Scientific enquiry

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The Association for Science Education
Promoting Excellence in Science Teaching and Learning

What is scientific enquiry?

Scientific Enquiry describes the processes and skills pupils should be taught and use, to find out more about the world and how it works. Arguably, all children (regardless of where they live and the curriculum their schools follow) should carry out scientific enquiry – skills and processes apply beyond formal curricular boundaries. It's about good science, after all!

The publication 'it's Not Fair…or is it? - Turner et al, takes the view that:

> 'Science enquiry is what children do in order to answer scientific questions about the world around them'.

As a definition of scientific enquiry, this works enormously well. Opportunities for scientific enquiry should be located centrally within any science curriculum, so that children gain a deeper understanding of science concepts in the context of questions they ask and answer.

What are the benefits of scientific enquiry?

As children carry out scientific enquiry they should develop a host of skills and competencies, knowledge and understanding, bringing enormous benefits to them as 'growing' scientists.
Scientific enquiry increases children's capacity to:

- Problem-solve and answer questions. Rich opportunities are provided where children explore their own ideas, develop and deepen conceptual understanding.
- Work with independence. Thinking and reasoning is nurtured alongside a host of qualities, including resilience, determination and confidence.
- 'Be a scientist'. A necessary toolkit of practical skills is developed and added to over time.
- Communicate effectively. Technical and scientific vocabulary is learned, practised and used, as children communicate evidence in a variety of ways, often with different audiences in mind.

Teachers should gain significant insight into children's capacity to explore ideas, use skills and gather evidence (for instance) as they carry out scientific enquiry. The inclusion of clear learning outcomes and success criteria within planning for teaching and learning, allows assessments of children's progress to be made relatively easily. What's more, evidence of children using and applying conceptual knowledge and understanding of science as they investigate and answer questions can be checked for and considered when making teacher assessment judgements.
In the English National Curriculum for Science (2013) scientific enquiry is referenced formally as 'Working Scientifically'.

In what ways is scientific enquiry different for different ages?

Primary science concepts are developed by pupils working scientifically. The aim is for teachers to facilitate the children learning for themselves. This is possible because the timetable is flexible to allow for longer or shorter activities, continuation of activities at an appropriate moment e.g. when required, not when timetabled. Primary teachers spend more time with their pupils and are therefore very aware of their needs. Science may be taught discretely or as part of a cross curricular approach and therefore children have very different perceptions e.g. do science twice a week, do no science (they will have done but they may not have realised this is what they were doing). There is sufficient time, if planned effectively for children to carry out a range of enquiries that support them to understand the scientific concepts, whilst also developing their scientific skills.

In secondary schools, pupils have greater access to more equipment to facilitate more complex and accurate measurements. When children move up to secondary they need to learn to work safely and competently in a laboratory.

Secondary students will be introduced to new types of scientific enquiry. For example, in chemistry they will be introduced to the use of analysis to identify substances (both quantitative and qualitative). Students are also expected to understand to more abstract and complex ideas when explaining their observations.

Secondary science is taught in discrete timetabled lessons spread over a week. Each lesson is a standard length. There is very little opportunity for flexibility in this. This has implications on the way that science is taught. The teacher may only teach the children for one lesson a week and will not have such an in-depth knowledge of the pupils' specific needs. Time constraints and safety concerns can lead to students having less ownership of their enquiries. This gives them less chance to develop their understanding of the science enquiry process. However, this does not have to be the case. It is important that secondary students continue to develop their science enquiry skills through whole science enquiries in addition to working on specific enquiry skills and the development of practical skills with an increased range of apparatus.

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How does scientific enquiry progress from primary to secondary? Wales

Wales adopted a skills based enquiry approach to teaching in 2008 with the introduction of a new curriculum. In Foundation Phase children work scientifically on a range of skills through an area of learning termed **Knowledge and Understanding of the World**.
The following links provide access to the Foundation Phase Curriculum for Wales:
http://gov.wales/docs/dcells/publications/150803-fp-framework-en.pdf

In KS2 and 3 these skills are extended, firstly the learners are taught communication skills that progress from KS2 to KS4, e.g. at KS2, how to search for information, how to communicate effectively using various forms e.g. speech, ICT, written and how to use standard and non-standard measures.
At KS2 and 3 pupils are then taught enquiry skills and are given opportunities to carry out different types of enquiry, e.g. pattern-seeking, exploring, classifying and identifying, making things, fair testing, using and applying models. These types of enquiry mirror those enquiries taught in England. The following link provides examples and further information on those.
http://learning.gov.wales/docs/learningwales/publications/140624-science-in-the-national-curriculum-guidance-en.pdf

