code of practice for safe laboratory working, often as a set of laboratory rules (e.g. see Box 2), should be on display and discussed with learners. Learners should be trained in good working practices and be made aware of hazards, risks and control measures for specific practical activities. Learners should be supervised adequately while carrying out experiments and where appropriate have safe practice demonstrated to them before they proceed. The identification of significant hazards, the assessment of risk and the implementation of control measures are important life skills. Science education plays an important part in their effective development through the first hand experience of laboratory and field practical work.

BOX 2

Laboratory Safety Rules

(From *Safeguards in the School Laboratory*, ASE [3])

- Only enter a lab when told to do so by a teacher. Never rush about or throw things in the lab. Keep your bench and floor area clear, with bags and coats well out the way.
- Follow instructions precisely; check bottle labels carefully and keep tops on bottles except when pouring liquids from them; only touch or use equipment when told to do so by a teacher; never remove anything from the lab without permission.
- Wear eye protection when told to do so and keep it on from the very start until all practical work is finished and cleared away.
- When using naked flames (e.g. Bunsen or spirit burners or candles) make sure that ties, hair, baggy clothing etc. are tied back or tucked away.
- Always stand up when working with hazardous substances or when heating things so you can quickly move out of the way if you need to.
- Never taste anything or put anything in your mouth in the laboratory. If you get something in your mouth, spit it out at once and wash your mouth out with lots of water. Tell your teacher.
- Always wash your hands carefully after handling chemicals, microbes or animal and plant material.
- If you are burnt or a chemical splashes on your skin, wash the affected part at once with lots of water. Tell your teacher.
- Never put waste solids in the sink. Put them in the bin unless your teacher instructs you otherwise.
- Wipe up small spills and report bigger ones to your teacher.

1.3.3 First aid and emergency treatment

School science laboratories have an exemplary safety record and although accidents are rare, science teachers should be prepared to deal with any emergency that may arise. Strictly speaking the term ‘first aid’ should be reserved for the treatment of casualties by a First Aider who has followed an appropriate training course and who has an approved, current First Aid Certificate. It is the responsibility of the employer to have adequate and appropriate provision for first aid. All staff must be informed of a school’s first aid arrangements. Although science staff may wish to be trained as First Aiders, it should be borne in mind that the ability of a science teacher to respond immediately to a first aid situation outwith their laboratory may be limited if they have classes engaged in practical work. Science teachers should also consider arrangements for first aid during fieldwork.

Immediate remedial measures

For some potential accidents in science laboratories, serious injury may be avoided if those present take *immediate remedial measures* in the time before a trained First Aider arrives. Detailed advice on immediate remedial measures that should be taken in a science laboratory can be found in *Safeguards in the School Laboratory ASE* [3]. Immediate remedial measures may require access to some first aid equipment. Guidance on immediate remedial measures should be part of a science department’s health and safety arrangements. Information and training on immediate remedial measures should be available to science teachers and technicians. Situations where immediate remedial measures may be required include:

- chemical splashes in the eye, on the skin and chemicals in the mouth;
- inhalation of gases;
- clothing and hair on fire;
- burns;
- electric shock;
- cuts;
- asthma attack, anaphylactic shock, epileptic fit, fainting etc.

1.3.4 Guidance on health and safety

Science teachers should comply with the health and safety training and instruction they receive from their employer and with the health and safety policies and codes of practice that they provide. Useful sources of advice on health and safety matters can be found on the current SSERC website (www.sserc.scot). Another excellent source of advice is the ASE publication *Safeguards in the School Laboratory* [3]. Both of these are essential reading and reference material for all science teachers.

Each school should have a physics or chemistry teacher (usually the PT Physics) trained as a radiation protection supervisor (RPS) who is responsible for managing the health and safety arrangements for radioactive materials. Each school should also have a science technician and/or biology teacher who is trained to level 3 microbiology as defined in the SSERC Code of Practice *Safety in Microbiology* [4] to ensure the safe preparation and disposal of microbiological materials for level 2 class work as defined in the Code of Practice.



Image: Grant Cochrane/FreeDigitalPhotos.net

1.3.5 Risk assessment

Central to good health and safety practice is the process of risk assessment. It is the responsibility of the employer to assess and control risk and to communicate these risk assessments and their associated control measures to employees. In implementing an employer's risk assessments science teachers should make a comparison between the risk assessment and the particular circumstances of the class to be taught and the room to be used. Thus for individual science teachers risk assessment is a thinking process based on the employer's guidance and the particular circumstances of the class being taught. A useful way to engage in this type of thinking is to apply the *SSERC Risk Assessment 5 Step Template* [5] based on *Risk assessment: a brief guide to controlling risks in the work place* [6] published by the Health & Safety Executive (HSE) and summarised in the diagram below. Employers will have specific procedures for risk assessment that science teachers should follow.

FIVE STEPS TO RISK ASSESSMENT

1
LOOK FOR THE
HAZARDS

2
DECIDE WHO
MIGHT
BE HARMED
AND HOW

3
EVALUATE THE
RISKS AND
DECIDE WHETHER
THE EXISTING
PRECAUTIONS ARE
ADEQUATE OR
WHETHER MORE
SHOULD BE DONE

4
RECORD YOUR
FINDINGS

5
REVIEW YOUR
ASSESSMENT
AND REVISE IT
IF NECESSARY



Developing science learning and teaching

2

2.1 Learning and Teaching in Science

2.1.1 The culture of science

Learning and teaching in science should reflect the culture and values of science as a human endeavour. The scientific values of honesty and integrity that are part of scientific investigation in presenting results and drawing conclusions should be reflected in learning and teaching. Learners should work collaboratively, considering alternatives and contrary points of view. Information and evidence should be evaluated objectively and used to draw conclusions, provide explanations, form hypotheses and to make predictions and generalisations. Such evidence based decisions should be viewed as the best that can be made given present evidence and not as absolute truths. Science understanding is always reviewed in light of new knowledge and experience.

2.1.2 Practical work

Purpose of practical work

Science is fundamentally a practical subject; it requires first hand evidence obtained in real time by observation, experimentation and investigation to form explanations, generalisations, predictions and conclusions. In learning and teaching, science practical work can fulfill a number of educational purposes including to:

- illustrate scientific phenomena to support and develop deeper understanding;
- develop competence in practical techniques;
- develop valid and reliable experimental designs;
- generate data for subsequent analysis;
- test hypotheses and draw conclusions.

It is unlikely that a particular piece of practical work would fulfill all of these purposes, but the science teacher should always be clear about what learning the practical work is intending to achieve. It is important to bear in mind that lessons which involve practical work should always achieve a learning purpose - they should be 'minds on' as well as 'hands on'.

Technician support

High quality practical work in science is in many cases dependent upon good technician support. School science laboratories should be equipped with class sets of frequently used equipment and materials. Equipment and materials used less frequently should be stored centrally, organised and serviced by technicians. Many schools use a 'tray system' for such materials associated with particular lessons. The new or recently qualified science teacher should think through what they would wish to have in their laboratory and what should be available from technicians. Schools should have an ordering system for equipment and materials held by technicians. Technicians can also build simple equipment for

practicals and try out new practical protocols as part of development work. Technicians often welcome the challenge of being involved in this type of development work and in being present during science lessons in a supportive role. Developing good creative working partnerships with technicians can be of enormous benefit to the quality of science lessons.

Routine laboratory work

As well as a school's more general expectations for conduct, dress and tidiness, learners should also be trained in the general routines of laboratory work. They should know where equipment and materials are stored and how to access and return them. They should be trained in the safe use of equipment and materials and be aware of their responsibility for the cleaning and tidying up of equipment at the end of a lesson including the reporting of breakages and spills. School laboratories should have a set of safety rules and learners should be trained in recognising hazards and be informed of the control measures that reduce risk of harm. It is common practice to have a set of such safety lessons at the start of a course or programme of study. Safety measures should be incorporated into student materials and form part of every practical lesson. Schools should have their own set of Laboratory Safety Rules. An exemplar of a set of safety rules produced by the Association for Science Education is shown in Box 2.

Planning laboratory work

Practical work in science should make use of both individual and collaborative work as appropriate. Individual work is necessary if the aim is to achieve competence in a practical technique whereas the planning of an investigation can be more valuable if carried out collaboratively. Learners will need to be briefed as to the purpose of the practical work but should be given a degree of autonomy to plan and organise the allocation and sequence of tasks. Procedures are often best demonstrated to learners and the use of video cameras to display intricate procedures in real time can be helpful. Where learners are developing their own experimental designs, teachers will have to check to ensure that the proposed procedures are both practicable and safe.

The assessment of laboratory work

Much of what passes for the assessment of practical work is actually the assessment of what is produced as a result of the practical work rather than the carrying out of the practical work itself. For example the analysis and evaluation of results obtained or the assessment of a scientific report. There is much to commend assessing these skills and capabilities in the context of practical work but they do not assess the carrying out of the actual practical work. Assessing the carrying out of practical work is best done by observation perhaps by using a carefully devised checklist or by assessing the precision and accuracy of results or the quality of a product (for example the yield of a chemical preparation or the quality of a microbiological subculture). Where competence in a laboratory technique has to be assessed learners should have several opportunities to develop their competence built into their programme of learning. This in turn increases the number of opportunities to assess their competence, reducing the need for a high stakes assessment event with its attendant pressures for teacher and learners, and makes the assessment an integral part of the learning programme.

The assessment of practical work has created difficulty where activities that are best carried out collaboratively have to be carried out individually to provide evidence for assessment. In particular this created problems for Standard Grade investigations and contributed to the criticism that many teachers have for these activities. However these investigations were part of a

wider project The Assessment of Practical Skills (TAPS) which was based on research into learning in science. As a set of learning activities, rather than assessment activities, these materials have much to commend them for collaborative learning through science investigation as part of the Broad General Education.

2.1.3 Progression in key concepts and skills

What is a concept?

In science people often talk about concepts, big ideas and that which is important and powerful to learn without making clear what they mean by these terms. Although there are different views on what these terms mean, in general concepts are considered either to relate to objects with similar properties (e.g. birds, elements, gases) or scientific phenomena (e.g. diffusion, momentum). Concepts may then contribute to the understanding of a *big idea*, for example the concepts of states of matter, compounds and elements and combustion could all contribute to understanding the big idea of conservation of matter. Similarly the concepts of variation and selection contribute to the big idea of evolution and the concepts of temperature and conduction contribute to the big idea of kinetic theory.

Concept progression

Concepts should be built into pathways of progression that lead to big ideas. Such concept pathways are often built into curriculum frameworks. For example through the levels of SQA qualifications and as exemplified in the *Concept development in the sciences* [13] paper for the knowledge and understanding associated with the experiences and outcomes of the Broad General Education in Science.

Teachers need to be clear about the big ideas that they are trying to establish. It is difficult to establish a pathway of concepts if you do not know where you are going! There is not necessarily one fixed progression pathway; a variety of concept pathways can lead to a big idea. Teachers can adapt and amend concept pathways or develop their own pathways to suit their learners. Concept pathways are not always linear, that is one concept does not always depend on the one before it, sometimes it is an accumulation of concepts that support the understanding of a big idea. Progression pathways can also cover an extensive span of time; often we are building to an end point towards the end of schooling or even establishing the ground for learning beyond school.

Skills progression

In general concept progression is related to the development of scientific knowledge and understanding. Progression in the development of scientific skills is related to the complexity of the situations in which the skills are applied.

The skills of scientific enquiry and investigation are the same at every stage of learning. For example learners at all levels in science will draw conclusions; however the data from which they draw their conclusions will become more complex as their learning progresses. Experiments may involve more variables or have more confounding variables that have to be controlled. As they progress, learners' understanding of science ideas will depend on them drawing upon a wider range of data and information and integrating that into their thinking as they develop explanations, form hypotheses and make predictions and generalisations about science that are based on increasingly complex evidence. It is vital in addressing issues of progression in science learning that progression in the development of science skills is as much part of the learning as is the progression in concepts related to knowledge and understanding.

