NFER review

Assessment for learning in primary science: Practices and benefits

Claire Hodgson

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Introduction

This review is a synthesis of a literature review that explored Assessment for Learning (AfL) practices and benefits in primary science. It will be useful for teachers, headteachers and policymakers interested in science and how AfL can help teaching and learning.

AfL is central to UK education policy. A greater understanding of the strategies teachers use to assess science and the methods being applied to improve teaching and learning in primary science will be very important to its success. In England, science tests at the end of key stage 2 have been abolished. This could result in less of a focus on science in primary schools in the future. However, a number of science organisations, including the Association for Science Education, supported the abolition of the tests. They felt practical investigative science was limited in primary schools because the tests were paper-based. AfL provides opportunities to assess science teaching and learning without written tests.

Although the future of statutory assessment at the end of key stage 2 is, as yet, undecided teacher assessment is likely to play an important role. This will require teachers to be experts in assessing pupils' learning, and AfL strategies can help with this.

The government says the STEM subjects (science, technology, engineering and mathematics) are essential to this country's economic success. Strategies for improving the teaching of these subjects, and the engagement of pupils in science at primary level, are vital for maintaining interest in science in secondary school and beyond.

Recommendations

AfL has clear benefits for pupils, their learning and lives. The literature review shows that teachers are aware of AfL and are implementing a range of AfL strategies in their science teaching. It also revealed recommendations for maximising AfL's benefits.

- Assessment co-ordinators, science co-ordinators and headteachers must be familiar with the many opportunities for using AfL in science teaching and exploit these to the full.
- Teachers must be given support to embed AfL in the science classroom and use a range of strategies, particularly self- and peer-assessment.
- Establish small research communities of teachers who undertake their own AfL Action Research projects. Teachers select and develop a few aspects of AfL in depth, exploring and investigating these aspects with their children. Results can then be shared with the other teachers.

Key findings

The literature review revealed key AfL strategies for teachers and strategies specific to teaching science. It highlighted the conditions that impact on AfL's success as well as desirable pupil outcomes that can be attributed to AfL.

AfL strategies involve:

- teachers explaining learning intentions and success criteria, or negotiating them with the pupils
- using questions and dialogue that promote deep learning
- self-assessment and peer-assessment
- creating an environment in which pupils can learn from each other
- providing feedback that promotes deeper learning
- enabling pupils to drive their own learning
- using summative tests for formative purposes.

AfL strategies specific to science:

- encourage analytical thinking
- prompt scientific thought and activity through questioning
- address scientific misconceptions
- support children in developing scientific language.

AfL will flourish best when:

- pupils feel confident and safe in the classroom
- teacher talk does not constrain pupils
- teaching is adapted to pupils' interests and responses.

Desirable pupil outcomes attributable to AfL are:

- authorship of their own learning
- constructing knowledge collaboratively
- reflecting on own learning which encourages deep learning
- addressing misconceptions
- improving self-efficacy and self-esteem and a greater willingness to participate
- learning to enquire.

Useful links

- References
- Full literature review
- Findings of teacher questionnaire survey

What is AfL?

AfL can be broadly defined as any assessment event that becomes or leads to a learning event.[1] The Assessment Reform Group has defined AfL as:

> *The process of seeking and interpreting evidence for use by learners and their teachers to decide where learners are in their learning, where they need to go and how best to get there.*[2]

Research, for example by Black and Wiliam,[3] suggests AfL benefits learning. Harlen (p176) says AfL is 'not something added to teaching, but is integral to it.'[4] AfL has become an increasingly important aspect of teaching and learning: pupils are being encouraged to take increasing responsibility for their own learning so they can become life-long learners.

What is primary science?

Different science curricula are followed in the four countries in the UK. However, there is a general consensus that the key aims of science teaching and learning in the primary classroom are to engage interest and enjoyment by fostering curiosity and creativity, and to develop the key scientific skills needed for a sound base from which to progress learning.

