Education research

Primary Science Quality Mark:
Learning from good practice in primary science

wellcome trust

What can we learn about current practice in primary science teaching and learning in England from the Primary Science Quality Mark award programme?

Jane Turner[1] with Steve Marshall,[2] Adam Farley[3] and Lydia Harriss[4]

[1] Primary Science Quality Mark, University of Hertfordshire.
[2] Primary Science Quality Mark, University of Hertfordshire.
[3] University of Hertfordshire.
[4] The Wellcome Trust.

What can we learn about current practice in primary science teaching and learning in England from the Primary Science Quality Mark award programme?

A report of a scoping project to find out which questions about the teaching and learning of science in primary schools can be answered from the submissions made in round one (2011) of the Primary Science Quality Mark award programme.

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Executive summary

Introduction

The Primary Science Quality Mark (PSQM) is an award programme to develop and celebrate the quality of science teaching in primary schools. PSQM submissions consist of a set of reflections and supporting evidence on practice in primary science. This research analysed a sample of 191 submissions made for PSQM round one (2011) to produce descriptive summaries of different aspects of primary science and to ascertain the potential of the submissions as an evidence base for further research.

Objectives of the research

The objectives of the research were:

- to summarise what can be learned about current practice in science teaching and learning from PSQM data
- to identify the further questions about science teaching and learning that could be answered by further research into PSQM data.

Research methodology

Members of an expert advisory team each read the same complete submission, then compiled an initial typology of categories to enable a sample of the data to be sorted and the research questions to be answered. Thirty-seven submissions were selected at random and coded using these categories (with some additions), and these summaries form the basis of this report. A further level of analysis then took place, using a list of 117 terms that emerged from the report summaries to enable more robust quantification of the data.

Key findings

Current practice in science teaching and learning

Profile of science in primary schools

There is consistency in the actions that subject leaders took to raise the profile of science in their schools in response to the perception that this profile had fallen over recent years.

Characteristics of good science teaching and learning

The submissions identify various pedagogic strategies and improved pupil attitudinal and attainment outcomes as evidence of good science teaching and learning.

Subject leader expertise

Primary teachers become science subject leaders via a variety of routes. Subject leadership expertise and confidence is developed through engagement with continuing professional development, external networks and from senior leadership support.

Science curriculum organisation

There is a high level of ongoing development of existing curriculum frameworks and enrichment through additional activities.

Science enquiry

Increasing and improving science enquiry is a focus of submissions and encompasses many differing pedagogical strategies.

Assessment in science

The removal of the science Statutory Assessment Test in 2009 is not regretted, but the subsequent increased importance on making reliable teacher assessment judgements has caused concern.

Resourcing primary science

Access to plentiful, up-to-date resources has a positive impact on the perceived quality of science teaching and learning.

Identification of further questions about science teaching and learning that could be answered by further research into PSQM data

During this analysis of less than 7 per cent of the total submissions made to date (2012), further questions were identified that could be answered through analysis of supporting documentation. The richness of the data confirmed their potential to inform current debates and developments in primary science.

Introduction

What is the Primary Science Quality Mark?

The Primary Science Quality Mark (PSQM) is an award programme to develop and celebrate the quality of science teaching and learning in primary schools. The PSQM aims to:

- raise the profile of science in primary schools
- provide schools with a framework and professional support for developing science leadership, teaching and learning
- celebrate excellence in primary science
- use networks to provide local support for science for schools
- assemble a rich database of current practice in primary science and make it accessible to the wider science education community.

Rationale for the PSQM

The PSQM was initiated in response to the acknowledged and continuing downgrading of science in primary schools – the result of its systematic squeezing by the National Literacy and Numeracy Strategies from 1998 onwards. This had a negative effect on participation in science-focused continuing professional development (CPD), despite the establishment of the National Network of Science Learning Centres in 2004.[5] It also reduced the development of new science teaching resources. The reduction in profile was noted in reports from scientific institutions, as well as in the influential Cambridge Primary Review, which commented that "science is far too important to both a balanced education and the nation's future to be allowed to decline in this way".[6,7]

Subsequent policy changes also had a negative impact on the profile of science in primary schools. A National Curriculum Review took place in 2008/09, led by Sir Jim Rose.[8] A draft revised curriculum, which had skills at its core and linked science and design technology in its subject specifications, was sent to all schools early in 2010. In addition, in 2009, the Science Standard Assessment Test (SAT) for all 11-year-olds in England was abolished and replaced with sample testing, although teacher assessment in science remained statutory. This apparent removal of science from the accountability register, combined with anticipated curriculum changes, had a negative impact on its status in many primary schools and led to the frequently voiced misconception that science was no longer a core subject in the primary curriculum.[9] The 'Rose' curriculum was not enforced before the change of government in May 2010 and was subsequently scrapped as a new National Curriculum review was announced. At the time of writing, the coalition Government's curriculum review is still to be finalised, although a draft Programme of Study for Science was published along with those for English and Maths in June 2012. Concerns have also been raised about primary teachers' lack of science-specific qualifications: the Royal Society reported that only 3 per cent of primary teachers hold both a first degree and an initial teacher training qualification in science.[10] It recommended that a specification for the requirements for specialism at different educational phases, from Key Stage 2 upwards, should be developed. The Wellcome Trust has taken this action forward by producing a definition of a specialist in primary science and, in 2012, piloting a 24-day CPD programme for primary science coordinators who do not have a science background – the Primary Science Specialist Programme.[11]

Development of the PSQM programme

A three-year national roll-out of the PSQM began in January 2010, after a two-year pilot phase. It was developed and led by the Science Learning Centre East of England and Barnet Local Authority, in partnership with the Association for Science Education (ASE). The PSQM programme had two main income streams from January 2010 to April 2013: fees from participating schools and grant funding from a Wellcome Trust Society Award, plus in-kind support from the University of Hertfordshire.

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[5] Royal Society. 2010. Science and Mathematics Education, 5-14. London: The Royal Society pp. 45–57.
[6] Royal Society. 2010. Science and Mathematics Education, 5-14. London: The Royal Society pp. 3–10.
[7] Alexander R (ed.). 2009. Children, their world, their education. The Cambridge Primary Review. London: Routledge. p. 493.
[8] Rose J. 2009. Independent Review of the Primary Curriculum: Final Report. Department for Education.
[9] Wellcome Trust 2011 Primary Science Survey Report.
[10] Royal Society. 2010. Science and Mathematics Education, 5-14. London: The Royal Society p. 36.
[11] The Wellcome Trust. 2012. Improving Primary Science (www.wellcome.ac.uk/Education-resources/Education-and-learning/Our-work/Teacher-training/WTS052326.htm).