Misconceptions

A key part of developing concepts into a progression pathway is dealing with misconceptions. Misconceptions are often logical constructs that make perfect sense even although they are incorrect. For example, young children if presented with a glass containing ice cold water will explain the appearance of a film of

water on the outside of the glass as being due to the glass leaking rather than condensation. One of the intellectual challenges of sciences to the learner is to put aside a logical construct that is incorrect and replace it with a construct, which although it may appear counter-intuitive, can be seen to be true based on new scientific knowledge or evidence. This is a fundamental aspect of science, the modification of an explanation based on a deeper scientific understanding gained from new knowledge or evidence. Part of the skill of the teacher is to support learners in making those transitions in their understanding by providing challenges that make them question their own assumptions.

Using progression to support learning

One of the key aims of science education is to make science that is complex and difficult to understand simple and accessible to learners. In providing simplified explanations to support learners understanding we have to be careful not to create what may become misconceptions at a later stage. The way to avoid this is to think through the progression of concepts across levels and stages. Often it can be helpful to start from the highest level you seek to achieve and work backwards to identify the underlying concepts in the progression. In science a large range of evidence is often gathered from which a big idea or theory is developed and teaching often follows this process. From a learning point of view it is equally valid to introduce a big idea, theory or construct at an early stage and then develop the underlying detail to develop deeper understanding. Both these approaches can be part of a progression pathway and it is for the teacher to decide the approach that best suits their learners.

BOX 3

Some Common Science Misconceptions

- Classification is mutually exclusive rather than hierarchical (for example an organism can be classified as both a bird and an animal).
- Plants get the raw materials for growth from the soil.
- Adaptation is a process of adjustment rather than due to variation and selection.
- When liquids evaporate they disappear.
- When nails get rusty they lose weight.
- The bubbles in a boiling liquid are bubbles of air.
- Under the same conditions metal is colder than plastic.
- Constant motion requires a constant force (failure to distinguish friction as a separate force).
- Heavy objects fall to Earth faster than lighter objects.

The way to handle misconceptions (or alternative conceptions!) is to provide evidence that challenges the misconception as a starting point for discussion, debate, research and experiment to find alternative explanations. Useful resources for science teachers who wish to explore this further include:

- Driver R. et al (1994), *Making sense of secondary science: Research into children's ideas* [7].
- Black P. and Harrison C. (2004), *Science inside the black box* [8].
- Jo Moules, Jo Horlock, Stuart Naylor and Brenda Keogh (2015), *Science Concept Cartoons Set 2* [9].

Science that is important and powerful to learn

Concepts that support understanding and enable learners to describe, explain and predict natural phenomena associated with the big ideas of science are powerful to learn and should be built into progression pathways. It is also important to provide learners with the opportunity to explore areas of science that are important to them, relevant to their lives and to the decisions they will have to make in life. Opportunities should be taken to progressively develop learners' understanding of the impact science has on everyday life in the 21st century and of the personal decisions they will have to make in relation to science issues that affect themselves, others and the environment.

BOX 4

Big Ideas in Science

Wynne Harlen in *Principles and big ideas of science education* notes:

- The goal of science education is not knowledge of a body of facts and theories but a progression towards key ideas which enable understanding of events and phenomena of relevance to students' lives.
- Identifying big ideas in science is a natural accompaniment to promoting inquiry-based science education.
- Current school science leaves many students untouched in developing broad ideas of science that could help understanding of things around them and enable them to take part in decisions as informed citizens.

Harlen W. (2010), *Principles and big ideas of science education* [10].

Progression in mathematical and literacy skills

Although concept development is often thought of in terms of scientific knowledge and skills, it also applies to the mathematical and literacy skills used in science. Here science teachers should have an awareness of the skills that their learners have in these areas and provide opportunities to use and develop these skills at appropriate points in their science learning. This is the true meaning of interdisciplinary learning; it is the transfer and application of knowledge and skills from one discipline to another by the learner.

2.1.4 Learning intentions and success criteria

Learning intentions and success criteria (the w.a.l.t. and w.i.l.f. seen in many classrooms) have been brought to the fore as a result of Assessment for Learning (AfL). Research (*Assessment for Learning - Beyond the black box* [10], 1999) shows that pupils learn more effectively if they know what they are expected to learn and what constitutes successful learning. This enables learners to assess themselves and helps them to understand what they have to do to improve. Thus learning intentions and success criteria

bring about more effective learning because they encourage the learner to take more responsibility for their own learning. It is vital to remember that it is getting pupils to take more responsibility for their own learning that leads to success, using learning intentions and success criteria is a mechanism for achieving that end.

Learning intentions for practical work

Much of the appeal of science lessons is in practical work where learners have to take responsibility for the work in hand. Hence the maxim 'the way to learn science is by doing experimental work'. The open ended, enquiry based investigative approaches of science may appear difficult to reconcile with stating learning intentions and success criteria because the outcome is unknown; it has to be found out. However the key to this is to identify the purpose of the practical work. It may be that the practical work involves planning and organising the execution of practical techniques to a standard of competence, or it may involve devising an experimental design, or it may involve following a protocol or procedure to generate data that is then analysed and evaluated. Once the purpose of the practical work is established then it should be possible to define the learning intentions and success criteria.

Being flexible about learning intentions and allowing for differentiation

In defining learning intentions and success criteria it is important to remain flexible. Although it is considered important not to have more than one to three learning intentions for any one lesson, that is something that is true for the learner not necessarily the



lesson as a whole. For example different learners may achieve different outcomes in a lesson and planning should allow for this. As pupils take responsibility for their own learning they may achieve different outcomes. That is why learning intentions and success criteria should be discussed and negotiated with learners. For example in a practical science lesson, learners may succeed in following a protocol, recording and presenting results appropriately and/or drawing different (yet valid) conclusions. The achievement of some or all of these is differentiation by outcome. In terms of setting achievable yet challenging goals by differentiation, differentiating by outcome is much more achievable for the teacher than differentiating by providing a range of different learning tasks which can quickly become unmanageable. Equally it is important to take advantage of learning opportunities in lessons as they arise. Such spontaneous opportunities can lead to learning that is both valuable and motivating for pupils, particularly if it has arisen from them, even although it is not part of the stated learning intentions and success criteria.

The key elements in all of this is giving responsibility to pupils for their own learning and the teacher processing the learning that has taken place towards the end of the lesson so that pupils can recognise what it is they have learned and what they need to do to improve. Learning intentions and success criteria are simply a means to that end.

2.1.5 Homework

Homework, attainment and learning

Research shows a positive relationship between homework and attainment. However there is no evidence that increasing homework is related to improved performance. Homework should be related to the learning taking place in the classroom. It can be designed to fulfil a range of purposes and the purpose of homework should be made clear to learners as should the expectations for successful completion. Homework can be used for revision and consolidation, which can give learners insight into the success of their learning and the required next steps and support for learning. However research shows that learners prefer interesting, challenging and variable tasks that are clearly defined and have adequate deadlines. Above all homework should be relevant to current learning, be purposeful and challenging.

Homework policy and feedback

There is much to commend discussing and negotiating homework strategy and policy with learners. The nature of and justification for homework tasks, the pattern of the homework programme and completion dates could all be negotiated and agreed with learners. Completion dates should also include deadlines for feedback on completed homework. Feedback could be by self, peer

or teacher assessment as appropriate and could be the subject for negotiation with learners. Feedback should support learning by helping learners identify what they need to do to improve. Research shows that comment only marking of several types (two stars and a wish for example) can achieve this whereas grades or marks have a negative effect. If marks or grades are to be used for feedback then their use should be justified and that justification should be made clear to learners so that they understand why it is being used.

2.1.6 Learner motivation

Motivation and achievement

Motivation is strongly linked to achievement. Learners who are highly motivated will be high achievers in absolute terms and in comparison with their peers and to their performance in other subjects where they are less motivated. Rehearsal and practice in past papers and excessive homework workloads as a strategy to promote achievement pale in comparison compared to encouraging motivation. That is not to say that coaching and mentoring learners in how to achieve is not valuable, however the focus should be on teaching how to learn so that learners develop strategies to overcome the challenges in their learning and to make the knowledge they have more accessible. These 'hints and tips' to aid understanding are key components in the teacher's repertoire to develop motivation in learners.

Motivation and learner responsibility

Motivation is improved where learners take responsibility for their own learning. In science this allows learners to be creative in formulating their own questions and hypotheses for investigation and in planning and designing experimental work. Responsibility is often best shared with others in collaborative work where ideas can be refined through listening to others and taking differing points of view into account. These kinds of experiences give learners the opportunity to think and make decisions in the same way that scientists do. Similarly collaborative learning activities that involve making decisions on the analysis and presentation of data collected by experiment provides actual scientific experiences as does the predicting, inferring and drawing conclusions from data collected at first hand.

Motivation and the culture in the teaching laboratory

Teachers can do much to create motivated learners by the culture and climate they create in the teaching laboratory. By creating an interesting scientific environment in the laboratory and emphasising relevant applications of science to everyday life, learners are then more likely to engage with their learning and develop scientific literacy skills. Learners can be involved by preparing displays of their work or by preparing displays or presentations on current science issues in the media. Over time teachers can develop a collection of regularly refreshed relevant themed displays of images, video clips, models, science equipment and artifacts to create interest. Teachers should have a spirit of partnership and cooperation with learners and share with them what is to be learned and the standards expected. Science learning should have an appropriate level of challenge that leads to success and personal satisfaction. Teachers should seek learners' ideas on science and value them in a sensitive and constructive way. Learners should receive regular supportive feedback on their work that identifies and rewards progress and identifies next steps for learning.

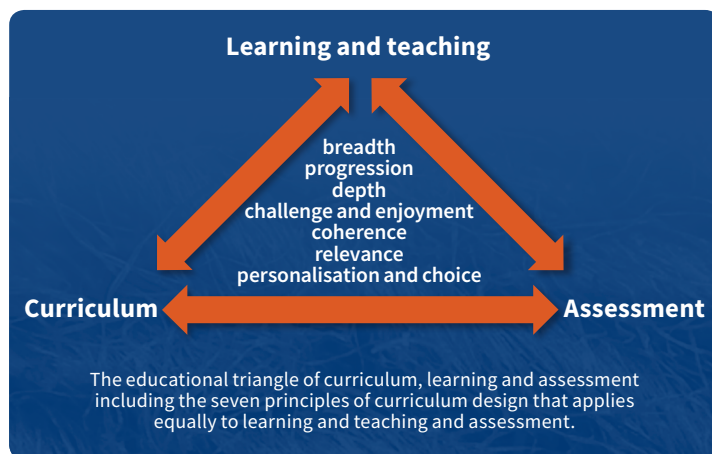
2.2 Assessment

2.2.1 Purposes of assessment

Assessment can fulfill three main purposes. It can be used to support learning, to monitor individual progress and to assess key milestones in learning.

Assessment and learning

Assessment should not be seen as separate from learning. Curriculum design, learning and teaching and assessment form an interconnected educational triangle. Efforts should be made to bring assessment and learning close together. Learning activities can provide evidence for assessment and assessment activities can provide opportunities for learning. Indeed, in an ideal world, the only difference between an assessment activity and a learning activity should be the conditions under which it takes place and the use that is made of the evidence of learning produced. Even then teachers should not become overly concerned over 'test conditions', the quality of the evidence used for assessment is often more important than the conditions under which it is gathered. The everyday activities of learning science can provide evidence of achievement of learners in what they say, write, make or do. By employing such an approach, teachers are more likely to achieve the holistic assessment that modern thinking about assessment demands.



Forms of assessment

In recent years there has been much discussion and debate on the value and purpose of assessment in science education. In this debate views can become polarised with some forms of assessment being viewed as a bad thing and other forms of assessment being considered a good thing. What often gets lost in this debate is that it is the purpose of assessment that is important and different forms of assessment are suited for different purposes. It is a question of using the appropriate form of assessment for a particular purpose. All forms of assessment can progress learning and it is in that way that assessment should be judged - what contribution does it make to learning?

Assessment that is embedded into teaching to support learning is often described as formative. Assessment that summarises where a learner has reached at a particular time is often described as summative. Unfortunately this distinction has led to some people thinking there are two forms of assessment, formative and summative. This is not the case; it is the use that is made of assessment evidence that is critical. To resolve this dichotomy emphasis is now put on the way assessment evidence is gathered. *Ongoing* assessment is the gathering of evidence from learning as it progresses and *periodic* assessment is evidence of learning at a particular moment in time either from accumulated evidence or from an assessment event.

Conditions for assessment

Much learning is collaborative and assessment to support learning and to monitor progress can be gathered when learners are working collaboratively. In the assessment of key

milestones, particularly for certificated qualifications, it may be necessary to impose conditions where the evidence generated for assessment is the sole work of the learner.