Primary science learning is about living things, materials and phenomena. It is intended to be relevant to pupils' everyday lives, helping them to learn about the world around them through 'hands-on' investigation and exploration, with opportunities for making observations and measurements. Concepts tend to be introduced through familiar contexts and concrete examples.

As understanding develops, pupils are given the chance to apply their knowledge to new and unfamiliar contexts, begin to make links between ideas and give explanations using simple models and theories. Systematic investigations allow for working alone and with others and making use of a range of reference sources. Pupils are encouraged to talk about their work and its significance, and to communicate ideas using increasingly precise subject-specific vocabulary.

AfL strategies

The literature review reveals a number of AfL approaches and strategies:

- sharing learning intentions and success criteria, or negotiating them with the pupils
- using questions and dialogue that promote deep learning
- developing self-assessment and peer-assessment
- creating an environment in which pupils can learn from each other
- teachers providing feedback that promotes deeper learning
- enabling pupils to drive their own learning
- using summative tests for formative purposes.

To what extent are these AfL strategies being used in primary science in English schools?

In a 2008 survey carried out in England, over 90 per cent of primary science teachers said AfL strategies were being used in their schools. A majority, 81 per cent, said they used AfL strategies in their own classroom.

The survey revealed that the AfL strategies most commonly used by teachers in every science lesson are:

- explaining learning intentions and success criteria, or negotiating them with the class
- using questions and dialogue that promote deep learning
- developing self-assessment and peer-assessment
- creating an environment in which pupils can learn from each other.

Sharing learning intentions and success criteria, or negotiating them with the pupils

This strategy might include teachers and/or pupils discussing and/or developing appropriate learning intentions and success criteria. This might necessitate teachers finding out about a pupil's understanding at the start of a topic and beginning with 'big' questions to set the scene.[5, 6] An example could be a teacher asking pupils to talk to each other about where butterflies go in winter, provoking questions for a project on mini-beasts.

Using questions and dialogue that promote deep learning

Questioning

Questioning is essential to the success of both AfL and science learning. It is one of the key AfL strategies discussed in the literature, with questions asked by both teachers and pupils. Different types of questions include: effective questions, open questions, questions for finding out misconceptions and questions as part of feedback to prompt further learning. The classroom climate was identified as key to promoting effective questioning.

Black and Harrison (p6) identify questions used by teachers and pupils for a range of purposes:

- comparing
- categorising
- grouping
- recognising exceptions
- predicting. [7]

The review highlighted a variety of question strategies.

- The teacher begins with 'big' questions to set the scene. These are open questions posed at the start of a lesson or topic and investigated through the development of further questions.[5, 6]
- Black and Harrison (p6) suggest asking the class to 'delve deep into their conceptual learning'.[7]
- The teacher uses 'rich' questions – questions that cannot be answered immediately and require pupils to devise a range of smaller questions that need answering before an answer to the rich question can be developed.

An example of a rich question, from Black and Harrison (p8), is: 'If you keep a drink with ice cubes in a thermos flask, do you need to leave the room for the ice cubes to melt?'.[7]

- The teacher uses clear, focused questions.[8]
- A question is displayed by the teacher and then reviewed over the course of the lesson(s). The teacher and pupils can monitor the developing understanding.[6]
- Pupils ask questions. Harlen explains this shows the 'cutting edge' of their understanding.[6]
- The formation of good questions is modelled by the teacher.[9]
- Stimulus materials are used by the teacher to provoke pupils' questions.[10, 11]
- Pupils are given opportunities to ask questions. Structures such as a KWHL chart are used, where pupils identify what they 'know' and 'wonder' about a topic, and identify 'how' they can find out and decide what they have 'learned'.[12]
- Pupils shut their eyes when they have been asked a question and then put up their hands when they have an answer. This encourages thinking for themselves without being intimidated by other pupils who instantly raise their hands.[13]
- The teacher provides 'wait time', allowing pupils to consider their answer before being asked for a response. A period of eight to nine seconds, or more, can encourage longer and more thoughtful responses that go beyond factual recall.[5]
- The teacher uses a 'no hands up' strategy, in which pupils are selected by the teacher rather than self-selecting by putting their hand up to show they 'know the answer'.[14]


Dialogue

Asoko and Scott (p158) discuss the importance of talk in science classrooms, explaining: ‘Language provides the fundamental means for communicating ideas, but it is also through talk, either with others or ‘in our heads’, that we can develop personal understanding’.[15] They go on to explain (p159) that ‘science lessons provide plenty of opportunities for talk’.[15]

The review identified a number of strategies to initiate dialogue.