By September 2012 a total of 500 schools had achieved PSQM awards, and 409 schools are in the process of working to achieve awards in 2013. This will equal more than 4 per cent of UK schools in the first full three years of the programme. The geographical spread is wide: schools in all parts of the UK are taking part, plus British Forces schools in Cyprus and Germany and British schools in Dubai and Qatar. The PSQM has been able to use existing networks within primary science education – notably the Science Learning Centre network, ASE membership and the AstraZeneca Science Teaching Trust – to build relationships, raise awareness of the programme, recruit hub leaders and schools, and disseminate positive outcomes. The programme has benefited from the financial support, commitment and goodwill of the science education community, which has supported the project at all levels. In 2011, the English schools inspectorate (Ofsted) reported that "Inspectors' interviews with staff in the schools that participated in the initiative confirmed the improvements in teachers' confidence and ability to teach science, with a consequent positive impact not only on pupils' performance but also on their engagement and enjoyment."[12]

Achieving a PSQM award

Primary school science subject leaders apply to take part in the PSQM programme and are appointed to local PSQM hubs. There are now more than 80 active PSQM hubs, which are led by PSQM-trained experts in primary science who support subject leaders through the year-long programme of professional development, school-based evaluation, action planning and implementation to develop all aspects of science teaching, learning and subject leadership. Subject leaders either approach PSQM independently or are recommended to join the programme by local primary science consultants or advisors. The current fee for participating schools is £595, for which the subject leader and a colleague receive a minimum of two days' CPD, online mentoring, access to all PSQM documentation, school membership of the ASE, a framed certificate and two invitations to PSQM award events (dependent on achieving the PSQM award). The head teacher's support is required before an application to take part is accepted.

The conclusion of this work is the PSQM submission, in which subject leaders reflect on the impact of taking part in PSQM against each of the 13 PSQM criteria (see 'Methodology') at a personal, professional and institutional level. Each school provides one submission, which contains 13 written reflections and selected supporting documentary evidence. The submissions are reviewed and moderated by other hub leaders before PSQM awards are made at gold, silver and bronze levels.

Research rationale and intention

PSQM submissions form a unique, large and comprehensive evidence base with the potential to offer answers to many pertinent questions about teaching and learning in primary science. At a time of review for primary science curriculum and assessment, these data clearly have significant value for policy makers, CPD providers, initial teacher education institutions, and professional bodies and funders; they could support the Wellcome Trust's strategic objective for education of 'improving the evidence base for informing policy and practice'.[13] Therefore, the Wellcome Trust granted funding to carry out an initial scoping project to answer the following questions:

- What can be learned about current practice in science teaching and learning from PSQM data?
- What further questions about science teaching and learning could be answered by additional research into PSQM data?

Methodology

To achieve a PSQM award, subject leaders evaluate the quality of their school's provision in science against the following criteria:

Subject management
A1: There is an effective subject leader for science.
A2: There is a clear vision for the teaching and learning of science.

[12] Ofsted. 2011. Successful Science. p. 49.
[13] Wellcome Trust. 2010. Inspiring Science Education: Extraordinary opportunities. Wellcome Trust Education Strategy 2010–2020.

A3: The current School Development Plan has appropriate and active targets for science.
A4: Science is valued as a subject.
A5: The science subject leader knows about science teaching and learning across the school.

Teachers and teaching
B1: Members of teaching and support staff continue to have opportunities for CPD within science that increases their skills, knowledge and understanding.
B2: There is a range of teaching and learning approaches.
B3: There is a range of up-to-date, quality resources specifically for teaching and learning science. ICT is used both as a tool and as a resource for teaching.

Pupils and learning
C1: All pupils are actively engaged in their own learning and achievement; independently making decisions, answering their own questions, solving real problems.
C2: Teachers are using a range of assessment approaches.
C3: Children enjoy their science experiences in school.

Broader opportunities
D1: Science supports and links with other curriculum areas and contributes to maximising whole school initiatives while retaining its unique status.
D2: There are clear links to other schools and outside agencies, organisations and/or communities to enrich science teaching and learning.

Members of an expert advisory team each read the same complete submission, including all reflective statements and supporting documentation, to begin identifying categories that could facilitate the sorting of a sample of the data and enable the research questions to be answered.[14] The group then compiled an initial typology of categories and agreed that only reflective statements would be analysed for this study. Using these categories, initial coding of the reflective statements from ten round one submissions (out of the 191 that were received in May 2011) began in August 2011. Additional categories and sub-categories that arose from the data were noted, and an extended list of categories was used to recode the initial ten submissions plus an additional 27. A total of 481 pieces of writing – 13 pieces from each of the 37 schools, each typically between 200 and 300 words in length – were coded and summaries compiled. These summaries form the basis of this report, accompanied by commentary and further questions for consideration.

A further level of analysis was then performed, using a list of 117 terms that emerged from the report summaries to enable more robust quantification of the data. All 37 summaries were read and manually coded for the 117 terms. A sub-sample of nine summaries were then re-coded by a different person and compared to the results from the original coding. The original coding and re-coding were found to agree to within 10 per cent.

The following should be noted:

- This is not a representative sample of primary schools. All subject leaders had chosen to take part in the PSQM programme and been supported by their head teacher.
- The subject leaders are self-reporting to achieve a PSQM award. Professional and honest self-evaluation is expected, but the requirement to demonstrate that certain criteria were met might have influenced the content. Furthermore, the structure of the framework and the questions that the subject leaders responded to will have influenced their reflections.
- A lack of reference to specific categories within a submission is not evidence that the category does not apply.
- Only the reflective accounts submitted by the subject leaders and, where available, their CVs were coded, not the supporting documentary evidence. CVs were available for 33 of the 37 submissions.
- All the schools in the sample were from England because the PSQM programme was limited to England at this stage.

[14] The expert advisory team was made up of members of the PSQM advisory group: Professor Wynne Harlen, Brenda Keogh, Emily Yeomans, Professor Derek Bell and external consultant David Shakespeare.