Assessment to support learning

What is referred to as formative assessment is based on the constructivist approach that learners make sense of their learning by relating it to what they already know. Therefore it is important that both the teacher and the learner know 'where the learner is at' in terms of the ideas they have that will form the basis of new learning. Merely adding new ideas to those that the learner already has may lead to poor understanding rather than *depth* of understanding and at worst will lead to confusion and learning by rote. Identifying the ideas that are the starting point for students' learning involves discussion and dialogue between learners and teachers. Both the teacher and the learner need to know the ideas that form a starting point in order to progress to the identified learning intentions. This involves challenging activities that will make learners think along with feedback and interventions from teachers to direct their learning. This approach is widely covered in initial teacher education and neatly summarised in the booklet *Science inside the black box* [8] published by King's College, London.

Much research has been done on misconceptions and ideas that learners hold about science concepts. This information can be valuable in raising the awareness of teachers about the kinds of misconceptions they may encounter when establishing the ideas learners have about science. There is much to commend teachers pursuing their professional reading by researching the commonly held misconceptions that learners have in their particular science subject area (see Box 3).

Tests, question papers and other assessment events

What is referred to as summative assessment is often regarded as a necessary evil. The impact of tests can be to focus attention on 'the desired answer' and examination technique which can lead to drilling and practice of response rather than developing understanding. Marking and grading with its attendant comparisons of learners can demoralise less successful learners lowering the self esteem (and with it performance) of all but high

attaining learners. Even high attaining learners can develop an antithesis to developing understanding if they are rewarded for rote learning that achieves high scores. The challenge therefore is to make summative assessment a positive learning experience as there is always likely to be a demand for the education system to grade students.

Making test question papers a positive learning experience involves both a philosophical approach by the teacher as well as practical measures. The teacher has to believe that learning designed to develop deeper understanding will result in better attainment than approaches based on drilling and practice that focus on expected answers. The research evidence that underpins the 'black box' booklets shows this is the case. That is not to say that teachers should not prepare learners in examination technique, it is a question of how that is done - it is a question of 'teaching *for* the test' rather than 'teaching *to* the test'.

2.2.2 Using test questions to support learning **Learning from test and examination items**

There is a responsibility on tests and examinations to support learning. A good assessment item that requires thinking can also be used for learning. Assessment items should show progression in the same way as learning by moving from knowledge and skills that are likely to be secure to more challenging ideas. In this way candidates are supported in providing responses by, for example, moving from smaller ideas to big ideas in the same way as they do in developing their learning. In assessing breadth of learning, candidates should be making connections between the ideas they have that goes beyond straightforward recall. In assessing challenge and application in unfamiliar contexts, candidates will learn new science as well as being assessed. In this way test items are encouraging learners to develop a deeper understanding of science by thinking about and

applying what they know and can do. Open ended questions can be used as a stimulus for discussion, debate and research in class. Questions on experimental procedures and data analysis can be used to develop skills in the evaluation of scientific research and reports. SQA past papers can be analysed to find the questions that provide such opportunities and be used or adapted as learning experiences. Such analysis as well as providing learning experiences will also give science teachers insight into the construction of question papers. Students' responses to assessment items can also be used to provide feedback to learners on knowledge and skills that are secure, consolidating or developing, to identify next steps in learning and what support for learning is required.

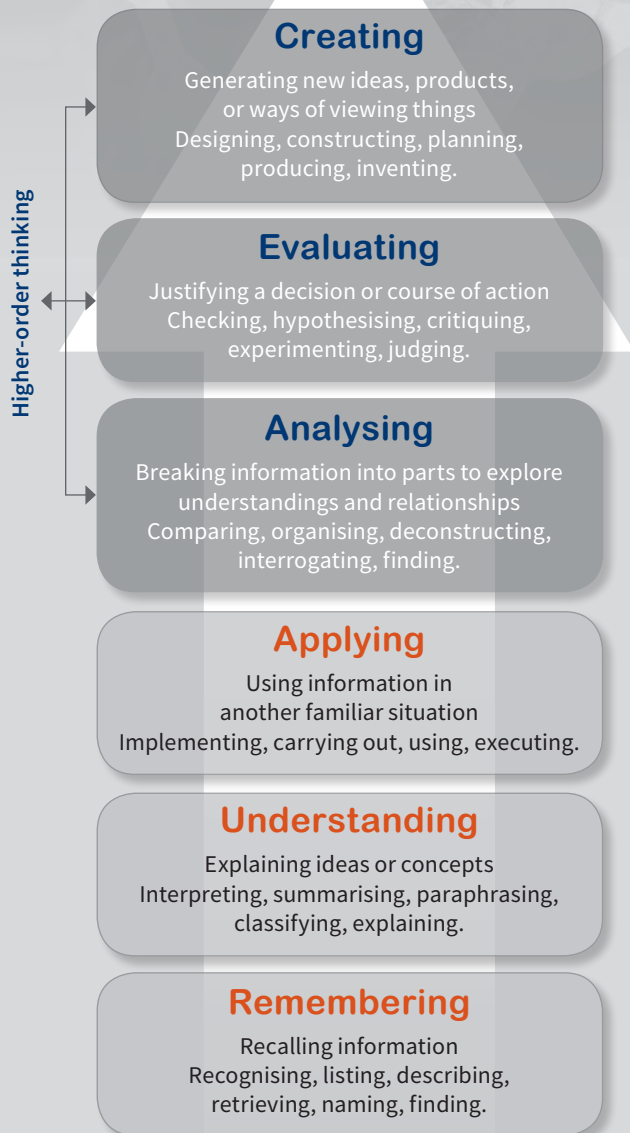
Learning about assessment

Exam confidence and examination technique are improved by engaging students in learning about the nature of tests and examinations. Self and peer assessment of tests helps learners to understand the assessment process and to identify areas for improvement in their learning. By devising marking schemes for tests collaboratively in groups, learners can sort out wrong ideas and develop their thinking. This can then be further developed by comparison to official mark schemes. It is important that teachers are patient and wait until learners reveal and reflect upon their various ideas and thoughts before they intervene. In some areas of science it has been shown that learners trained to generate and then answer their own questions outperform comparable groups prepared in conventional ways. None of this is revolutionary; students who collaborate with their peers when revising often come up with these approaches of their own accord. These practices provide more meaningful learning than the drilling and practice often encountered in supported study activities.

2.2.3 Evidence of achievement

As teachers gather evidence of learners' progress from their everyday work in what they say, write, make or do they will see evidence of achievement at a particular level. They will also gather evidence periodically from accumulating examples of this everyday evidence and from assessment events. Teachers within a department will want to discuss this evidence and agree what evidence exemplifies a particular standard. In recognising an individual learner's achievement at a particular level, teachers

REVISED BLOOM'S TAXONOMY



will want to decide if the learner is secure, consolidating or developing in their achievement. To make these decisions teachers will want to consider their evidence against the knowledge, understanding and skills of science to be acquired and the attributes of the Four Capacities as they relate to science. In making decisions about secure, consolidating or developing useful resources to draw upon are the descriptions of breadth, depth and application of learning below, the higher order thinking skills in Bloom's revised taxonomy and the broad features of assessment in *Curriculum for Excellence: Sciences Principles and practice* [12].

Assessment in the Broad General Education

In the Broad General Education, periodic assessment can be derived from ongoing assessment information derived from young people's learning experiences if it is reviewed against the descriptions of achievement at different levels as exemplified by the Experiences and Outcomes and Benchmarks. It can also be arrived at by checking what learners can do at a certain time by giving tests or special tasks. The tests or special tasks are likely to have a limited set of test items which will not provide evidence of achievement for all the learning goals of the Experiences and Outcomes and the associated Benchmarks and so there will be a degree of inference in the achievement of a particular level. Whichever approach is adopted, or a combination of the two, moderation of assessment information will be required to establish a confident and secure agreed understanding that the standard for a level has been achieved.

Assessment in the Senior Phase

In the Senior Phase SQA is responsible for the assessment of achievement. The following National Qualifications are available:

- National 3, National 4, National 5, Higher and Advanced Higher Biology;
- Higher Human Biology;
- National 3, National 4, National 5, Higher and Advanced Higher Chemistry;
- National 3, National 4, National 5, Higher and Advanced Higher Physics;
- National 3, National 4, National 5 and Higher Environmental Science;
- National 2 Science in the Environment;
- National 3 and National 4 Science;

- National 3, National 4, National 5, Higher and Advanced Higher Computing Science;
- National 2 Information and Communications Technology;
- National 4, National 5, Higher and Advanced Higher Engineering Science;
- National 5 and Higher Psychology;
- National 4 and National 5 Practical Electronics;
- National 5 Laboratory Science: Skills for Work Course;
- Statistics Award (SCQF level 6) a free-standing Unit.

Although Unit assessments will be removed from National Courses at National 5 and above, the Units will remain available as free-standing qualifications should teachers wish to use them. In addition free-standing Units from previous SQA courses in Biotechnology, Geology and

Managing Environmental Resources also remain available as qualifications. Units are assessed on a pass/fail basis; they are not graded. Unit Assessment Support Packs (UASPs) are available from the SQA Secure web-site via your school SQA coordinator. Units are marked internally by teachers and are subject to verification by SQA.

SQA also offers the Scottish Baccalaureate in Science - a group award comprising a selection of Advanced Higher and Higher qualifications along with an Interdisciplinary Project.

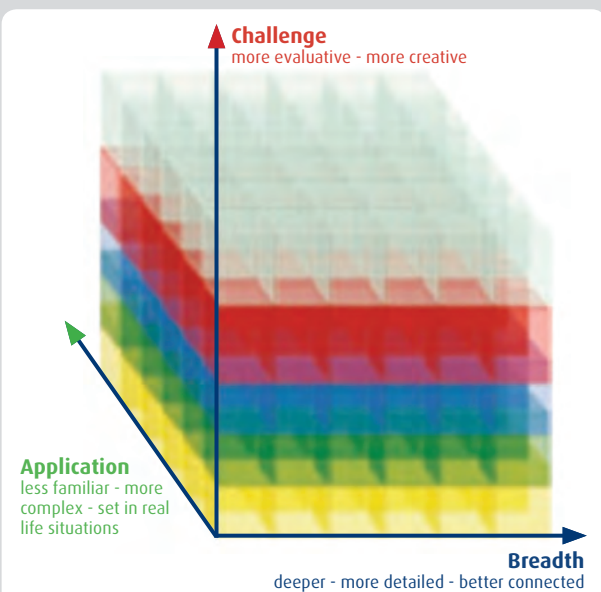
To achieve a course award at National 2 and 3 candidates must pass all the Units that comprise the course. At National 4 candidates must pass all the course Units and an Added Value Unit to achieve a course award. Courses at National 2, 3 and 4 are awarded as pass/fail; they are not graded. National 5 and Higher courses will be assessed by a Question Paper and an Assignment and graded on the marks achieved in both of these assessment components. Advanced Higher courses will be assessed by a Question Paper and a Project and graded on the marks achieved in both of these assessment components. Question Papers, Assignments and Projects will be marked externally by SQA. Flyleaves for submitting candidate Coursework can be found on the SQA secure website.

2.2.4 Breadth, challenge and application

Breadth, challenge and application are key features of assessment. They are also key features of the curriculum and of learning and teaching, further demonstrating the interrelationship between and the need for a coherent approach to the educational triangle of curriculum, learning and assessment.

Breadth

Breadth does not only refer to knowing more, it also refers to the integration of what is known and being able to see and make connections between existing knowledge and to new knowledge. It involves the learner in processing their knowledge into categories and hierarchies, thus improving their recall and ability to draw on their knowledge for different purposes including developing a deeper understanding. Breadth also encompasses depth where the learner acquires more detailed knowledge in specific areas as they make progress in developing their understanding. Establishing deeper understanding leads to creating fuller and better explanations.



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

Challenge

Challenge is associated with higher order thinking skills particularly, although not exclusively, with Bloom's revised taxonomy. In science the higher order thinking in Bloom's taxonomy applies to the skills of scientific investigation and enquiry. In particular learners should be applying skills of critical evaluation to the science research they read and be becoming more creative in their own experimental designs. Challenge in science is also associated with applying skills and knowledge in situations that are less familiar and more complex. This can be done by, for example, increasing the range of information and data or by increasing the number and type of variables to be considered.