- ‘Concept cartoons’ are used to present a scientific concept which a group of ‘cartoon children’ are discussing. For example, three cartoon children may give different responses to the question ‘shall we put a coat on our snowman?’, which show a range of understanding and misconceptions about the effect of the coat. The cartoon provides a basis for learners to discuss which cartoon child they think has the best idea and why.[10, 16]
- Pupils use puppets to represent different viewpoints, taking ownership of ideas away from individuals and placing them on the puppets.[11]
- Teachers allow thinking and discussions to ensue.[11]
- Teachers discuss ideas with pupils in individual interviews.[17]
- Dialogue between teachers, pupils and peers allows for the co-construction of ideas by, for example, a teacher posing questions to elicit what pupils think. Further discussion elaborates on previous answers helping to construct conceptual knowledge. When teachers paraphrase a pupil’s response, this allows the opportunity to co-construct a response with the teacher and peers.[18]

Self-assessment and peer-assessment

Self- and peer-assessment are key to making pupils more autonomous, able to identify their own learning needs, and develop their own next steps.

Pupil self-assessment

The review found a number of strategies to help pupils assess their own learning.

- Self-monitor and check progress.[19]
- Self-diagnose and recognise learning needs.[19]
- Self-reflect on good learning practices.[20]
- Link thinking across learning practices.[19]
- Use plenary self-evaluation.[20]
- Pupils colour squares for goal statements to indicate their confidence in achieving a given goal. Pupils tend to be honest as this is a private activity in which the results are shared only between the pupil and the teacher.[21]
- Self-mark against specific criteria.[20]
- Use concept mapping to show understanding of a particular topic or idea by illustrating links between different concepts. This can reveal misconceptions.[22, 23, 24]
- Rate understanding of a learning objective on a scale of one to three. This visual response, with fingers held up to indicate where they fell on the scale, allows the teacher to see who needs help with particular concepts, thus providing immediate feedback on what further teaching is required.[21, 25]
- Rate understanding using ‘traffic light’ colours to show good (green), partial (amber) or little (red) understanding.[7]

Peer-assessment

Pupils engage in paired-assessment against specific criteria, ideally agreed amongst themselves. In this activity, Lindsay and Clark (p17) say ‘children [...] frequently demonstrate their level of understanding through their assessment comments.’ [20]

Creating an environment in which pupils can learn from each other

Pupils learn from each other all the time through observation and trying out their ideas on their peers. This is why peer dialogue and questioning are so important for pupils' learning. There are specific strategies teachers use to encourage pupils to learn from each other.

- Show and tell: teachers and pupils use interactive whiteboards to display an answer for plenary discussion.[26]
- Jigsawing: pupils become 'experts' about a specific topic and 'teach' it to a group of pupils, who then teach them about another topic.[21]

Providing feedback that promotes deeper learning

Research shows a teacher's feedback produces significant improvements if it:

- is given within a trusting relationship between feedback-giver and feedback-receiver
- is given in the form of negotiation and co-construction
- is not focused on the pupil's own self-worth but on learning itself
- is given when the pupil is ready to receive it
- is given when the pupil wants to receive it because it accords with their own values and goals
- addresses valued criteria
- encourages the pupil
- stresses positive achievements, both in the past and future
- encourages the pupil to take action to continue or improve current progress
- aims towards sustained changes in the pupil's thinking, rather than 'quick fixes' of immediate tasks
- allows the pupil to reflect on their own learning and take control over it.[27]

This review also revealed other important aspects of feedback.