The skills of enquiry can be described as those of planning, developing and reflecting and these are broken down into different skills, details of which can be found in the following Science in the National Curriculum for Wales. http://learning.gov.wales/docs/learningwales/publications/140624-science-in-the-national-curriculum-en.pdf

By KS4 the learners build on prior knowledge and “study the way that science and scientists work within society. They consider the relationship between data, evidence, theories and explanations and develop their practical, problem-solving and enquiry skills, working individually and in groups. They evaluate enquiry methods and conclusions both qualitatively and quantitatively, and communicate their ideas with clarity and precision. Learners develop their ability to relate their understanding of science to their own and others, decisions about lifestyles, and to scientific and technological developments in society.” (DCELLS, 2008, p. 23).

Currently Wales assesses in Foundation Phase as Foundation Phase Outcomes and at KS2/3 and 4 as levels. Details of these can be found in the links already provided for each age group.
In Wales a new curriculum and assessment is currently under development by Professor Donaldson which will see science come under the umbrella of an Area of Learning and experience (AoLE) called ‘science and technology’. A draft should be available in 2019, so at this point it is felt that appropriate links are provided to show that Wales utilises the process of working scientifically, but that currently we cannot show its relationship to the finished ASE document until the changes are secure.

Further information on the new curriculum for Science and Technology Area of Learning and experience
https://gov.wales/docs/dcells/publications/180131-science-en.pdf

How does scientific enquiry progress from primary to secondary? Scotland

Scotland's 'Curriculum for Excellence' (CfE) was initiated in 2009 to transform education by providing a coherent, more flexible and enriched curriculum from 3 to 18. It recognises that learning is lifelong, and aims to help learners develop the skills they need for learning, life and work in an ever-changing world.

What is The Curriculum for Excellence? https://education.gov.scot/scottish-education-system/policy-for-scottish-education/policy-drivers/cfe-(building-from-the-statement-appendix-incl-btc1-5)/What%20is%20Curriculum%20for%20Excellence?
Links on this page include those to the **Benchmarks for Science**

Benchmarks have been developed to provide clarity on the national standards expected within each curriculum area at each level. They set out clear lines of progression across each curriculum area from Early to Fourth Levels. Their purpose is to make it clear what learners need to know and be able to do to progress through the levels, and to support consistency in teachers' and other practitioners' professional judgements. Benchmarks are designed to be concise and accessible, with sufficient detail to communicate clearly the standards expected for each curriculum level
https://education.gov.scot/improvement/learning-resources/Curriculum%20for%20Excellence%20Benchmarks
These benchmarks describe the skills needed for **scientific enquiry** as well as the science content statements

Links to other aspects of the Scottish Curriculum are listed as
Experiences and Outcomes
Principles and Practice
Building the Curriculum
These can also be found on the What is the Curriculum for Excellence? page
https://education.gov.scot/scottish-education-system/policy-for-scottish-education/policy-drivers/cfe-(building-from-the-statement-appendix-incl-btc1-5)/What%20is%20Curriculum%20for%20Excellence

How does scientific enquiry progress from primary to secondary? England

‘The best schools ensured that pupils had sufficient time to be taught and subsequently develop the skills of scientific enquiry.’

Page 44, Maintaining Curiosity – A survey into science education in schools, November 2013

Working scientifically can be considered as divided into two separate but linked aspects

- Science enquiry
- Skills to carry out science enquiry

Both start in the primary phase and are further developed in the secondary phase.

Science enquiry

In the English primary curriculum five types of enquiry are explicitly named in all year groups

- Observing changes over time
- Noticing patterns
- Grouping and classifying things (noticing similarities and differences)
- Comparative and fair testing
- Finding things out using secondary sources of information (researching)
- Modelling is not explicitly mentioned but will be used

These types of enquiry will be used by children from year 1 to year 6 across the different subject areas as appropriate (biology, physics and chemistry).

This is developed in the English secondary KS3 curriculum – although the different types of enquiry are not explicitly named

> ‘select, plan and carry out the most **appropriate types of scientific enquiries** to test predictions, including identifying independent, dependent and control variables, where appropriate.’

KS3 objective within ‘Experimental skills and investigations.

It is important that secondary teachers are aware of the types of enquiry that are used in primary schools and how the secondary curriculum builds on these. The following examples are not a complete list and does show repetition as concepts are revisited at greater depth.