Application

Application is about using the knowledge and skills of science in new situations. It is of direct relevance to learners in appreciating the impact of science and technology on everyday life and in making and justifying personal decisions about things that involve science. Application involves using existing scientific knowledge when interpreting new scientific information and/or data in textual, tabular or graphical forms. It can involve using a relationship, equation or formula to find a quantitative or qualitative solution to a scientific problem. It is also used in the creative processes of designing experiments and using knowledge and observations to formulate questions and hypotheses to investigate. The application of knowledge is used in drawing conclusions and in making predictions and generalisations.

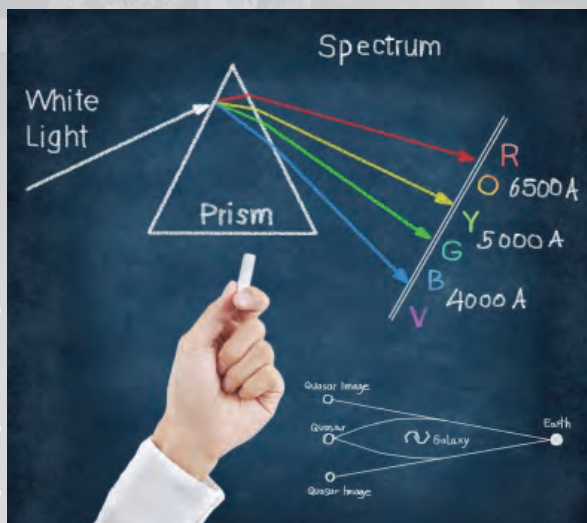
2.2.5 Moderation activities

Curriculum moderation

The purpose of moderation is to achieve a shared and clear understanding of expectations and standards. Traditionally teachers thought of moderation activity in relation only to assessment but it also plays an important role in developing the curriculum and in developing approaches to learning and teaching. The reflection and dialogue between teachers that takes place in planning the curriculum is a moderation activity. In planning the science curriculum for any particular class or group of learners, teachers will identify what the curriculum should achieve by working with sources such as the *Curriculum for Excellence: Sciences Principles and Practice* [12] paper to develop a clear understanding of curricular goals. By discussing learning activities and approaches to delivering the curriculum, teachers will develop a shared understanding of the science knowledge and skills that have to be developed and how that relates to previous and future learning as part of a planned progression. They will also consider how science connects to learning in other curriculum areas and how it contributes to the development of literacy and numeracy skills and to promoting health and wellbeing.

Assessment moderation

In moderating assessment teachers will seek to design instruments of assessment that are valid - that is they assess what the curriculum and the learning sets out to achieve. Validity is an important first step in the quality assurance of assessment. Such moderation should not only take place within a science department, it should also occur between schools and be compared to national standards to ensure that a common standard is being applied to all learners. Valid assessments along with applying assessment in the same way to all learners are crucial aspects in making assessment fair. Assessment must also be reliable - that is the same standard must be applied by all teachers. This can be achieved by teachers collaboratively devising mark schemes to agreed or given standards and by cross marking and engaging in discussion about the results to ensure that the standards are being reliably applied.



Involving learners in moderation

Learners should also be involved in moderation activity. Self and peer assessment (including learners devising assessments) gives learners the opportunity to apply the quality assurance processes of validity and reliability. By engaging learners in this type of moderation activity they will develop a clear understanding of the standards and expectations for their learning in science.

SQA and moderation

SQA uses moderation activity in the verification of its qualifications.

Question papers devised by item writers and examining teams are quality assured for validity against the assessment specification published in the course specifications by item checkers and assessment reviewers. Marking reliability is quality assured by markers being briefed by the examining team and then marking practice scripts. Markers then

progress to marking 'qualification' scripts where their suitability as markers is assessed. During marking live scripts, markers receive on-going support, monitoring and feedback on their marking from examining team leaders to ensure marker reliability. Opportunity exists for teachers to be involved in all of these stages of SQA procedures.

For qualifications that are set and/or marked by centres, verification of the assessment is carried out by SQA to ensure validity and reliability. Unit Assessment Support Packs (UASPs) are set to the Unit Assessment specification and checked in a similar way to question papers. Schools may devise their own Unit assessments (or modify existing UASPs) to the Unit specification and have them verified by SQA although few do so; most schools use the existing UASPs. The reliability of the marking of UASPs is verified by SQA checking a sample of a school's Unit Assessments. Normally this would be done at the first presentation and then at intervals thereafter to ensure standards are being maintained. Again there are opportunities for teachers to be involved in these procedures.

2.2.6 Assessment and SQA

Information on standards of assessment

As the body responsible for awarding qualifications, the SQA provides both information about its qualifications and opportunities for teachers to become involved in its awarding processes. The subject pages for science qualifications on the SQA website contain the Course Specification and Course Assessment Task (CAT) documents for each science subject, previous exam papers and marking instructions, data booklets and a variety of other publications for download. Of particular interest and importance are the Course Reports which comment on candidate performance in external assessment and the Subject Updates and Webinars which provide updates on assessment issues and advice for presenting teachers. Course Reports identify areas where candidates have performed well and found difficulty in Question Papers and Coursework. Schools receive information on candidates component marks for Question Papers and Coursework directly from SQA. There is also a link to the Understanding Standards website which aims to give teachers a deeper understanding of the marking in their subject.

The examples provide the opportunity to understand and apply marking standards and to compare your responses to experienced markers. In addition from time to time the SQA provides Understanding Standards Events for teachers - these are advertised on the SQA website.

For courses which are assessed internally by Unit assessment (National 2, 3 and 4) Unit Assessment Support Packs (UASPs) can be downloaded from the SQA secure website through your school SQA coordinator. The assessment packs contain unit assessments and marking guidance for teachers. The SQA secure website also contains a section on Understanding Standards for Unit assessment. Further advice for teachers on candidate responses to Unit assessment can be found in the Key Messages from the Unit verification process on the subject webpages.

Becoming involved in SQA assessment

There is also the opportunity for teachers to become involved in SQA procedures as an appointee. Information on becoming an appointee can be found in the appointee section of the SQA website. Teachers can be recruited as Question Paper markers, item writers, item checkers, and assessment reviewers. They can also be recruited as Coursework Assignment and Project markers and verifiers for Unit assessment. Teachers are expected to be currently delivering a course and to have a minimum of two years experience in presenting candidates for a qualification depending on the appointee position. Appointees gain valuable experience in their appointee roles which can benefit their teaching. Appointee positions are paid and release from school arranged where appropriate.

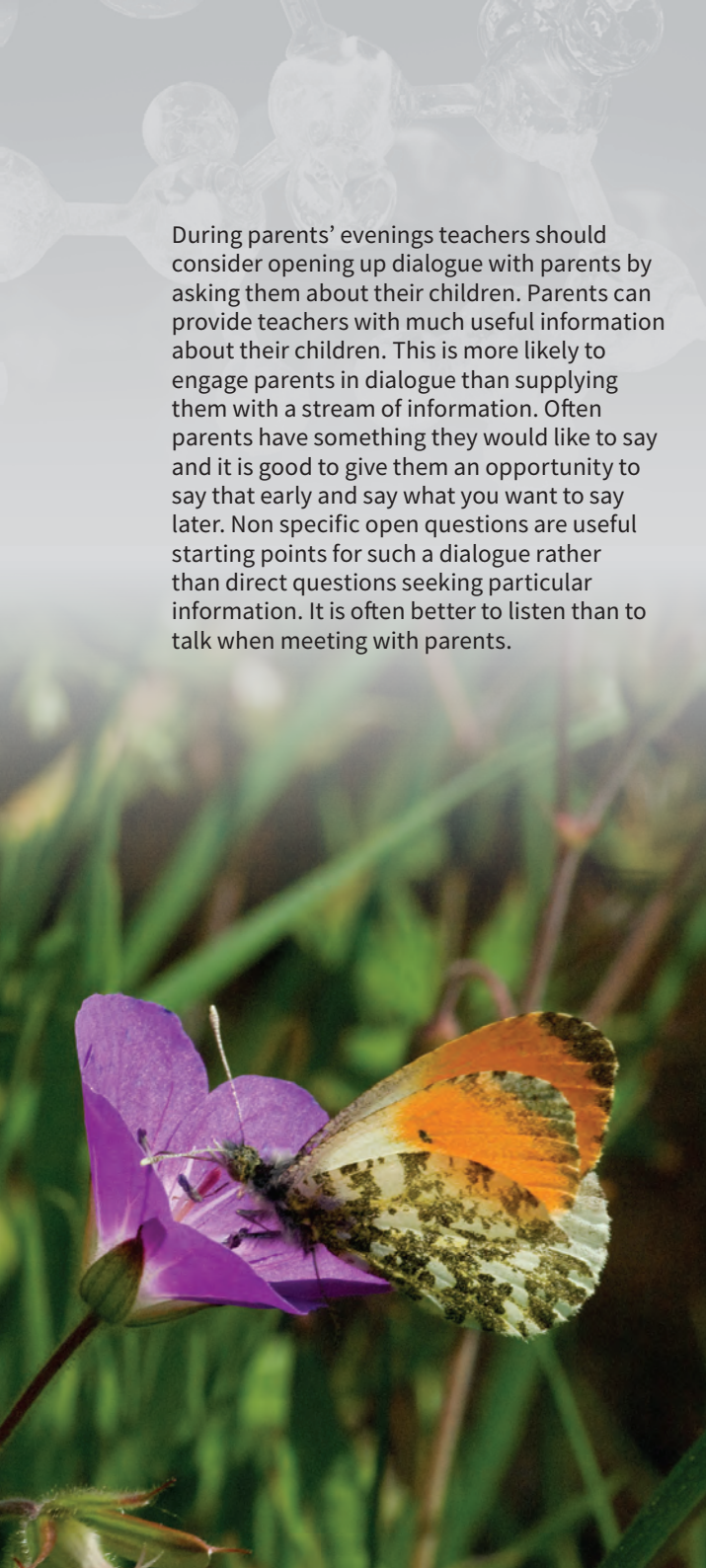
2.2.7 Reporting Reporting information

Reporting provides information for learners, parents and teachers about progress in learning, achievement and next steps. Much of the reporting to learners takes place informally through teaching interventions and ongoing formative assessment. Marking strategies for learners' work should be viewed as opportunities to give feedback and hence report on progress, achievement and next steps. Within a school there will be mechanisms to share such reporting within departments and other members of staff. Such mechanisms can be used to celebrate success through, for example, wall displays, assemblies and pupil presentations.

Reporting to parents

Schools will have processes for reporting to parents through written reports and parents' evenings often at planned specific times of the year. As well as more formal parents' evenings, schools may have more informal open evenings for parents to view the work of the school. These can provide opportunities for teachers to communicate the aims and purposes of science education to parents and to engage them in the types of activities that will be part of their children's science education. Such opportunities help parents to better understand their child's education and to make school reports more meaningful to them.

Schools will have specific formats for reporting to parents often at key points of a learner's journey through school such as after the 'settling in' period in first year, the profile produced at the end of the Broad General Education and after the school prelims in the Senior Phase. Reporting formats will have a structure and perhaps a bank of standard statements that teachers will have to work within. For example these may make use of the categories secure, consolidating and developing. Teachers should attempt to make reports personal conveying to parents that they know the learner well as shown in the example in Box 5.

A close-up photograph of a butterfly with orange and white wings, speckled with black and green, perched on a vibrant purple flower. The background is a soft-focus green field.

During parents' evenings teachers should consider opening up dialogue with parents by asking them about their children. Parents can provide teachers with much useful information about their children. This is more likely to engage parents in dialogue than supplying them with a stream of information. Often parents have something they would like to say and it is good to give them an opportunity to say that early and say what you want to say later. Non specific open questions are useful starting points for such a dialogue rather than direct questions seeking particular information. It is often better to listen than to talk when meeting with parents.

BOX 5

Example of a Report to Parents of a Learner in S1 Science

Julia shows interest and applies herself well in her science lessons. She is making good progress in learning and understanding science and is on track to achieve level three by the end of S2. She enjoys working with others but needs to develop confidence in developing and putting her own ideas forward. She is careful and methodical in carrying out experiments but needs to think more about the purpose, aims and design of practical work. Her work is always neatly presented and reported. She now needs to work on using her knowledge when drawing conclusions and discussing her work to identify limitations and improvements.