- Marking can provide constructive feedback and inform future planning.[28]
- Marking should be done against defined learning objectives.[25]
- Constructive feedback should be given during discussions and practical tasks.[28]
- Teachers should provide comment-only marking, with no grades.[5, 21, 29, 30]
- Pupils respond to the teacher's feedback on comment sheets with their own thoughts and evidence of changes they have made.[5]

Enabling pupils to drive their own learning (a practice and an outcome)

Formative assessment practices can help pupils reflect on their on learning and increase motivation.[19,20] Harrison and Harlen (p190) also say they can result in pupils thinking more broadly about the way they learn, encouraging a 'deep rather than a surface approach to learning'.[19]

Research, for example Watkins *et al.*, 2001[31], indicates ways in which pupils can drive their own learning. For example:

- reflecting on their own learning strategies and commenting on how helpful these have been
- feeding back on the usefulness of specific lessons
- having some choice about what and how they learn.

Other strategies identified in the review are:

- producing concept maps and drawings at the start of a new topic based on key words[24]
- describing, at the start of a topic, what pupils already know and what they would like to learn – this information is then used to drive learning forward.[7, 9, 10]

Using summative tests for formative purposes

Summative and formative assessments are used for different purposes. However, there are occasions where summative tests can be used for formative purpose. For example, when pupils:

- compare answers to test papers and devise their own mark-scheme based on a group consensus and understanding of the question[21]
- set test questions for their peers[21]
- look at test papers they have taken in previous lessons and highlight 'key words'. (The teacher goes through the mark-scheme for each question, inviting pupils to interject and question the reasoning behind the 'official' answers.)[32]

AfL strategies specific to science learning

A number of the aspects of AfL are specific to science teaching and learning. These include when teachers:

- encourage analytical thinking
- prompt scientific thought and activity through questioning
- elicit scientific misconceptions
- support children in developing scientific language.

What is happening in schools? – AfL in the science classroom

The 2008 survey of primary science coordinators in England revealed that AfL was used in science because it can improve the quality of teaching and learning. Just over three-quarters of teachers reported using AfL in science. Several teachers indicated it had been introduced in science because of its successful implementation in English and maths.

Encouraging analytical thinking

Lindsay and Clark (p18) say self-assessment leads to 'children becom[ing] more scientific in their enquiries'.[20] Consequently, pupils think more analytically. They also say (p18) self-assessment encourages pupils to be 'constantly involved in the scientific process and their role within it'.[20]

Self-assessment encourages children to raise questions. Lindsay and Clark (p18) say considering their own development and reflecting upon their learning:

> *constantly reinforces understanding of the skills and knowledge they are acquiring ... For example, one child commented, 'My graph shows that the greater the number of layers, the greater the thermal insulation'. This leads naturally to the next question for investigation: Does the thickness of the layers make a difference?*[20]

Prompting scientific thought and activity through questioning

Questioning is an important feature of science talk and, says Harlen (p167), a 'key feature of scientific activity and of teaching science'.[6] The literature related to this area referred to 'diagnostic' questions and 'productive' questions.

Diagnostic questions can reveal clear and precise information about what a pupil understands. They can be used to prompt investigative science work because pupils are inclined to want to find out the answers for themselves. The literature review shows that many concepts in science are not understood or that there is only a limited amount of understanding. Some evidence suggests pupils are more accurate in investigative science when presented with a specific question because they are keen to make sure experiments are fair so they can find the answers.[33]

Chin (p110) refers to 'productive questions' which stimulate physical or mental activity and reasoning.[9] These are particularly useful in science because they help to advance pupils' thinking.[9] Productive questions, says Chin (p110), include measuring questions, comparison questions, action questions and reasoning questions, and can be raised by the teacher or pupils.[9]

Eliciting scientific misconceptions

Concept cartoons can prompt questions that motivate investigative work in science. For example, a cartoon showing parachutes and the thoughts of cartoon children could stimulate a discussion and an investigation into which parachute will fall the slowest. In this way, pupils discover for themselves if answers suggested in the cartoon are true or false. This can lead to a shift in thinking as pupils demonstrate for themselves that their original thinking was either right or wrong.[10, 11, 16]