- The sample of encoded submissions was randomly selected and has not been categorised using any external datasets (e.g. inspection data or demographic data).

Ethics

All PSQM participants in round one submitted data under the following privacy clause:
Material will become the copyright of the Primary Science Quality Mark, but if used the school's name will be acknowledged and permission will be obtained first before any material is published.

All participating schools have been informed that submissions may be used anonymously for research purposes.

Findings

What is the profile of science in primary schools, and how have participating PSQM subject leaders sought to change it?

Summary

- Twenty-eight of 37 subject leaders described an increase in the profile of science as a result of their actions.
- From their descriptions, it can be inferred that the profile of science had been falling in their schools over recent years, evidenced by a lack of attention from senior management, less curriculum time, and reduced budgets for professional development and resources.
- The actions that subject leaders took to raise the profile of science in their schools were largely consistent and included raising its visibility and awareness with all members of the school community, demonstrating strong subject leadership, leading and supporting changes to the science curriculum and pedagogy, and making links with outside organisations.

Twenty-eight of 37 subject leaders whose PSQM submissions were analysed in this scoping study perceived that the profile of science had risen in their school during the preceding year, as a result of their participation in the PSQM. Although only three of the subject leaders specifically described how the profile of science had fallen in their school in recent years, it can be inferred from the large number of references to raising the status of science that a falling profile had been a concern for many schools, as noted in another Wellcome Trust study.[15]

"We were acutely aware that the profile of science was in danger of being lowered to that of a foundation subject."
PSQM submission 2011

The three schools that specifically described a reduction in status cited the removal of SATs and the policy-level focus on literacy and maths as the reasons. Their submissions also indicated a reduced focus on science from senior management resulting in minimal or no staff meeting time allocated to science, no one being encouraged or permitted to attend science-specific CPD, no reference to science on the school development plan, no time allocation for the subject leader to monitor the teaching and learning of science, limited budget allocation for science resources, and an overall perception within school that science was of secondary importance to literacy and numeracy.

Subject leaders explained that participation in the PSQM programme legitimised their plans to raise the profile of science and enabled them to garner support from many sectors of the school community. All applications to take part in the PSQM are countersigned by the head teacher, who agrees to support the subject leader.

There is significant consistency in the actions that subject leaders took to raise the profile of science in their schools, which can be divided into the following groups.

Actions that raise the visibility of science in school:

- creating science-related displays in corridors and entrance halls (32 of 37)
- running science days and weeks (28 of 37)
- holding science assemblies (18 of 37)
- running science clubs (17 of 37)
- reporting science-related activities on the school website and in school newsletters (11 of 37)
- establishing a science notice board in the staff room (4 of 37)
- publicising school science activities in the local press (6 of 37)
- using notices and signs to promote science all around the school – for example, in outdoor areas and/or the school garden (4 of 37).

[15] Wellcome Trust 2011 Primary Science Survey Report.

Actions that include other members of the school and wider community:

- actively involving parents in science in school through special events, home–school challenges and new parent evenings (24 of 37)
- talking to children about science and responding to their opinions (35 of 37)
- raising governor awareness by attending meetings, producing reports, forming a science working party to include governors and inviting governors to attend PSQM training events (13 of 37)
- making links with other schools and external agencies (32 of 37).

Actions that adapt the curriculum and pedagogy:

- creative approaches to curriculum planning, linking subjects (37 of 37)
- more visits and visitors with a science theme (36 of 37)
- promoting more practical activities (33 of 37)
- focusing on science enquiry skills (27 of 37)
- ensuring there are relevant contexts for science, linking to children's own experiences (23 of 37)
- supporting more formative uses of assessment in science (24 of 37)
- encouraging more creative approaches to recording (22 of 37)
- allowing teachers autonomy to move away from rigid schemes of work (19 of 37)
- increasing opportunities for science investigation (20 of 37)
- science homework (15 of 37)
- increasing curriculum time for science (6 of 37).

Actions that have a direct relationship with school leadership:

- developing and sharing a whole-school vision for science based on principles of procedure (37 of 37)
- having regular science staff meetings (29 of 37)
- subject leaders and other staff members attending and sharing CPD (33 of 37)
- implementing a programme of science curriculum monitoring and evaluation (34 of 37)
- appointing a science subject leader (2 of 37; most schools had already appointed one).

Most subject leaders described an improvement in the profile of science in their schools, evidenced by the following impacts:

- Thirty of 37 subject leaders reported that science was now identified on the school development plan.
- Twenty-eight of 37 cited students' opinions that more science was happening and that it was more engaging.
- Fifteen of 37 identified an increased enquiry focus in teachers' short-term planning.
- Sixteen of 37 noted that colleagues' enthusiasm for science generally and awareness of current initiatives had increased.
- One of 37 subject leaders reported an increased allocation of leadership and management time to science.

Discussion

PSQM criteria A2 requires subject leaders to demonstrate that there is 'a clear vision for the teaching and learning of science'. It is interesting to note that subject leaders submitted considerable detail to demonstrate that science is valued with plentiful descriptions of actions taken to increase the profile of science within the school. However, there were few descriptions of schools' visions for science or why learning science is important in primary schools. Subject leaders tended to articulate vision in terms of subject profile or processes rather than values or benefits. Often, comments from parents or children used to evidence the high value placed on science described how enjoyment in 'doing science' means it is valued, rather than explaining its value in terms of learning.

It should be remembered that all participating subject leaders took part in face-to-face CPD led by hub leaders who had attended hub leader training run by the PSQM programme leaders. This cascaded model of training uses evidence of effective actions from the PSQM pilot participants, so the consistency in actions from the round one participants analysed here is not surprising.

Further questions

- Is there a shared vision for science teaching and learning in English schools? What are the values and aims that inform this? Do teachers see it in terms of developing important skills, knowledge, understanding and attitudes that children will build on at later stages of their education? What societal value do they identify?
- What factors promote teacher autonomy? What are the impacts of greater autonomy?
- What mechanisms enable teachers to share good practice?

What do PSQM subject leaders believe characterises good science teaching and learning in primary schools?

Summary

Subject leaders described good teaching and learning in science in two ways:

- Pedagogy – making links between the programme of study and children's own experiences, linking curriculum areas, teaching science through enquiry, using assessment for learning (AFL) strategies and being dependent on teacher confidence.
- Pupil outcomes – attitudinal (notably enjoyment) and successful learning.