How does scientific enquiry progress from primary to secondary? Northern Ireland

Science in Northern Ireland primary schools is taught as part of the curriculum Area of Learning called The World Around Us, which places a focus on the development of knowledge, skills and understanding in geography, history, science and technology.

Foundation stage

Some of the principles underpinning the foundation stage, state that children learn best when they:

- have opportunities to be actively involved in practical, open ended and challenging learning experiences that encourage creativity;
- have opportunities to initiate experiences;
- are actively involved in planning, reviewing and reflecting what they have done.

http://ccea.org.uk/curriculum/foundation_stage/areas_learning/world_around_us

The children at this stage should have opportunities to use their senses in order to “develop their powers of observation, their ability to sort and classify, explore, predict, experiment, compare, plan, carry out and review their work.” The skills and concepts are to be developed during play and other planned activities or topics.

KS1 and KS2

These key stages require that “children experience continuity and progression” in concepts, knowledge and skills ensuring that pupils move eg:

- *from* making first hand observation *to* collecting real data;
- *from* identifying similarities and differences *to* investigating similarities and differences, patterns and change;
- *from* recognising a fair test *to* designing and carrying out a fair test

http://ccea.org.uk/curriculum/key_stage_1_2/areas_learning/world_around_us

Aspects of the Thinking Skills and Personal Capabilities framework aim to explicitly foster many of the skills which are directly linked to working scientifically, namely:

- sequencing, ordering, classifying, making comparisons;
- making predictions, examining evidence;
- asking focused questions;
- seeking out questions to explore and problems to solve;
- selecting, classifying, comparing and evaluating information;
- selecting most appropriate method for a task;
- using a range of methods for collating, recording and representing information;
- experimenting with ideas and questions

http://ccea.org.uk/curriculum/sen_inclusion/thinking_skills_personal_capabilities/microsite

KS3

In KS3 science is taught as a discrete subject. The curriculum states that:

Pupils should have opportunities, through various contexts, to:

- develop skills in scientific methods of enquiry to further scientific knowledge and understanding:
- plan for investigations,
- obtain evidence,
- present and interpret results;
- develop creative and critical thinking in their approach to solving scientific problems;
- research scientific information from a range of sources;
- develop a range of practical skills, including the safe use of science

http://ccea.org.uk/curriculum/key_stage_3/areas_learning/science_and_technology

	Examples in primary	Examples in secondary
Observing changes over time **This is when observations or measurements are made at regular intervals)**	Long term studies of how plants and habitats change through the year Taking observations of ice melting, water cooling Measuring pulse rate after exercise	Effect of amylase on breakdown of carbohydrates (within a lesson) Effect of insulation on the cooling of hot water (is combined with fair testing) (within a lesson) Osmosis (over two lessons) *This is usually KS4* Evaporation of water from a solution to leave crystals (over several lessons) Growth of bacteria on plates (over several lessons) Cooling curve – stearic acid (within lesson)
Comparative and fair test **This involves exploring cause and effect**	Investigating how shadows change size Investigating air resistance using parachutes Investigating dissolving rates Investigating properties of materials	Reactivity of metals with water – after demo of Group 1 compare other metals reacting with water and dilute acid – consider how to compare – mass; size; volume of liquid; how to measure reaction (number of bubbles, volume of gas, qualitative) Hooke's law – independent & dependent variables (mass & length of spring) Changing angle of reflection – independent & dependent variable (angle of incidence & angle of reflection) Ohm's law – measuring current & voltage through a wire Effect of insulation on cooling of water – look at the variables to keep the same Energy content of different food – comparison may need weighing of the food Resistance of a wire – see Ohm's law; could also measure the current through different lengths of wire Strength of an electromagnet – vary current & number of turns of wire; difficulty in measuring accurately since paper clips may be too big.