2.3 Developing the Science Curriculum

A science curriculum should foster the inherent curiosity learners have to understand the science they encounter as part of life in the 21st century. It should develop their experience of scientific knowledge in a structured and systematic way and develop skills of scientific enquiry and evaluation so that they are able to become scientifically literate citizens. The science curriculum will also, for some learners, provide a basis for further learning and future career pathways related to science and technology.

2.3.1 Developing a curriculum framework for science

Guidance on the science curriculum in Scotland is provided through Curriculum for Excellence for the Broad General Education and in the SQA Arrangements documents for qualifications in the Senior Phase. Teachers should use these documents regularly as a point of reference during their teaching. They should also be used when developing learning and teaching programmes and when monitoring and reviewing their teaching. It is important to read beyond the experiences and outcomes for Curriculum for Excellence and the content tables in SQA qualifications. *Curriculum for Excellence: Sciences Principles and practice* [12] and *Curriculum*

for Excellence: Sciences Concept development in the sciences [13] are essential reading to inform thinking about the science curriculum. In the same way SQA arrangements documents, in addition to guidance on assessment, include essential information on the skills component of courses and guidance on learning and teaching approaches that will help to inform the development of a science curriculum.

The main purposes for learning in the sciences from Curriculum for Excellence (Box 6) and the framework of knowledge, understanding and skills from the CfE Highers in the sciences (Box 7) are central to what is expected of a science curriculum in Scotland. These are not exclusive or stage dependent, both apply to science education at all stages and should be used as such. A number of other science curriculum documents are useful sources to consider when thinking about what a science curriculum should achieve. The framework for science reasoning from the TIMMS survey (Box 9) is useful when thinking about the skills of scientific investigation and enquiry. The Nuffield Foundation Definition of Science Literacy (Box 8) is useful when thinking about how science relates to and impacts on everyday life. This list is not exhaustive and there are other science curriculum frameworks that will also provide useful stimuli when thinking about developing a science curriculum in school. Teachers should also consider the attributes and capabilities associated with the Four Capacities of Curriculum for Excellence (Box 10) when devising a curriculum framework for their science courses.

BOX 6

Purposes of Learning in the Sciences

(from *Curriculum for Excellence: Sciences Principles and Practice* [12])

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.

BOX 7

SQA Framework for Knowledge, Understanding and Skills in CfE Higher Sciences

- Demonstrate knowledge of science by making accurate statements.
- Apply science knowledge to new situations, interpreting information and solving problems.
- Demonstrate understanding of science by providing explanations and by integrating different areas of knowledge.
- Select relevant information from a variety of sources.
- Present information appropriately in a variety of forms.
- Process information accurately, using calculations, where appropriate.
- Plan, design and carry out experimental procedures to test hypotheses or to illustrate effects.
- Evaluate experimental procedures.
- Draw valid conclusions and give explanations supported by evidence or justification.
- Make predictions and generalisations based on evidence/information.

2.3.2 Developing scientific literacy

Citizens of the future will live in an increasingly scientific and technological world. To be an effective and contributing citizen in that world a person will have to be able to identify the scientific issues underlying national and local decisions and express a position that is scientifically and technologically informed. By becoming scientifically literate they will also develop the important life skill of being able to pose and evaluate arguments based on evidence and to apply conclusions from such arguments.

Although there is a range of views about what constitutes scientific literacy, there are three elements which occur frequently in considering scientific literacy. They are:

- how things work - the knowledge of science;
- how science works - how science is done;
- making decisions - what is done with science.

Scientific knowledge

Science knowledge is a key component of the science curriculum. Although science knowledge has always been considered important for its own sake, the real value of knowledge is in developing understanding and using that understanding to suggest explanations, to make predictions and generalisations and to formulate questions for investigation. Learners should be able to ask, find or determine answers to questions derived from curiosity about everyday experiences. They should develop the ability to describe, explain and predict natural phenomena.

The curriculum should identify the knowledge that is important and powerful to learn. These key concepts should be identified and organised into progressive pathways over the curriculum levels to support the development of understanding. The knowledge content of the science curriculum should reflect current science issues that learners will encounter in the media so that science learning is not seen as separate from the real world. Knowledge should encompass a complexity of information to provide the challenges of integrating knowledge, applying knowledge and providing explanations appropriate to the curriculum level.

Scientific methodology

Learners should be engaged in scientific methodology, the doing of science. They should have first hand experience of observational and investigative science work. Although assessment for certification requires individual work from candidates, learners should work collaboratively to develop their scientific skills. As well as reflecting how science is done in practice, collaboration develops the communication skills of conveying ideas and points of view and accommodating the views of others. Scientific progress depends upon the sharing and debating of ideas, information and research findings. Learners should collaborate to formulate hypotheses to investigate, develop experimental designs, carry out practical work and evaluate experimental results. Reports of scientific investigations should be written in clear, succinct and unambiguous language so that they can be repeated by others.

Scientific decisions

An important aspect of scientific literacy is to make decisions based on evidence. Learners should be able to process raw data and present it in a suitable form so that trends, patterns and relationships can be readily seen. They should be able to interpret tables, graphs, diagrams and other forms of representing data. Learners should recognise a fair test and be able to evaluate the validity of experimental designs and the reliability of recorded data. They should be able to draw valid conclusions from data; and explanations, predictions and generalisations should be supported by evidence. They should be able to source, read and understand articles about science in the media and comment on the validity of the conclusions. Learners should be able to justify personal decisions and points of view about things that involve science based on evidence. They should be able to comment on and discuss the impact of science and technology on everyday life.

BOX 8

Nuffield Foundation Definition of Science 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.

BOX 9

The Framework for Science Reasoning from the Trends in Mathematics and Science Study (TIMSS) Survey

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.

2.3.3 Developing health and wellbeing, literacy and numeracy through science

All teachers have a responsibility to contribute to learning in Health and Wellbeing, Literacy and Numeracy as well as participating in interdisciplinary learning. Science naturally provides opportunities to develop learning about Health and Wellbeing, Literacy and Numeracy as well as presenting opportunities for other interdisciplinary learning.

Interdisciplinary learning

It should be remembered that the desired outcome of interdisciplinary learning is that learners have the opportunity to integrate their knowledge and ways of thinking from other disciplines with their science to raise questions, solve problems and offer explanations of the world around them in a way that they could not with science alone. This does not necessarily require a special project, nor a science teacher to teach outwith their own discipline, it can simply be the learner applying what they have learned in another discipline in the context of their science learning. Equally science learning can be applied in the context of learning in other disciplines and science teachers can contribute to that in an advisory capacity in the same way as teachers from other disciplines can contribute advice to science lessons. The key to this is establishing relationships with teachers from other disciplines so that you can learn what other learning pupils will be able to bring to their science lessons. It is important not to lose sight of the science content of lessons when addressing wider curriculum priorities and linking with other areas of the curriculum. Science lessons should achieve science learning intentions and provide the opportunity for other learning priorities and link to other curriculum areas where it is appropriate.

Health and wellbeing

Much of an individual's health and wellbeing depends on the decisions they make and these decisions can be influenced by their self esteem. The science curriculum provides extensive opportunity to learn the skills of evidence based decision making including contexts related to health and well being. In a wider context, public health policy is invariably evidence based and that can provide study material for both health related decision making and the scientific method. When learning to identify hazards, assess risk and suggest control measures in science, contexts can be explored that relate to the learner's personal health and provide them with the opportunity to reflect on and discuss their attitudes and values to their own health and wellbeing. In a similar way when considering the evidence on which ethical decisions on science issues are made learners can explore attitudes and values related to their own self worth and beliefs.

Literacy

Literacy skills provide the means by which science learners develop their science skills by thinking creatively and communicating with others. The skills of critical literacy are directly applicable to evaluating reports of scientific findings in general and more particularly to identifying attempts to influence and persuade in the reporting of science in the media. Literacy skills contribute to collaborating with others by making relevant contributions and taking account of others' points of view in, for example, the planning of investigations. Distilling key ideas from texts and summarising them is both a scientific and literacy skill. In communicating scientific findings, literacy skills are used in scientific report writing to describe methods, provide evidence for conclusions and to reflect on, evaluate and explain experimental approaches. The writing of scientific reports can be described as the functional writing of literacy.

Numeracy

Skills of numeracy have a long association with work in science. Calculations are used to solve problems and analyse information. In analysing data learners use numeracy skills to interpret and evaluate graphical data to comment on trends, patterns and relationships and to draw conclusions. Numerical and graphical data can be used to establish formulae and equations that can then be used to solve problems including algebraic manipulations. Numeracy skills are also used to select appropriate information from tables, charts, diagrams and graphs and to display continuous and/or discrete data appropriately. In comparing sets of numerical data, numeracy skills are used to find the mean, median, mode and range of sets of results and to carry out other statistical analyses using spreadsheets and other software. Scientific notation is used to express large or small numbers in a more efficient way. In evaluating experimental results numeracy skills are used to establish inaccuracy and error and to understand the impact they have on the confidence with which the results can be viewed. In genetics an understanding of probability can be used to predict the outcome of crosses and to solve problems.



BOX 10

The Four Capacities of Curriculum for Excellence

successful learners

with

- enthusiasm and motivation for learning
- determination to reach high standards of achievement
- openness 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 reasoned 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 informed choices and decisions
- evaluate environmental, 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

2.3.4 Developing skills for learning, life and work through science

The SQA has developed a framework of Skills for Learning, Life and Work (Box 11) to be used in the development of qualifications and in support of Curriculum for Excellence. It consists of five areas: literacy; numeracy; health and wellbeing; employability, enterprise and citizenship, thinking skills.

Literacy, numeracy, health and wellbeing

As part of meeting their responsibility for Curriculum for Excellence, science teachers will contribute to the development of learners' Literacy, Numeracy and Health and Wellbeing as described above.

Employability

The science curriculum should prepare learners for employment by engaging them in science activities that are relevant and related to the world of work including the use of ICT in capturing and displaying experimental data and in processing large data sets. In working with others in science, learners develop the work related abilities to influence and negotiate, to take ideas forward and to plan, organise and carry out practical tasks. The science curriculum should foster interest and enthusiasm in the applications of science that relate to areas of employment.

Enterprise and citizenship

In recognising the role of creativity and inventiveness in the sciences and appreciating the impact of science and technology on everyday life learners will learn about the use of initiative and innovation in science and how to be enterprising. In learning about the importance of honesty and integrity in scientific research and by having concern for the impact of science and technology on the environment and on the rights and responsibilities of others, learners will develop qualities related to leadership and citizenship.

Thinking skills

Science develops the thinking skills of remembering and identifying, understanding, applying, analysing, evaluating, and creating. Uniquely in science, because of its practical experimental approach, these thinking skills are developed through actual first hand experiences in real time as they are in the world of work.



BOX 11

SQA Framework of Skills for Learning, Life and Work

(Further more detailed information on the skills that contribute to each of the areas below is available from the SQA website.)

Literacy

This is the ability to communicate by reading, by writing, and by listening and talking.

Numeracy

This is the ability to use numbers to solve problems by counting, doing calculations, measuring, and understanding graphs and charts. This is also the ability to understand the results.

Health and wellbeing

This is the ability to take care of yourself and others, and to be responsible for your learning and welfare. It includes managing your feelings, developing a positive and active attitude to life and building relationships with others.

Employability, enterprise and citizenship

This is the ability to develop skills, understandings and personal attributes - including a positive attitude to work, to others and the world's resources.

Thinking skills

This is the ability to develop the cognitive skills of remembering and identifying, understanding, applying, analysing, evaluating, and creating.