The criteria that subject leaders identify as characterising good science teaching and learning can be divided into two main groups, associated with input or outcome.

Input characteristics

These were generally described in terms of pedagogy and planning: the strategies that teachers use to support children's learning in science. These can be grouped into the following approaches, which are usually described separately but used concurrently.

1. Making links between subjects

- The subject leaders all described the importance of linking science with other curriculum areas (most frequently maths, ICT and literacy). This is described as a relatively innovative strategy, which moves away from how science has been taught before and towards a more creative way that is relevant to children's interests and builds on other learning.
- Another marker that subject leaders used to indicate good science was it extending beyond the boundaries of the classroom: through trips outside the school (33 of 37), into children's homes via homework or home–school activities (27 of 37), or into outdoor spaces at school (23 of 37).

2. Science enquiry

A focus on teaching science through enquiry was reported by 27 of 37 subject leaders. Only one subject leader defined science enquiry in terms of an evidence-based approach to answering questions about the world; the majority of subject leaders defined science enquiry in terms of what teachers and children do in science lessons, with a strong focus on the context and purpose of science enquiry activities. Little reference was made to how the development of children's conceptual knowledge of science is managed in an enquiry-based approach.

Under the umbrella term of 'science enquiry', the following teaching strategies were identified:

- using children's questions to inform planning (26 of 37)
- supporting children's autonomy when planning and carrying out science activities (26 of 37)
- stimulating and responding to children's curiosity (12 of 37)
- encouraging risk-taking and the idea of science as a speculative activity (3 of 37)

Subject leaders also described the skills that children use when answering scientific questions:

- planning (13 of 37)
- exploring (9 of 37)
- data collection and analysis (5 of 37)
- fair testing (4 of 37)
- predicting (4 of 37).

There were fewer references to observing, drawing conclusions or devising explanations.

Twenty-four of 37 subject leaders perceived a strong connection between science enquiry and children's engagement in practical work. The importance of accessible and appropriate practical resources, used safely, was frequently identified (27 of 37) as a prerequisite of good science learning.

Twenty of 37 subject leaders referred to the importance of children and teachers using scientific vocabulary correctly.

3. Assessment for learning
Techniques often identified as AFL strategies were cited by 24 of the 37 subject leaders as characteristics of good science teaching and learning. Subject leaders referred to:

- the importance of talk and discussion in enabling children to share and develop their ideas with each other and with adults (27 of 37)
- collaboration and group work (19 of 37)
- peer and self-assessment in science (15 of 37)
- teachers building on children's prior learning and addressing misconceptions (13 of 37)
- teachers and children sharing formative feedback (6 of 37)

4. Confident and enthusiastic teaching
Twenty-five of 37 subject leaders identified the importance of teacher confidence and enthusiasm, referring variously to knowledgeable teachers and to teachers ready to learn with the children, take risks and share understanding with each other.

Characteristics linked to outcomes
1. Enjoyment
The most frequently identified characteristic of good science teaching and learning is pupil enjoyment (31 of 37), which was variously defined as children having fun, showing enthusiasm, and being excited and engaged.

2. Learning
Seven of 37 subject leaders cited evidence that children are clearly making progress in science learning, including as evidence teacher assessment judgements made against National Curriculum level descriptors or children transferring scientific skills to other curriculum areas.

Discussion
One of the core documents that subject leaders must submit to gain a PSQM award is a brief statement of principles describing how they identify when good science teaching and learning takes place. This was introduced after the first PSQM pilot, when all participants chose to submit their school policy for science in response to criteria A2, 'There is a clear vision for the teaching and learning of science'. Analysing the subject leaders' description of practice in their schools alongside the supporting evidence (teachers' planning, pupils' work and attitudinal data) revealed that these policy documents served very little function in disseminating a shared vision for science teaching and learning. Therefore, the professional development facilitated by PSQM hub leaders supports subject leaders in creating a set of shared principles and using them to develop and evaluate practice. For the purposes of this study, the documents were not analysed separately, but references to their content in the reflective statements were noted and coded.

There is a high level of uniformity in these principles as described in subject leaders' reflections; the focus seems to be shared equally between pedagogical inputs and attitudinal, rather than attainment, outcomes. Subject leaders describe how they found the strategy of collating and sharing principles of procedure with colleagues (and, often, children and parents) both useful and liberating. It would be interesting to reflect on the influences behind these commonly selected principles, as they seem to be in opposition to the way that many teachers thought science had to be taught in schools in England to meet the requirements of the science SAT. Enquiry-based science education, AFL, practical work and 'putting the wow into science' are all phrases that have currency in primary science in England, but the SAT and statutory teacher assessment have been the only systematic and policy-level influence on science in primary schools in recent years.

It is interesting to consider whether the principles shared by many PSQM subject leaders' schools indicate a significant rejection of policy-led influences on science. Alternatively, are they an acknowledgement that teachers believe science should be evaluated against a wider range of criteria than attainment data? Subject leaders do not refer to an evidence base or research that lies behind their shared principles but refer to them as having been compiled from experience of what works and what they would like to happen in their classrooms. Is this evidence of a tension between what teachers feel they have to do and what they believe is the right thing to do?

Further questions

- What have been the main influences on teachers' practice in science teaching and learning over recent years? How were the strategies, techniques and values derived and shared? How deep is the understanding of them? What do teachers understand by enquiry-based science, AFL in science and the role of practical work? How do they evaluate new strategies and techniques? What influence do they have on teachers' professional judgements about quality in science teaching and learning?
- Is 'children having fun' an educationally valid criterion for evaluating the quality of science in a school?
- What is the relationship between Ofsted inspection criteria, attainment data and teachers' personal professional judgements?
- Can an assessment model be designed that supports the principles that teachers identify as underpinning good learning in science?

How do PSQM subject leaders describe their professional expertise?

Summary

- For the primary teachers in the sample, there was no single route to becoming a science subject leader. Subject leaders ranged from those with science qualifications and science-related professional experience to recently qualified teachers with no formal science background.
- Subject leadership expertise and confidence was developed through engagement with CPD, external networks and senior leadership support.
- There was no discernible difference in the amount and type of leadership activity undertaken by subject leaders with a science background and those without.
- Effective science leadership had a perceived positive impact on the profile and quality of science teaching and learning within a school, and it developed confidence in the subject leader to take on further leadership roles.