	Examples in primary	Examples in secondary
Classifying **This involves sorting and grouping according to similarities and differences**	Classifying rocks, plants, animals, materials	Food tests to classify different foods – extend to carbohydrates containing sugar or starch Using indicators to classify household chemicals (acids/alkalis), Endothermic and exothermic reactions – does the temperature go up or down Properties of elements – research activity looking at melting point; boiling point, density etc. Reactivity series – comparing the reactions of metals with water or dilute acid Metals vs non-metals – compare conductivity of heat & electricity. Conductors/non-conductors
Researching **This involves using secondary sources to find answers to questions**	Using keys to identify plants and animals Learning what animals eat Learning about the digestive system, circulatory system, planets	Carbon cycle, Composition of atmosphere, Indicator species; Pollution; Waves Planets Drugs & their effects on the body Ceramics, polymers & composites & their uses Indicator species – what lives where including pond life and lichens Pond dipping and use of keys to identify organisms caught
Modelling	Concrete models e.g. of the digestive system, movement of Earth and Moon, circulatory system	Abstract scientific models such as the particle model or force diagrams

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Skills to carry out scientific enquiry

To be able to work independently pupils need to develop a set of skills that they can then use whilst carrying out different types of enquiry. They need to be able to

- Ask questions
- Make predictions
- Decide how to carry out an enquiry
- Take measurements
- Record data
- Present data
- Answer questions using data
- Draw conclusions
- Evaluate their enquiry

Again, these skills will be revisited with increasing complexity as the pupils progress through primary to secondary. It is important when pupils start year 7 that teachers look for the skills the children already have, particularly as the demands at Key Stage 2 have become more complex. The Mathematics curriculum for year 6 states that pupils should be taught to interpret and construct pie charts and line graphs and use these to solve problems and also that pupils both encounter and draw graphs relating two variables, arising from their own enquiry and in other subjects.

The English secondary curriculum divides these skills using four broader categories. The skills from primary are further developed mainly in 2 and 3.

1. Scientific attitudes (including the development of theories and the role of science community)
2. Experimental skills and investigations
3. Analysis and evaluation
4. Measurement (including units of measurements and mathematics)

Another important aspect of Working Scientifically is to support pupils to gain an understanding of how the science community works scientifically. In years 5 and 6 pupils will begin this process by identifying scientific evidence that has been used to support or refute ideas or arguments, learning about how ideas have changed over time. In Key Stage 3 they will broaden this understanding by considering how theories develop as earlier explanations are modified to take account of new evidence. The pupils also gain an appreciation of why published scientific results are peer reviewed.

A further important area of understanding is the pupils' appreciation of the need for quality evidence on which to base theories. Again, this is introduced in year 5 and 6 in the pupils' own enquiry work as they are expected to begin taking measurements, using a range of scientific equipment, with increasing accuracy and precision, taking repeat readings when appropriate. They are also expected to start reporting and presenting findings from enquiries, including explanations of and degree of trust in results. This is developed in Key Stage 3 to include repeatability and reproducibility not only in the student's own work but also in considering the objectivity or other people's research.
These aspects of working scientifically are important in terms of progression towards KS4 and are vital skills in supporting young people to develop into scientifically literate citizens who can critically evaluate scientific evidence.

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Progression from key stage 1 – key stage 4

	5-7 year olds	7-9 year olds	9-11 year olds	11-14 year olds
Scientific attitudes			taking measurements, using a range of scientific equipment, with increasing accuracy and precision, taking repeat readings when appropriate reporting and presenting findings from enquiries, including conclusions, causal relationships and explanations of and degree of trust in results, in oral and written forms such as displays and other presentations identifying scientific evidence that has been used to support or refute ideas or arguments.	pay attention to objectivity and concern for accuracy, precision, repeatability and reproducibility understand that scientific methods and theories develop as earlier explanations are modified to take account of new evidence and ideas, together with the importance of publishing results and peer review evaluate risks

	5-7 year olds	7-9 year olds	9-11 year olds	11-14 year olds
Experimental skills and investigations	asking simple questions and recognising that they can be answered in different ways observing closely, using simple equipment performing simple tests gathering and recording data to help in answering questions.	asking relevant questions and using different types of scientific enquiries to answer them setting up simple practical enquiries, comparative and fair tests making systematic and careful observations and, where appropriate, taking accurate measurements using standard units, using a range of equipment, including thermometers and data loggers gathering, recording, classifying and presenting data in a variety of ways to help in answering questions recording findings using simple scientific language, drawings, labelled diagrams, keys, bar charts, and tables	planning different types of scientific enquiries to answer questions, including recognising and controlling variables where necessary taking measurements, using a range of scientific equipment, with increasing accuracy and precision, taking repeat readings when appropriate recording data and results of increasing complexity using scientific diagrams and labels, classification keys, tables, scatter graphs, bar and line graphs	ask questions and develop a line of enquiry based on observations of the real world, alongside prior knowledge and experience make predictions using scientific knowledge and understanding select, plan and carry out the most appropriate types of scientific enquiries to test predictions, including identifying independent, dependent and control variables, where appropriate use appropriate techniques, apparatus, and materials during fieldwork and laboratory work, paying attention to health and safety make and record observations and measurements using a range of methods for different investigations; and evaluate the reliability of methods and suggest possible improvements apply sampling techniques.