Puppets are another way for ideas to be talked through because the puppets can own the ideas rather than the pupils. Using the puppets, pupils tend to justify their explanation in a more evidence-based way, which is an essential quality of science learning.[11]

Learning journals allow pupils to record their misconception and chart progress through an investigation, evidencing shifts in understanding and showing the resolution of misconceptions.[34]

Supporting children in developing scientific language

Mercer et al. (p362) say pupils with experience of exploratory talk, ‘where [they] share information, all are invited to contribute, opinions are respected and considered and reasoning must be clear’, scored significantly better in assessments of science knowledge than pupils without this experience.[35]

Pupils can benefit from developing and presenting their understanding of scientific ideas and concepts in a variety of ways beyond writing, such as through extensive talk with teachers emphasising the use of simple and visual stimuli.[10, 11, 16, 17]

It is important to highlight language in science learning by explicitly teaching pupils how to talk about natural phenomena in a scientific way.[15]

Conditions that impact positively on AfL

There are three main factors that impact positively on AfL:

- pupils feeling confident and safe in the classroom
- teacher talk that does not constrain pupils
- teaching adapted to pupils' interests and responses.

AfL will flourish best when pupils feel confident and safe in the classroom

An appropriate climate allows pupils to feel comfortable about sharing their ideas and misconceptions without ridicule or embarrassment.[10, 11, 16, 36] Children work in groups and offer group responses – it seems less threatening if an answer turns out to be wrong if it was offered as the result of group discussion and agreement.[10]

It is helpful if the teacher suspends judgements when pupils are explaining their thinking.[11] The pupils receive an open and warm reception from the more knowledgeable adult. Pupils' ideas are shown to be valued if the teacher repeats them and writes them down rather than dismissing them if wrong.[36]

AfL will flourish best when teacher talk does not constrain pupils

The review identified three types of talk, each with differing consequences.

There are two types of talk which tend to constrain pupils.

- Chin (p1316) explains the three stages of triadic dialogue: an initiation (normally by the teacher), pupil response, and then a teacher evaluation. Chin (p1316) says, this is 'often perceived to have restrictive effects on pupil thinking as responses are brief and teacher framed'.[18]
- Authoritative discourse is where the teacher controls what happens. Pupils respond with single, detached words to the questions. Asoko and Scott (p160) explain that this 'does not really explore and take account of children's ideas as they arise.'[15]

In contrast, pupils are not constrained by interactive talk. The teacher explores pupils' views and takes account of them, even if they are different from accepted ones.[18] The use of concept cartoons is one way of fostering a climate of mutual respect of ideas. This can generate talk that is exploratory and interactive.[10, 11, 16]

AfL will flourish best when teaching is adapted to pupils' interests and responses

There are a number of strategies for adapting teaching to pupils' interests and responses. The teacher can:

- allow time for pupils to think, discuss and give a considered response[15]
- adjust questioning to accommodate a range of answers, respond to pupils' thinking, and guide them through inquiry-based discussions[13, 18, 37]
- avoid rephrasing a question if it is not readily answered because this can prevent finding out how the pupils would have responded to the initial question[14]
- try to ascertain pupils' understanding before teaching begins, so misconceptions are identified[5, 6, 7, 9, 10]
- not let testing dominate the discourse.[1, 38]

Desirable pupil outcomes attributable to AfL

AfL has a number of benefits. However, the links between AfL strategies and improvements are not causal, only likely, and further research is required.
The desirable outcomes for pupils are:

- experiencing authorship of their own learning
- constructing knowledge collaboratively
- reflecting on own learning which encourages deep learning
- misconceptions being addressed
- improving self-efficacy and self-esteem and a greater willingness to participate
- learning to enquire.

What benefits have schools observed?

A survey of primary science teachers in England showed that the majority (84 per cent) agreed pupils respond well to AfL in science. It has helped them to acquire a greater knowledge of their pupils' needs in science and pupils' work has benefitted. The majority (85 per cent) agreed AfL makes a valuable contribution to teaching and learning in science. Nearly three-quarters (73 per cent) said they would like to make more use of AfL in science. The majority (81 per cent) also think AfL is 'just good teaching'.