Subject leaders participating in the PSQM programme are required to demonstrate that there is an 'effective subject leader for science'. The reflective summaries submitted to meet this requirement can be divided into three sets:

- data that describe the derivation and development of their professional expertise
- data that describe the different activities that science subject leaders specifically engage in to fulfil their role
- data that describe the impact of an effective science subject leader.

These datasets are of particular relevance to the topical issue of subject specialism in primary schools.[16]

Becoming a science subject leader

1. Background and prior experience

Thirty-three of the subject leaders submitted CVs detailing educational qualifications as part of their PSQM submission.

- Fourteen of 33 had at least one science A level.
- Twelve of 33 had science degrees: four held psychology degrees and one held a BSc in geography.
- Nine of 33 subject leaders had taken a specialism in science as part of their BEd or PGCE course.

More than half the subject leaders in this sample do not have a qualification in science beyond GCSE level.

[16] The Royal Society. 2010. Science and Mathematics Education, 5-14.

2. Why do primary teachers take on the role of science subject leader?
Thirteen of the subject leaders in the sample explained that they chose to take on the role because they enjoyed science, some passionately.

- For seven of 37 subject leaders, this enthusiasm had persisted since childhood and their own education.
- Five of 37 explained how it was teaching science themselves that had inspired them.

Other routes to science subject leadership were:

- being given the job as a first leadership role (four of 32)
- assuming the role alongside other leadership roles (11 of 32)
- moving to primary from secondary science teaching (one of 32).

Seven teachers who had been asked to take on the role admitted feeling anxiety when they were first appointed because they did not have the appropriate expertise or experience to carry it out.

Developing subject leader expertise
Subject leaders in the sample described how they had developed the skills to lead science effectively; some acknowledged that it had been a challenge that required hard work and commitment. Even where subject leaders expressed high levels of subject knowledge confidence, there was frequently an acknowledgement that this was not enough to lead science teaching and learning effectively. Four methods were identified as key to developing subject leadership skills:

1. Engagement in primary science-specific CPD
Thirty-three subject leaders had taken part in CPD provided by the local authority, Science Learning Centre or ASE, usually in one-day courses or conferences. Many described this as vitally important.

"Although I have a scientific background, the CPD I have received has been invaluable in equipping me with necessary strategies and current understanding in the teaching of science."
PSQM submission, 2011

Eleven subject leaders citied their participation in the PSQM process as having had a major impact on their leadership skills.

2. Senior management support
Working closely with other leaders was identified by 27 of 37 subject leaders as a way to develop leadership skills, including being mentored or coached by a more experienced colleague and participating in whole-school development planning. For 13 subject leaders, this included working with governors.

3. Involvement with external networks
Learning from others was often cited as a crucial outcome of engagement with CPD. Twenty-six of 37 subject leaders actively engaged with primary science education forums, whether face to face via local Subject Leader Networks groups that meet regularly (15 of 37), by attending ASE events (nine of 37), or by reading ASE journals and other online or print publications (11 of 37).

4. External recognition for subject-specific expertise
Nine of 37 of the sample of subject leaders had developed their science leadership skills beyond their own school, by becoming Advanced Skills Teachers and supporting colleagues in other schools, acting as PSQM hub leaders or mentors, or contributing to professional development at Science Learning Centres, in initial teacher education institutions or via the national pilot project for Assessing Pupils' Progress (APP).

Being a subject leader
There is a high level of uniformity in the behaviours that subject leaders attributed to their role.

1. Making the role visible
Subject leaders recognised the importance of a school having a visible, active and enthusiastic leader for science to drive the subject in the staff room and beyond, including in public areas in schools and on virtual learning environments. The ways they described their role included "working hard to keep the

profile of science high" and "making a noise about science". For the leadership role to be effective, subject leaders acknowledged that it requires validation from both colleagues and senior management. Some subject leaders identified the importance of the science leader being visible and known to children and parents. Being able to deal with issues quickly and 'keeping up to date' were also cited as important.

2. Organising events and resources
Subject leaders associated several organisational tasks with their role, including:

- distributing and maintaining science resources for the school (37 of 37)
- organising family science events (24 of 37)
- planning and leading whole-school science days and weeks (28 of 37)
- developing outdoor wildlife areas, allotments, ponds and science trails (16 of 37)
- managing a science budget (nine of 37).

3. Monitoring and evaluation
Subject leaders reported high levels of monitoring activities, including:

- lesson observation (27 of 37)
- work and planning scrutiny (31 of 37)
- analysing assessment data (15 of 37)
- pupil surveys (35 of 37) and parent surveys (ten of 37).

Subject leaders described evaluating the outcomes of these activities to identify and share staff CPD needs and school-wide pupil attainment targets, and to inform school development plans and policies.

4. Professional development and support for colleagues
Subject leaders provided professional support in science teaching for colleagues in a variety of ways, including:

- working on a one-to-one basis with colleagues (e.g. mentoring newly qualified teachers or coaching teachers who requested support, modelling lessons, or arranging team teaching or lesson study) (33 of 37)
- leading staff meetings for teachers and other colleagues to disseminate external CPD they had taken part in, focusing on new strategies for teaching or assessment (29 of 37)
- adapting published schemes of work and assessment frameworks (17 of 37)
- sharing articles from ASE journals (11 of 37).

It is interesting to note that there seems to be no correlation between the amount of internal CPD and support provided by subject leaders and the level of their science qualifications.

5. Develop external links
Many subject leaders actively developed links with organisations and individuals beyond their own school to enhance the quality of science teaching and learning.

- School or individual membership of ASE has been one of the benefits offered to PSQM participants. Sixteen subject leaders report actively engaging by attending national or regional ASE conferences or local events or by reading, using and sharing ASE articles and resources.
- Other external links identified include:
- building productive relationships with local authority and Science Learning Centre colleagues (nine of 37)
- working with local secondary schools (24 of 37), higher education institutions (one of 37) or local industry partners (seven of 37).

Impact of subject leader actions
In their PSQM submissions, subject leaders reflect on the impact they perceive as a result of their actions. The impact most frequently described in our sample was a raised profile for science (28 of 37).

- In two schools, subject leaders noted that the place of science within the curriculum had shifted significantly: it was allocated more time and taught by all teaching staff.
- Specific impacts on pedagogical and learning outcomes are also identified, particularly resulting from leadership actions that focused on science enquiry:
    - an increase in the amount and range of practical work taking place (24 of 37)
    - children displaying more independence (26 of 37)
    - teachers more confident in diverging from rigid schemes of work (19/39).