2.4 Drawing the Curriculum, Learning and Teaching and Assessment Together

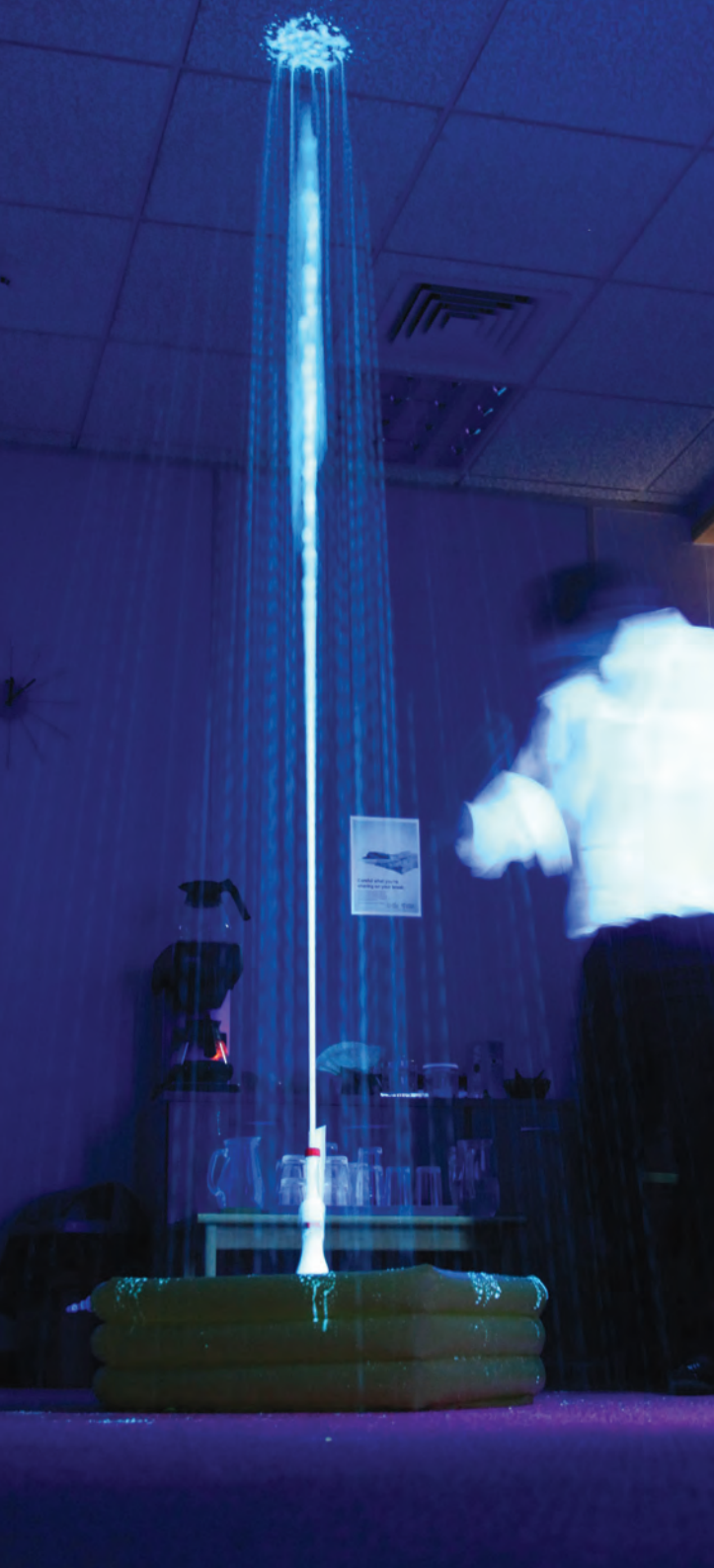
Reference has already been made to the interrelated triangle of curriculum development, learning and teaching and assessment. What follows is an illustration of how the principles outlined in these three sections of this booklet can be applied in science education. The example that will be illustrated relates to the idea of condensation. This is not intended to be a prescriptive approach it is merely an illustration to demonstrate the thinking that underpins science education in the 21st century.

2.4.1 The misconception (or alternative conception)

Young children if presented with a glass containing ice cold water will explain the appearance of a film of water on the outside of the glass as being due to the glass leaking. Although older children will probably still not hold this misconception, we can use the misconception to challenge their thinking about condensation. For example, teachers could develop their own concept cartoon by addressing the question - Where does the water on the outside of the glass come from? Possible suggestions to discuss could be: the water comes from inside the glass; the water comes from the air; water is attracted to the surface of the glass; cold things are always wet. Through addressing these questions learners should be encouraged to come up with possible explanations to account for the film of water. Not only should learners discuss possible explanations, they should also form hypotheses and test them experimentally and/or research other evidence to support their explanations.

2.4.2 The learning

Some learners may well suggest *condensation* as an explanation. On its own, the word condensation does not constitute an explanation; it is merely a term given to the observed phenomenon. Science learning seeks *deep understanding* that is conveyed by an explanation based on understanding, knowledge and where appropriate evidence. A suitable explanation might involve reference to the different states of matter and the conditions under which a change of state takes place. It might also make reference to relative humidity, saturation point and their relationship to temperature change.



2.4.3 Breadth, challenge and application

Deep learning requires not only deep understanding it involves breadth, challenge and application. In this case breadth might include an understanding of dew point, the formation of white frost and the conditions under which they take place. Breadth may also involve depth by providing explanations at a molecular level involving kinetic theory. Challenge could be addressed by seeking an explanation for precipitation (in the meteorological sense) that forms rain, snow, hail and mist. Other challenges could be to use what has been learned about kinetic theory to explain evaporation and the conditions under which it takes place or to explain the density of ice compared to water and the anomalous expansion of freezing water. Application could also involve social aspects related to real life by exploring condensation in housing and its social consequences as well as the explanation behind its management through heating, ventilation and insulation (e.g. controlling condensation on windows, ceilings, walls, cold water storage tanks and pipes).

Deep learning does not only involve using knowledge and understanding to provide explanations. The curriculum learning experiences that the teacher provides should also involve skills of scientific investigation and enquiry. There should be related relevant opportunities to plan, design and carry out investigations; to analyse and present data; to draw conclusions and to make predictions and generalisations; and to critically evaluate the scientific work of others. All of these experiences will be associated with outcomes for learning. These outcomes should allow for differentiation so that all learners can achieve at a level that provides them with a suitable level of challenge. Where some of these outcomes are associated with a particular level they can be used for reporting achievement at that level.

2.4.4 The curriculum design

Thought will have to be given to where condensation lies in a progressive pathway of concepts. Understanding of condensation may be supported by developing concepts of states of matter, temperature, heat, saturation and relative humidity first. Thought should also be given to the best way to sequence the concepts of melting, evaporation, condensation and freezing involved in the water cycle. Consideration will also have to be given to identifying suitable opportunities for science skills development through practical work. In particular in this area opportunities exist for hypothesis testing, experimental design and fair testing through controlling variables. There are also good opportunities with condensation for relating the science to real life as indicated above.

2.4.5 The assessment

Assessment has to match the curriculum design. That is we have to “assess what we profess” and assess the stated curriculum outcomes. Care has to be exercised that assessment is not merely nominal. Assessment has to go beyond naming and describing (in this instance condensation) and test the higher order thinking skills (in Bloom’s taxonomy for example) and breadth, challenge and application. In assessing skills the context should not be limited to a familiar context but should also provide opportunities to use the skills in contexts that are less familiar and more complex. In this way, by looking at the assessment of deeper understanding, teachers will be better placed to make judgments about learning being secure rather than consolidating or developing. A well designed curriculum and learning and teaching will naturally produce evidence of achievement in what learners say, write, make and do without excessive resort to

summative assessment. The focus of assessment should be on the broad areas included in the Purposes of Learning in the Sciences in Box 6 and the SQA Framework in Box 7 rather than curriculum minutiae.

2.4.6 Action research and self evaluation

All of the above can seem a daunting prospect but it is not expected to be completed in one year for the entire science curriculum! Rather this is a lifelong approach to science education that provides a basis for continuous improvement and progress. By monitoring the progress of learners against expected outcomes and by engaging in action research and its evaluation the science teacher will become the reflective self evaluating professional that 21st century science education demands.



Continuing to make progress

3.1 Continuing Professional Development

Although new and recently qualified science teachers will have undergone an intensive period of professional development in their initial teacher education it is important that the momentum of professional development is maintained throughout the science teacher's career. Schools, Local Authority education departments, other organisations and agencies will aim to provide continuing professional development (CPD) for science teachers. Although such support is of significant benefit to a teacher's professional development it is important that science teachers view their CPD as something in which they take the initiative and exercise control over rather than being something that is done to them or for them.

3.1.1 The impact of CPD on teaching practice

When seeking out and evaluating available CPD opportunities it is important to weigh up the impact that the CPD is likely to have on the teaching of science. Research has shown the kind of CPD that is likely to have an impact on teaching practice. For example, consider the matrix shown in the table below based on the research of Joyce and Showers. Presentations, lectures or reading about new ideas and approaches simply raises awareness of these issues, and although valuable in increasing knowledge, is unlikely to have any great impact on teaching. Observing someone modeling or demonstrating new ideas or approaches, either by visiting their classroom or by them teaching your class will lead to a greater understanding of what is involved. Then practising the approaches with your own classes will help you to develop your skills. If you then work with a colleague who can observe and give you feedback in these new approaches your skills will develop further. Coaching is less direct than feedback and uses open ended non judgmental questions to encourage you to reflect on your own practice and further refine your skills. This kind of process can give structure and substance to the opportunities that many schools now create for teachers to visit each others' classrooms. In this way science teachers can manage their own CPD by finding out about new ideas, observe others using them, practising them yourself and arranging for someone to observe you and provide feedback or coaching. Such exchanges need not of course be restricted to your own school; there is much to commend such movements between teachers from differing schools. When trying out new ideas and approaches it is wise in the first instance to do it with classes where the chances of success are high and leaving the more challenging classes until your skills are more highly developed.

TRAINING METHOD	LEVEL OF IMPACT			
	Raises awareness of new ideas	Develops understanding of underlying concepts	Acquire new skills	Embeds new skills in teaching practice
Reading, presentation or lecture on new skills	✓			
Observing the skills in practice	✓	✓		
Practise skills in workshops or with your own classes	✓	✓	✓	
Feedback on using new skills in the classroom	✓	✓	✓	✓
Coaching by peers in the classroom	✓	✓	✓	✓

3.1.2 Keeping subject knowledge up to date

Science teachers should also keep their knowledge of science up to date. Science is now such an expansive field that no undergraduate course can be all encompassing and the development of new scientific knowledge is becoming increasingly exponential. There is a danger that science teachers merely become experts in what they teach rather than experts in science. In an era where curriculum change is becoming increasingly frequent it is more important than ever to keep abreast of developments in science. There are opportunities to take additional science qualifications in higher education on a part time basis and in addition there are bespoke science courses, meetings and seminars, often organised by bodies such as SSERC, learned societies, educational trusts and further and

higher education that update subject knowledge. Science teachers can also keep up to date through professional reading about science. Increasingly employing authorities are recognising this as legitimate CPD activity. Where possible such reading should be used to do more than keep you informed. A useful focus is to discuss your professional reading with other science teachers and to consider the implications about what you have read for developing the science curriculum in your school.

3.1.3 The GTC standard for full registration

The probationer science teacher whether as part of the teacher induction scheme or by following the flexible route to registration will have much of their CPD activity based around meeting the requirements for the Standard for Full Registration (SFR) of the General Teaching Council for Scotland (GTC). Staff within a school will have a coaching and mentoring role in supporting you to meet the requirements for the SFR. Central to that process is an ongoing entitlement to professional review and development (PRD) which will continue throughout your teaching career and is

currently being reviewed by the GTC on behalf on the Scottish Government. It is possible to achieve the SFR in more than one science subject for appropriately qualified science teachers. Science teachers who wish to be qualified in a second subject should ensure as soon as possible that the experience they will gain in their probationary year will meet the requirements for full registration in both subjects. Information about all of these issues is available on the General Teaching Council for Scotland website.

3.1.4 CPD and the school improvement plan

As well as the personal review and development process being used to identify a science teacher's CPD needs, CPD needs are also identified through the school development or improvement plan. As all teachers are engaged with and contribute to the school improvement plan there is an opportunity to play a part in determining the CPD that will be made available to teachers through the improvement plan. In addition other CPD opportunities will arise and there should be sufficient contingency in a school system to take advantage of these opportunities as they arise. For example SQA professional development workshops may be available in science subjects and the Society of Biology, Royal Society of Chemistry and Institute of Physics all hold days for science teachers in May/June as well as various other courses and events organised by SSERC, further and higher education and learned societies and organisations.

3.1.5 SSERC and CPD

SSERC is a shared service funded by all thirty two of Scotland's Local Authorities, independent schools and further education colleges to provide guidance on health and safety and technical advice on science education through an advisory service and CPD. In addition SSERC is funded by the Scottish Government and the National STEM Learning Centre to provide CPD for science teachers and technicians at schools and colleges in Scotland.