	5-7 year olds	7-9 year olds	9-11 year olds	11-14 year olds
Analysis and evaluation	using their observations and ideas to suggest answers to questions	gathering, recording, classifying and presenting data in a variety of ways to help in answering questions recording findings using simple scientific language, drawings, labelled diagrams, keys, bar charts, and tables reporting on findings from enquiries, including oral and written explanations, displays or presentations of results and conclusions using results to draw simple conclusions, make predictions for new values, suggest improvements and raise further questions identifying differences, similarities or changes related to simple scientific ideas and processes using straightforward scientific evidence to answer questions or to support their findings.	recording data and results of increasing complexity using scientific diagrams and labels, classification keys, tables, scatter graphs, bar and line graphs using test results to make predictions to set up further comparative and fair tests reporting and presenting findings from enquiries, including conclusions, causal relationships and explanations of and degree of trust in results, in oral and written forms such as displays and other presentations identifying scientific evidence that has been used to support or refute ideas or arguments.	apply mathematical concepts and calculate results present observations and data using appropriate methods, including tables and graphs interpret observations and data, including identifying patterns and using observations, measurements and data to draw conclusions present reasoned explanations, including explaining data in relation to predictions and hypotheses evaluate data, showing awareness of potential sources of random and systematic error identify further questions arising from their results.
	5-7 year olds	**7-9 year olds**	**9-11 year olds**	**11-14 year olds**
Measurement		making systematic and careful observations and, where appropriate, taking accurate measurements using standard units, using a range of equipment, including thermometers and data loggers	solve problems involving the calculation and conversion of units of measure, using decimal notation up to three decimal places where appropriate (Maths) use, read, write and convert between standard units, converting measurements of length, mass, volume and time from a smaller unit of measure to a larger unit, and vice versa, using decimal notation to up to three decimal places (Maths)	understand and use SI units and IUPAC (International Union of Pure and Applied Chemistry) chemical nomenclature use and derive simple equations and carry out appropriate calculations undertake basic data analysis including simple statistical techniques.

Pictorial representation of progression in:

- Scientific attitudes
- Experimental skills and investigations
- Analysis and evaluation
- Measurement

Scientific attitudes

5-7 year olds	
7-9 year olds	
9-11 year olds	1. Take repeat readings, with increasing accuracy and precision and consider degree of trust in results 2. Identify that scientific evidence may support or refute earlier ideas
11-14 year olds	1. Show concern for accuracy, precision, repeatability and reproducibility 2. Understand that scientific ideas develop over time with new evidence and ideas 3. Evaluate risks

Experimental skills and investigation

5-7 year olds	2. Ask questions 3. Make observations using simple equipment 4. Recording data
7-9 year olds	1. Use results to make predictions for new values 2. Ask relevant questions 3. Carry out simple investigations 3. Take measurements using a range of equipment 4. Record data in a variety of ways
9-11 year olds	1. Use test results to make predictions to set up further tests 2. Plan investigations to answer questions 3. Take repeated measurements using a range of equipment, considering accuracy and precision 4. Record data in ways of increasing complexity
11-14 year olds	1. Make predictions 2. Plan investigations to answer questions considering safety 3. Take reliable results using a range of equipment, considering reliability of method and suggesting possible improvement 4. Record data gathered using more than one techniques

Analysis and evaluation

5-7 year olds	1. Identify and classify 2. Use observations to answer questions
7-9 year olds	1. Present data in a variety of ways 2. Answer questions giving explanations 3. Make simple predictions based on results 4. Suggest simple improvements
9-11 year olds	1. Present data in ways of increasing complexity 2. Use data to give a scientific conclusion 3. Use results to set up further investigations 4. Suggest improvements to increase degree of trust in results
11-14 year olds	1. Present data choosing appropriate method 2. Draw conclusions based on data giving reasoned explanations in relation to prediction 3. Identify further questions arising from their results 4. Evaluate data taking into account potential sources of error 5. Apply mathematical concepts and calculate results

Measurement

5-7 year olds	
7-9 year olds	1. Use standard units when taking measurements
9-11 year olds	
11-14 year olds	1. Understand and use SI units and IUPAC chemical nomenclature 2. Use and derive simple equations to carry out equations 3. Data analysis