Discussion
There is no defined route to becoming a science subject leader in a primary school, and the sample of reflections coded here shows clearly that it is most commonly a mixture of personal interest (often fuelled by background science knowledge) and opportunity that leads to a teacher taking on the role. Four of 37 subject leaders in the sample stated that it was a first leadership role, and there was an overlap between this group and the group of seven of 37 subject leaders who admitted feeling anxious about their capacity to fulfil the role. However, the data clearly indicate that there is no direct correlation between having a science background and the amount of leadership activity in which a subject leader engages.

Subject leaders tend to define their role in terms of the things they do, rather than the specific knowledge they possess. A positive attitude towards science is frequently referred to as vital, but scant reference is made to the necessity of a thorough understanding of the big ideas or methodologies specific to science. It is clear that primary teachers identify the need for subject-specific CPD to enable them to carry out the leadership role effectively; however, the CPD they report as beneficial helps them to do the operational aspects of their role (e.g. carry out lesson observations, make reliable teacher assessments, and support colleagues to introduce new teaching and learning strategies). Few subject leaders identify developing their personal subject knowledge as important, although the PSQM award criteria do not focus on teachers' personal subject knowledge. Subject leaders recognise that they require senior management support and respect to carry out leadership activity, and that they benefit from engaging with wider science education networks and partners. These initial findings raise interesting questions about the concept of subject specialism in primary schools. What is understood by the term? What does it mean in terms of a broad and balanced primary curriculum? What specific background and/or training does a primary teacher need to be an effective primary science subject leader? Is this the same as is required to be a science specialist teacher who is teaching all science across a primary school?

A small number of schools that submitted for PSQM awards in 2011 had science leaders who taught science throughout the school, reducing significantly or even completely the need for colleagues to teach science. They did not appear in this random sample. It would be interesting to compare the activity and effectiveness of these subject leaders with the generalist teacher with a science leadership role.

Further questions
- How does background experience and science subject knowledge affect perceived effectiveness as a science leader?
- What effect is the reduction in local authority capacity to support primary science having within schools? Are schools identifying a gap? Are schools linking with other local and national networks? If so, which ones?
- What is the link between subject leaders' self-evaluated indicators of effective science leadership and other, external accountability criteria of effectiveness (e.g. attainment data and Ofsted judgements)?

How is the science curriculum organised in PSQM schools?

Summary
- There was a high level of development and ongoing adaptation of existing curriculum frameworks, notably the QCA scheme of work for science.
- Curriculum development followed one of four models (often with overlaps): cross-curricula planning, linking science to real-life contexts, skills-based planning or implementation (typically with adaptation) of an alternative published curriculum framework.
- The science curriculum was enriched by additional activities.
- Science subject leaders valued professional development to support curriculum development.

Teachers participating in the PSQM programme submit evidence of science curriculum planning and reflective statements to explain the rationale and impact of their chosen science teaching and learning frameworks.

Subject leaders' reflections on science curriculum planning and organisation indicate a high level of development and ongoing adaptation of existing curriculum frameworks that are based on the English National Curriculum for Science.

"If I had to use one word to describe our science curriculum, it would be 'dynamic'."
PSQM submission, 2011

Impetus for curriculum development seems to be attitudinal; subject leaders wanted the science to be more engaging for both teachers and children. Patchy National Curriculum coverage or poor attainment outcomes also influenced decisions about curriculum development.

In many instances, the identification of particular curriculum frameworks was not explicitly stated. Twelve of 37 subject leaders reported using the non-statutory Qualifications and Curriculum Authority Scheme of Work (QCA SOW) for science as a basis for science curriculum planning; all of these described it as something they had adapted and extended.[17] Thirteen subject leaders identified a definite move away from using QCA SOW as a planning structure. In general, teachers found the QCA SOW too prescriptive; they also suggested that it lacks variety and has insufficient focus upon practical work and science enquiry, and that it doesn't facilitate links to other subjects, particularly design technology. However, it was acknowledged that the spiral nature of the QCA SOW makes it a useful tool for ensuring National Curriculum coverage and progression.

The models that subject leaders identified in terms of curriculum planning can be classified into four groups, with some overlaps between the groups:

Cross-curricula planning (37 of 37)
A more creative approach to lesson planning was often described synonymously with an increased focus on cross-curricula planning. Subject leaders described encouraging colleagues – often directly, through the imposition of 'curriculum maps' – to link science with other curriculum areas. This might be through a topic or thematic approach, linking subject content from history, geography or PE with science. Subject leaders reflected that colleagues and children find this approach motivating and enjoyable. One school identified science as a key curriculum driver, providing a rich source of opportunities for cross-curricula learning to develop important skills and motivate learners, and had this approach validated by Ofsted. Again, the importance of external CPD to support subject leaders in implementing this approach was highlighted, as was the need to work well with other subject leaders within school.[18]

Two subject leaders raised concerns that as a result of this approach, science was becoming too diffuse and essential scientific skills and understanding may not have been focused on sufficiently.

Linking science to real-life contexts (23 of 37)
Subject leaders described a focus on contexts for science learning that build on children's own experiences and interests, and are not constrained by prescribed schemes of work or by repeating lessons from previous years. These included lesson stimuli designed to engage children in purposeful investigation and often linked to actual events, such as snowy weather, news stories, visits, visitors, interesting artefacts and scenarios, stories or games. Subject leaders noted that teachers and children were invigorated by this approach and reported greater levels of enthusiasm for science.

Skills-based planning
Twenty-seven subject leaders described using the development of skills as a whole-school planning and assessment framework. This approach was often linked to thematic or cross-curricula planning, where the whole curriculum is organised into topics to ensure National Curriculum coverage, but each lesson or group of lessons has a clear skills focus and assessment decisions are made against an identified skill progression. Subject leaders reflected that this focus leads to more practical work, which has led to some additional resourcing and CPD needs. Science-specific skills were usually highlighted alongside ICT, literacy and numeracy skills as curriculum organisation tools. Again, the result was greater pupil engagement and motivation.

[17] QCA 2000-2009 (www.nationalstemcentre.org.uk/elibrary/resource/4481/key-stages-one-and-two-schemes-of-work-science).
[18] Creative Cross Curricula Science was the most popular course at regional Science Learning Centres 2010–11.