New and recently qualified science teachers will be familiar with SSERC CPD through the Scottish Universities Science School, workshops for student science teachers and courses for probationer science teachers. SSERC also provides two part residential courses for biology, chemistry and physics teachers (and also for primary teachers), leadership training for science curriculum leaders and health and safety training. Other specialist short face to face courses are provided from time to time on various aspects of science education as well as interactive e-learning.

SSERC CPD aims to both develop teaching skills in relation to Curriculum for Excellence and to update science knowledge. Skills acquired in SSERC CPD two part courses are practised and applied back in schools with follow up and review in part two to support the acquired skills having an impact on laboratory teaching practice. SSERC publishes an annual calendar of CPD opportunities available on their website.





3.1.6 Education Scotland

Education Scotland provides a variety of resources and materials on its website that can be used to support CPD. New and recently qualified science teachers will be familiar with the science experiences and outcomes and the benchmarks that exemplify national standards but it is also important that they reflect on the Principles and Practice paper which outlines the key features for all science education. From time to time HMI produce a specific report on science education and the most recent of these *Sciences 3-18 Curriculum Impact Report, 2013* [14] provides a 'state of the nation' report outlining key strengths and aspects for development including links to useful reference documents, resources and organisations.

3.1.7 SQA and CPD

The SQA website science subject pages are essential reading for all science teachers as they contain the current course specifications and coursework tasks for each science subject, previous exam papers, marking instructions and data booklets. These documents are central to preparing candidates for qualifications. The subject course reports, also available on the website, identify areas where candidates performed well and found difficulty in the question paper and coursework. This information provides a useful starting point when reviewing teaching approaches and preparing candidates in the future. The course reports also contain information on grade boundaries and statistical information. Update letters from science subject Qualification Managers provide useful advice and information on delivering science qualifications. There is also a link to the Understanding Standards website which provides the opportunity to practice marking to SQA standards. Becoming involved in SQA procedures as an appointee is also useful CPD as is attendance at the subject Understanding Standards Events provided by SQA. Subject specific webinars are also provided on the subject webpages.

3.2 Action Research

There are different views as to what constitutes 'action research' and how it should be carried out often influenced by the background of the researcher, the outcomes they hope to achieve and the scale of the research. In the context of a practising science teacher the purpose of action research is to bring about improvement in *your* teaching and/or the learning of *your* pupils. In that sense it is personal to the teacher although you may wish to collaborate with other like minded teachers to increase the scale of the research. Box 12 lists the key features of action research. Further information on carrying out your own research on what works best can be found in the SSERC publication *Evidence Based Education - A guide for teachers considering carrying out their own school based research* [15] available for download from the Leadership pages in the Subject Areas section of the SSERC website.

BOX 12

Key Features of Action Research

The key features of action research are:

- The research forms part of the teaching process, it does not detract from or disrupt teaching
- Decide on a focus for the research. Action research does not require a precise hypothesis, nor do you need to begin with a specific question or problem although you may wish to do this. It could start from a general idea that something could be improved, based on a promising new idea or recognition that existing practice falls short of aspiration.
- Develop a plan for the research. Decide what evidence you want to collect on which to base your future decisions. This may be evidence from current practice and/or evidence gathered from new or changed practices. You may wish to include a control group for comparison. You will need to consider if your research has any ethical issues. Evidence may be data that already exists or you may have to collect new evidence. Evidence may be exam or test data, questionnaires or surveys, learners' work, observations, data on pupil choices, destinations etc.
- Analyse the data by looking for patterns or themes across the evidence. Use graphs, charts, diagrams, tables and statistical analysis where appropriate to analyse the data. Triangulate the evidence with other sources of evidence and with the experience and views of learners and your peers to increase the scope of your analysis.
- Evaluate your evidence in terms of conclusions, identifying future courses of action and further research where necessary.
- Share what you have learned with learners and colleagues within and outwith your own school and with parents as appropriate. Summarise your findings, conclusions and intended future actions in reports, presentations, posters, website posts, blogs or podcasts as appropriate. Remember, you do not have to justify your action research to others or convince them of its worth, you did it to inform and improve your own practice. What others do with it or think of your action research does not matter, the point of sharing with others is to provide them with information on a 'take it or leave it' basis.

3.2.1 Carrying out action research

In selecting an area or topic for action research it is important to be reasonably sure you can do something about the issue you have identified. You should take a pragmatic approach and identify something that you can influence and that is not beyond your scope. Also aim to address one small aspect of your work. While it might be true that you cannot change the world, you can certainly change your bit of it; and if everyone changed a small bit at a time, a lot of change could happen quickly. The value of carrying out action research is that it makes you think about your practice and seek ways to improve. This is the basis of what in some



Image: Lemonade/FreeDigitalPhotos.net

quarters is referred to as the 'reflective professional'. The strength of action research is that it has an evidence base and is not based on opinion, supposition or unfounded assertions.

The outcome of action research may not give a clear indication of how to improve. The changes to learning and teaching you have implemented may be no better than existing practice. The data collected may be inconclusive and shed no light on issues that could be tackled. You should not be disheartened by this. As you know from scientific research not all research leads to a scientific breakthrough! However the knowledge gained from such action research is valuable in contributing to your own learning and in the analysis there may be pointers as to further action research that could be undertaken. Research is often like this, you need to engage in a spiral of linked and progressive research projects to move from the present reality to the desired goal.

SSERC two part residential science subject courses require participants to undertake a 'gap task' between the two parts of the course. The gap task is an ideal opportunity to engage in action research where you can share the outcomes with your peers in a supportive environment.

3.3 School Self Evaluation and Inspection

3.3.1 School self evaluation

All secondary schools will have in place processes and procedures for their self evaluation. Often these are built around the improvement or development planning process, the production of a school Standards and Quality Report or its equivalent and its quality assurance processes for learning and teaching.

As a new or recently qualified science teacher you are likely to be involved in the school improvement planning process through the production of a science department improvement plan that contributes to the school plan or through a whole school process that engages all staff in the school improvement plan. This cyclical process will start with an evaluation of where the school or department is now in terms of what it has set out to achieve in its aims, vision and previous improvement plan. As a result priorities to be addressed with associated outcomes and success criteria are identified for the current development plan. Then task and targets for action are identified that should be specific, measurable, achievable, realistic and timed (SMART). Some of these tasks may be allocated to the new or recently qualified science teacher to implement, probably along with other teachers. Success criteria associated with these tasks should be set out in the improvement plan so that you can assess the impact of the improvement plan. Then the cycle returns to a process of review through self evaluation to inform future action and improvement planning.

The purpose of school and department improvement plans is to focus improvement work on agreed priorities and to reduce the development workload to a manageable level. In doing this schools will also consider the workload of the 'maintenance agenda' that keeps the everyday work of learning and teaching progressing smoothly. Funding resources (including teacher time) are often associated with the priorities in the improvement plan and so if science teachers are engaged in that work resources may be available to them to take development work



Image: Renjith Krishnan/FreeDigitalPhotos.net

forward. Funding may also be available for action research projects so again that is a way in which resources for development work can be available.

The outcomes of a school's development and improvement work as well as the results of its wider self evaluation will be reported in its Standards and Quality Report which will be made available to Local Authority managers, parents and other interested parties. It is a useful document to read if you are appointed to or are applying for a new school.

As part of a school's self evaluation there may be a programme of classroom visits to observe learning and teaching in addition to the coaching and mentoring associated with the Standard for Full Registration. If so there is likely to be a procedure that is followed so that the visits focus on learning and teaching to an agreed agenda with time arranged for feedback and discussion.

3.3.2 Self evaluating your own work

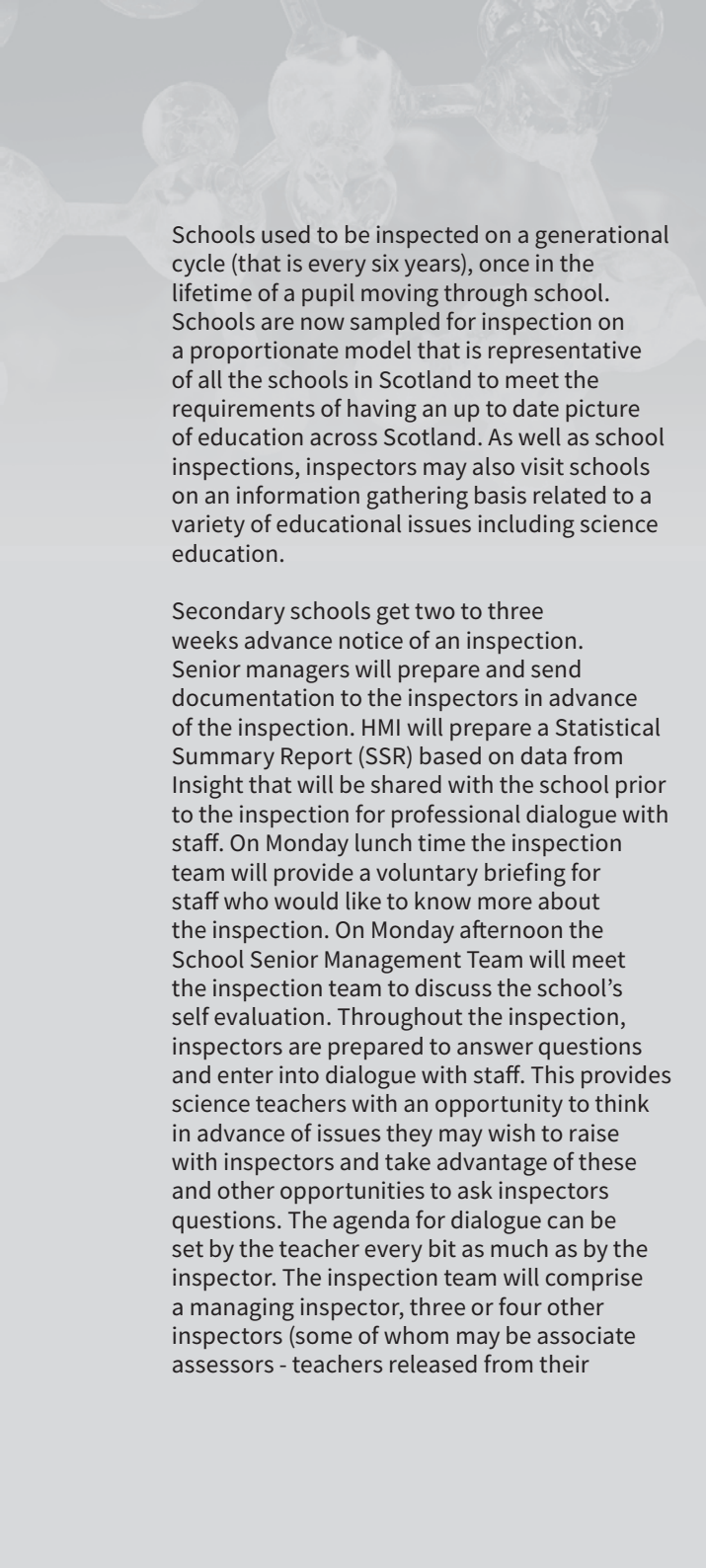
All science teachers should evaluate their own work. Much of school self evaluation is based on approaches developed by school inspectors (HMI). Schools use *How Good is our School? (HGIOS?)* [16] and other HMI publications on self evaluation (for example, the *STEM self-evaluation and improvement framework*) [17]. Although these publications are good for setting a framework for self evaluation they do not deal with the specific detail that science teachers may look for to develop their own standards for good practice. Science teachers should use these frameworks as a basis from which to develop specific standards for science learning.



Self evaluation is more than achieving a measured level of performance or making a comparison to others. Science teachers should be clear about the learning intentions of their lessons and the outcomes they set out to achieve. You are more likely to self evaluate successfully if you are engaged in devising the standards you aspire to achieve in your teaching. Documents that are useful in helping you to set the standards you hope to achieve in your teaching include: the Principles and Practice paper for CfE in the sciences (Box 6), the SQA frameworks for knowledge, understanding and skills in science subjects (Box 7), the TIMMS survey framework (Box 8), the Nuffield definition of science literacy (Box 9) and the capabilities of the Four Capacities (Box 10). SSERC has drawn all of these together in their publication *Quality Assuring a Science Curriculum* [18] available for download from the Leadership pages in the Subject Areas section of the SSERC website. From time to time HMI publish a report on science subjects. These are all worth seeking out, retaining for reference and reading closely. In particular the HMI report *Science: a portrait of current practice in Scottish schools* [19] is particularly useful for self evaluation as it identifies signposts for the characteristics displayed by successful learners and points for reflection on the types of learning experiences that support learners in achieving these characteristics. Once you have set out what you hope to achieve drawing on these resources then it is a case of retaining or gathering the evidence as to what extent learners have achieved these goals. That is the crux of self evaluation, and then you will have the supporting evidence to answer the questions that the more generic frameworks for self evaluation ask.