Authorship of their own learning

Through AfL, pupils become more self-critical and proactive learners.[20] Pupils take responsibility for their learning[39] and direct their activities towards their own learning goal because it is set by them rather than being externally imposed.[19, 20] Pupils monitor their own learning and progress[6, 19, 23] and can identify the areas in which they feel confident, and those that they need to develop. The ability to direct their own learning[9, 19, 40] benefits both them and wider society and is, as Harlen (p30) points out, 'an essential outcome of education'.[40]

Self-assessment helps pupils to question their understanding and reflect upon the development of their own scientific knowledge and skills.[19, 20, 34] Through developing an increasing awareness of their role in their learning, Lindsay and Clarke (p18) say pupils 'become more scientific in their enquiries'.[20]

Constructing knowledge collaboratively

Peer-assessment builds on the AfL notion of learning as a co-constructivist activity whereby learning occurs as a result of social interaction.

When taking part in peer-assessment activities, pupils are on an equal footing rather than there being a 'novice and expert' situation. Harrison and Harlen (p189) say pupils see themselves as partners in the teaching-learning process.[19]

Many learning theorists indicate lasting learning comes from social interaction and co-construction of ideas.[31, 41] Pupil collaboration allows this to happen and group work can also encourage critical thinking.[19, 20, 21] Teachers gain insight into pupils' understanding as a result of seeing them reflect on their peers' assessments.[20]

Peer-assessment can help bring misconceptions to the fore, say Black and Harrison (p47), and increase pupils' willingness to present work more clearly.[21]

Reflecting on own learning which encourages deep learning

The use of strategies such as self- and peer-assessment result in pupils being more reflective 'both about the task in hand and more broadly about the way they learn [and therefore] encourage a deep rather than a surface approach to learning,' say Harrison and Harlen (p190).[19]

Addressing misconceptions

When pupils identify misconceptions, they can become more active in their own investigations. This is more likely to lead to a further shift in thinking.[10, 11, 16, 23]

Learning journals make it acceptable for pupils to have misconceptions and then chart the changes in their understanding.[34]

Concept cartoons can promote conceptual change through the provision of a motivating starting point for a science activity. They can encourage consideration of different viewpoints and debate, leading to self-motivation and self-sustaining conversations.[10,16]

Improving self-efficacy and self-esteem and a greater willingness to participate

The eye-shutting method results in more pupils attempting to answer questions. It allows for a longer response time and encourages more pupils to participate. This can enhance self-efficacy.[13]

AfL can help to reduce stress and anxiety when collaborative work is being carried out because the focus is not solely on the individual. High stress levels are associated with low self-efficacy and self-esteem. Group work, in turn, helps to develop positive teamwork skills, which can then lead to raised individual self-efficacy and self-esteem.[32]

Using summative tests for formative purposes can help give pupils a 'sense of control over the assessment process and confidence in tackling exams,' say Daws and Singh (p72).[32]

Learning to enquire

AfL requires pupils to be actively involved in their own learning and assessment. Assessment does not have to include a measurement. Rather, it can take the form of enquiry.[38] Naylor and Keogh (p73) say involvement in purposeful enquiry and assessment activities can potentially result in and also constitute pupils' learning.[39]

Questioning as part of enquiry is a useful tool for diagnosing misconceptions.[8, 33] When pupils investigate questions for themselves, the tasks become more motivating and satisfying.[8, 33]

When pupils make enquiries by discussing their own learning, and receive formative feedback, it can 'dramatically affect the way [they] become involved in their own learning,' say Markwick *et al.* (p54), and this can lead to improved enjoyment of and authorship in science.[42]

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National Foundation for Educational Research
The Mere, Upton Park,
Slough, Berks SL1 2DQ

Tel: 01753 574123
Fax: 01753 691632
Email: enquiries@nfer.ac.uk

www.nfer.ac.uk