Implementation of alternative published curriculum framework
Seven of 37 subject leaders in the sample reported that their schools had 'bought in' curriculum frameworks, which were based on the National Curriculum but organised individual subject content into cross-curricula themes and topics. There is clear evidence within subject leaders' reflections of these curricula being evaluated using a wide range of criteria. Subject leaders spoke positively about the impact of 'bought in' curriculum frameworks in terms of teacher and pupil engagement and manageability, but concerns were expressed about the thoroughness of the curriculum coverage for science and the ensuing progression of skills and knowledge. Subject leaders recognised the need to adapt and develop these commercial thematic schemes, just as they had with the QCA subject-based framework.

Along with these curriculum planning models are many references to curriculum enrichment science activities (see 'cross-curricula planning', above), such as dedicated science weeks, days, outings, visits and visitors; science clubs; science homework; family science events; and whole-school science competitions.

Discussion
The PSQM submissions analysed for this report were compiled during 2010-11, at a time when the science curriculum could be considered to be in limbo; therefore, it is interesting that all science subject leaders in the sample, without exception, report curriculum planning as an ongoing process. It would seem that active science subject leaders, in partnership with senior school leaders and teaching colleagues, are not waiting to be told how to do it but are busily ensuring a continual process of curriculum development and working hard to ensure that science is instrumental to the curriculum in their schools. It would be interesting to ask whether this occurs in schools that have not chosen to engage with the PSQM process. Are the dissatisfactions with the QCA SOW expressed in a majority of schools and, if so, what are they are doing about it? Is the impetus for cross-curricula planning strong in all schools, not just those involved in the PSQM?

It seems that within this sample group, there are no concerns about the National Curriculum for Science being 'overloaded' or requiring 'slimming down'. The impetus for curriculum development is process driven; subject leaders and teachers seem to be driven by the aim of helping children to behave like scientists to develop their scientific knowledge and understanding.

A clear outcome from the reflections coded under curriculum planning is that this is an activity that requires strongly motivated and expert leadership. Professional development is also considered important and influential. Two subject leaders in the sample had studied the primary science curriculum at Master's level. From the sample, it would also seem that curriculum development requires significant levels of cooperation from colleagues, at both class teacher and subject leader level.

Further questions
- What type of support are subject leaders going to need to support curriculum development and evaluation when the new National Curriculum for Science is introduced?
- How widely is the concept of teachers as curriculum developers, rather than deliverers, shared among policy makers?

Which pedagogical strategies are used in science teaching and learning in PSQM schools?

Summary
- There was a concerted move towards learning through enquiry in science.
- This was a significant innovation for schools.
- The terms 'enquiry' and 'science enquiry' were used synonymously.
- Learning through enquiry encompassed many differing pedagogical strategies.

PSQM criteria B2, 'there is a range of teaching and learning approaches', requires science subject leaders to reflect on the range of strategies practised in their school, and specifically on their role in extending the range. Subject leaders also evaluate pedagogical strategies in response to criteria C1 ('All pupils are actively engaged in their own learning and achievement; independently making decisions, answering their own questions, solving real problems'), which directs them to focus on enquiry-based learning. Responses to

the first of these criteria overwhelmingly described an emphasis on enquiry-based approaches to science teaching and learning, which is then elaborated on further in responses to C1. It is impossible to tell how far meeting criteria C1 influenced responses to B2, but from the combined reflections, it is clear that subject leaders placed substantial importance on encouraging enquiry-led pedagogy in their schools. It should be noted that no distinction was made in any reflection between enquiry and science enquiry.

It is clear that for the majority of schools, (science) enquiry-based learning was an innovation in practice, developed as a response to several evidenced needs and opportunities. Subject leaders describe the following reasons for this approach:

- Monitoring evidence showed a lack of classroom time spent on developing science enquiry skills and understanding.
- In pupil surveys and interviews, children described enjoying science lessons that were more active and practical and where their ideas were valued; importantly, they were turned off science by passive, teacher-dominated, writing-focused lessons where they were simply being taught facts.
- It was recognised that science teaching was not making use of relevant opportunities to connect scientific ideas and approaches to children's real-life experiences.
- Teachers felt that a more 'daring' approach to lesson planning was legitimised because the science SAT had been abolished and curriculum guidance to schools from central government indicated that professional autonomy was permitted.

"Each Y5 class came up with a separate investigation during their Gases Around Us topic. I was delighted by this as it was unsolicited; the children genuinely seemed interested in (a) whether all acid drinks produced the same amount of CO_2 when mixed with an alkali and (b) whether all bubble baths were equally bubbly. I abandoned the existing plan and let them follow their own ideas. Reflecting on the outcome of the juices experiment, they then asked if there was a better way of measuring acidity, which led on to using indicator paper and the PH scale. This natural extension of our work would not have happened without the flexibility which we are now daring to allow ourselves in science."
PSQM submission, 2011

A science enquiry-based approach was identified strongly in the subject leaders' responses as concentrating on the process of learning, moving away from a didactic knowledge-focused approach. This seemed to be a significant and rather daunting transition for many teachers. Throughout their reflections, teachers indicated that they needed to develop their own confidence before they could allow their pupils' curiosity to influence the questions investigated in their science lessons. In addition, teachers indicated that more confidence would enable them to better support children in making independent decisions about how to carry out investigations and, to a lesser extent, to encourage children to be creative about how they decide to communicate their findings. Thirteen of 37 subject leaders in the sample participated in Science Enquiry courses (led by Science Learning Centres or local authorities) to develop their skills and confidence and cascaded this training to colleagues across the school, either in staff meetings or through peer support activity.

However, despite the almost universal inclusion of science enquiry-based learning as an important pedagogical strategy, the reflections do not indicate a clear, shared understanding of the purpose of science enquiry methodology. Instead subject leaders describe elements of the process of science enquiry (see 'science enquiry', p. 11).

As described above, 24 of 37 subject leaders evidenced a strong connection between science enquiry and children's engagement in practical work. The importance of practical activity was widely reflected upon, and its major value was expressed in terms of pupil engagement and enjoyment. Subject leaders also reflected positively on the opportunities that children's practical work offers for teacher assessment. In addition, subject leaders perceived that practical work promotes children's collaboration and communication skills.