3.3.3 School inspections

From time to time secondary schools will be inspected by HMI. In addition some local authorities carry out visits similar to inspections by education authority staff such as quality improvement officers and teachers (often senior managers) from other schools. The model of HMI inspections changes from time to time and information regarding the current model can be found on the Education Scotland website. It is important to bear this in mind as when a school is informed of a pending inspection older staff may assume the inspection will take the same form that they have previously experienced when in fact it has changed.



Schools used to be inspected on a generational cycle (that is every six years), once in the lifetime of a pupil moving through school. Schools are now sampled for inspection on a proportionate model that is representative of all the schools in Scotland to meet the requirements of having an up to date picture of education across Scotland. As well as school inspections, inspectors may also visit schools on an information gathering basis related to a variety of educational issues including science education.

Secondary schools get two to three weeks advance notice of an inspection. Senior managers will prepare and send documentation to the inspectors in advance of the inspection. HMI will prepare a Statistical Summary Report (SSR) based on data from Insight that will be shared with the school prior to the inspection for professional dialogue with staff. On Monday lunch time the inspection team will provide a voluntary briefing for staff who would like to know more about the inspection. On Monday afternoon the School Senior Management Team will meet the inspection team to discuss the school's self evaluation. Throughout the inspection, inspectors are prepared to answer questions and enter into dialogue with staff. This provides science teachers with an opportunity to think in advance of issues they may wish to raise with inspectors and take advantage of these and other opportunities to ask inspectors questions. The agenda for dialogue can be set by the teacher every bit as much as by the inspector. The inspection team will comprise a managing inspector, three or four other inspectors (some of whom may be associate assessors - teachers released from their

school to act as inspectors) and a lay member. The lay member is a member of the public with an interest in but no professional involvement in education. They will meet with parents and groups of pupils to consider partnerships with parents, relationships between staff and pupils and the local community.

School inspections no longer inspect and report on subject departments nor do they provide detailed feedback on lessons observed with a judgement based on a six point scale. HMI do not do 'crit' lessons. On Monday afternoon, Tuesday and into Wednesday and Thursday inspectors will visit classrooms with a particular focus on learning, teaching and assessment. The inspector visiting science classes may not have a science background, although if there is an inspector with a science background in the team it is likely they will visit science classes. Although time is limited for dialogue when lessons are observed, there will be a brief discussion between inspector and teacher about the learning and teaching that takes place. The accumulated evidence from these observations will inform the view taken of learning, teaching and assessment in the school as a whole. At the end of the day on Tuesday there is a voluntary professional dialogue drop-in session for staff with the inspection team. On Wednesday lunchtime inspectors also make themselves available to talk with staff. During the inspection groups of teachers and pupils will be invited to participate in focus groups. Science teachers should take these opportunities to discuss progressing science education with inspectors. On Thursday the inspection team meets to consider their findings and on Friday morning they report back to senior management. School Senior Management are expected to report back the inspection findings to staff on the Friday afternoon. After the inspection HMI will produce a Summary of Inspection Findings (SIF) and will return a draft to the school and education authority to check for accuracy. After ten weeks a report to parents in the form of a letter is published on the Education Scotland website along with the Summary of Inspection Findings (SIF). These are useful documents to read if you are applying for a job in a school. (As are the school improvement plan and the school standards and quality report that it sends to HMI prior to the inspection.)

In conclusion

The new or recently qualified science teacher is at the start of a professional journey. In many respects this is a journey that never ends. Nor should it, the key to becoming an expert science teacher is through a process of continuous improvement. This is the expectation that is now placed on the modern science teacher (see for example Box 1 and *Teaching Scotland's Future*).

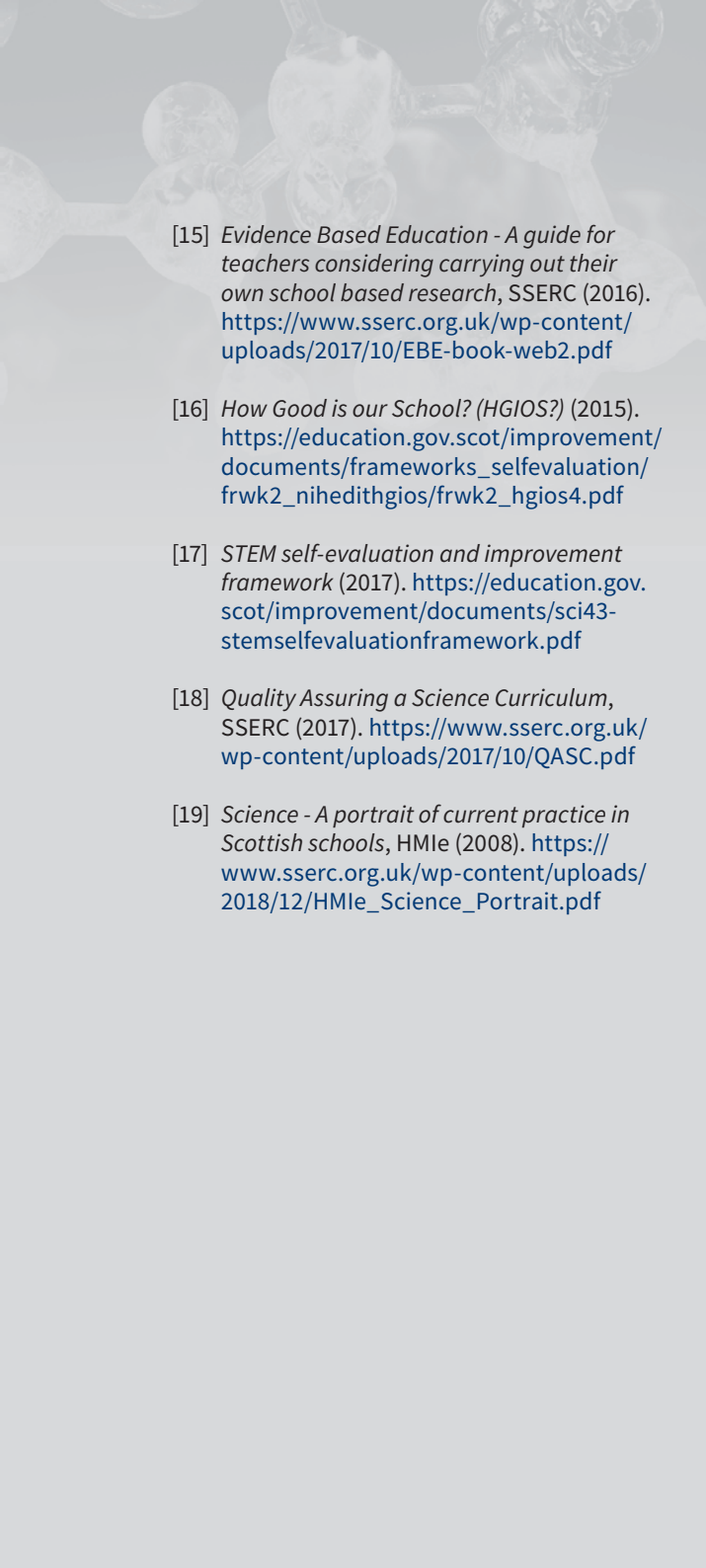
This is a challenging situation; there is much that can deflect you from your journey. The everyday demands of teaching effectively can be a full time job! Issues of classroom and learner management, administrative procedures and protocols can all take time and energy. Although these will have to be addressed it is important to retain a vision of the science teacher you aspire to become and to create and take opportunities that will help you to achieve that goal when you can.

Often education initiatives are generic in nature and the challenge for science teachers is to apply and translate the principles of such initiatives into the context of science. This is a two fold process. Science is well placed to deliver wider educational goals and science teachers should be champions of how science can make its particular contribution to these goals. In delivering these goals however, it is also important to ensure that the learning continues to develop a deep understanding of the science and scientific skills that are part of a modern science curriculum.

Good luck on your never ending journey!

References

- [1] *Teachers Matter - Attracting, developing and retaining effective teachers*, OECD (2005). <https://www.oecd.org/education/school/34990905.pdf>
- [2] *Teaching Scotland's Future - Report of a review of teacher education in Scotland (The Donaldson report)*, Scottish Government (2010). https://www.sserc.org.uk/wp-content/uploads/2018/12/TeachingScotlandsFuture_DonaldsonReport.pdf
- [3] *Safeguards in the School Laboratory*, 11th Edition, ASE (2006).
- [4] *Safety in Microbiology - A code of practice for Scottish schools and colleges*, SSERC (2018). https://www.sserc.org.uk/wp-content/uploads/2018/06/SSERC-Safety_in_Microbiology_Code_of_Practice.pdf
- [5] *SSERC Risk Assessment 5 Step Template*. <https://www.sserc.org.uk/health-safety/risk-assessment-process/>
- [6] *Risk assessment: a brief guide to controlling risks in the work place*, INDG163, HSE. <http://www.hse.gov.uk/pubns/indg163.pdf>
- [7] Driver R. et al (1994), *Making sense of secondary science: Research into children's ideas*. Routledge: New York.
- [8] Black P and Harrison C. (2004), *Science inside the black box*. nferNelson: London.
- [9] Jo Moules, Jo Horlock, Stuart Naylor and Brenda Keogh (2015), *Science Concept Cartoons Set 2*. Millgate House Education: Sandbach.
- [10] Harlen W. (2010), *Principles and big ideas of science education*. ASE: Hatfield. <https://www.ase.org.uk/bigideas>
- [11] *Assessment Reform Group (1999), Assessment for Learning - Beyond the black box*. University of Cambridge School of Education: Cambridge.
- [12] *Curriculum for Excellence: Sciences Principles and practice*. <https://education.gov.scot/Documents/sciences-pp.pdf>
- [13] *Curriculum for Excellence: Sciences Concept development in the sciences*. https://www.sserc.org.uk/wp-content/uploads/2018/12/Conceptdevelopmentinthesciences2_tcm4-550290.pdf
- [14] *Sciences 3-18 Curriculum Impact Report (2013)*. https://education.gov.scot/improvement/documents/sciences/sci14_sciencescurriculumimpact/sciences-3-to-18-2013-update.pdf

- 
- [15] *Evidence Based Education - A guide for teachers considering carrying out their own school based research*, SSERC (2016). <https://www.sserc.org.uk/wp-content/uploads/2017/10/EBE-book-web2.pdf>
- [16] *How Good is our School? (HGIOS?)* (2015). https://education.gov.scot/improvement/documents/frameworks_selfevaluation/frwk2_nihedithgios/frwk2_hgios4.pdf
- [17] *STEM self-evaluation and improvement framework* (2017). <https://education.gov.scot/improvement/documents/sci43-stemselfevaluationframework.pdf>
- [18] *Quality Assuring a Science Curriculum*, SSERC (2017). <https://www.sserc.org.uk/wp-content/uploads/2017/10/QASC.pdf>
- [19] *Science - A portrait of current practice in Scottish schools*, HMIE (2008). https://www.sserc.org.uk/wp-content/uploads/2018/12/HMIE_Science_Portrait.pdf



SSERC (Scottish Schools Education Research Centre), 2 Pitreavie Court, South Pitreavie Business Park, Dunfermline KY11 8UU. Telephone 01383 626070, enquiries@sserc.scot, www.sserc.scot

SSERC is a Company Limited by Guarantee (Scottish Company No. SC131509) and a registered educational charity (Scottish Charity No. SC017884) Registered Office - 5th Floor, Quatermile Two, 2 Lister Square, Edinburgh EH3 9GL.

© 2018 SSERC. This publication may be reproduced in whole or in part for bona-fide educational purposes provided that no profit is derived from the reproduction and that, if reproduced in whole or in part, the source is acknowledged. ISBN 978-0-9531776-6-0.