In many of the subject leaders' reflections, there was a distinct overlap between the pedagogical strategies they described as enquiry-based learning and strategies that are often described more widely as AFL strategies (e.g. using KWL grids, questioning and other techniques to probe children's understanding and possible misconceptions, encouraging a supportive classroom climate in which children share their ideas

freely, implementing self- and peer-assessment, and giving formative feedback; see 'What do PSQM subject leaders believe characterises good science teaching and learning in primary schools?', above).[19]

Talk was identified by 27 of 37 subject leaders as a pedagogical approach that has been used in many schools, in terms of teachers' questioning techniques (sometimes in terms of eliciting higher-order thinking in children) and in terms of teachers encouraging children to develop their scientific ideas through talking. Puppets have been introduced in 16 of the 37 schools in the sample to encourage and support children's talk in science, often to good effect.

Learning science outside the classroom is another frequently described pedagogical strategy, which 23 of 37 science subject leaders spent considerable time and effort developing. Their reflections indicated that in many cases provision for this form of pedagogy was ongoing and heavily dependent upon school resources (financial and personnel) and surrounding ecology. Sixteen of 37 subject leaders described the development of school wildlife areas, gardens, ponds, Forest School projects and allotments being underway and, importantly, noted that teachers and support staff will require further CPD to engage fully with learning science outside. In addition to developing and timetabling regular use of their own outdoor spaces, 33 of 37 subject leaders also organised field trips to beaches, woodland, farms and urban environments where science takes place (e.g. industrial sites, observatories and hospitals). Twenty-four of 37 subject leaders in the sample made use of local secondary schools to broaden children's scientific experiences.

"A good example of this is the Year 5 Night under the Stars. The children are studying space as their topic and are coming to school from 7pm till 9pm to observe the sky. The following day they are using Star Lab online telescope to try and relate this to what they have seen."
PSQM submission, 2011

The set of teaching and learning strategies that subject leaders identify in their schools also includes the following (note that 'strategies' has been interpreted in a loose way to include resources):

- inviting science professionals into school, both formally (e.g. STEM ambassadors and secondary science teachers) and informally (e.g. parents) (34 of 37)
- Concept Cartoons (17 of 37)
- greater use of ICT to support science learning: digital microscopes, data loggers, video and digital cameras, voice recorders and video clips, virtual experiments (i.e. interactive ICT resources for demonstrating and/or exploring scientific concepts), and simulations (19 of 37)
- stories (11 of 37)
- role play (4 of 37)
- primary UPD8[20] (4 of 37)
- thinking hats[21] (2 of 37)
- songs (4 of 37).

Subject leaders' reflections indicated that teaching and learning strategies were highlighted to demonstrate clearly the principles of good science teaching and learning shared across the school.

Discussion

Science enquiry has been a statutory part of the National Curriculum for Science since its introduction, and since then there have been policy-level interventions (SATs), national initiatives (e.g. Getting Practical) and inspection advice (Success in Science) designed to encourage teachers to teach science through enquiry, rather than didactically.[22,23,24] In the majority of schools in the sample, however, learning through science enquiry is described as an innovation in practice requiring significant changes to pedagogy, with consequent demands for CPD, planning revisions and new resources.

[19] A KWL grid can be used in planning at the beginning of a topic or to follow progress for children to indicate 'What I know, what I want to find out and what I have learned'.
[20] An ASE resource comprising downloadable science activities for children aged 5–11 based on topical events.
[21] A decision-making classroom strategy derived from on Edward de Bono's book *Six Thinking Hats* (Penguin 2009).
[22] National Curriculum Assessment (SATs) introduced for science in 1999 and scrapped in 2009.
[23] SCORE 2009 Getting Practical – Improving Practical Work in Science.
[24] Ofsted 2011 Successful Science.

Does this indicate that the enquiry-focused interventions have not had the desired impact? Or is a more thoughtful explanation required? Should the science education community attempt to identify what it is that teachers understand by the word 'enquiry' in terms of science teaching and learning, and what the influences on their practice have been? In the subject leaders' reflections, references to specific science enquiry skills are vague and focus mostly on how to get children engaged in the process of doing science. It would be interesting to examine the supporting documentation more closely to look for evidence of children learning to systematically raise scientific questions, collect and analyse data, develop explanations, and evaluate their work.

The PSQM training programme for hub leaders and schools refers to Lawrence Stenhouse's three characteristics of 'extended professionalism':

- the commitment to systematic questioning of one's own teaching as a basis for development
- the commitment and skills to study one's own teaching
- the concern to question and to test theory in practice.[25]

Subject leaders are thus made aware that participation in the PSQM requires some level of critical evaluation of professional practice; therefore, it is interesting to consider how subject leaders reflect on their role to develop and evaluate science pedagogy. PSQM hub leaders help subject leaders to produce action plans that clearly demonstrate how a need for an action has been agreed, how it will be met and the intended impact. Various rationales for how subject leaders engage with and promote particular pedagogic approaches are identified in the reflections sampled, including personal and professional concern or interest, a desire to address an identified need, being 'sent' on a course, and being told or invited to take part in a school or local authority initiative. It is interesting to know which of these results in long-term change to professional behaviour. Are any strategies ever judged to be ineffective or unsuitable and then abandoned? How is a subject leader persuaded to try something new, and how do they persuade colleagues? Does research evidence ever convince them to try something new? What is the role of school senior managers or local authority advisory personnel? Do financial bursaries to attend training affect which strategies are adopted? What is the impact of free or subsidised resources?

In the spirit of critical connoisseurship, PSQM subject leaders are directed to evaluate the impact of any changes to pedagogy, rather than simply submit evidence that they have tried a new approach to teaching and learning. It is encouraging therefore to see how subject leaders have used evidence from pupil surveys, lesson observations and, in a few instances, attainment data to demonstrate the very positive use of new pedagogical strategies on pupil attitude and outcome and on teachers' professional satisfaction.

Further questions

- What is understood by learning through science enquiry? What similarities and differences would a systematic analysis of the supporting documents submitted in regards to science enquiry against the intended aims and outcomes of national initiatives (such as Getting Practical) or international projects (such as *la main à la pâte*) evince?[26,27]
- Analyse existing programmes for supporting pedagogy in primary science, such as the Science Learning Centre programme, against needs for development and understanding seen in the PSQM submissions. Are needs being met? Do particular programmes lead to the implementation of particular pedagogies?

How is science learning assessed in primary schools?

Summary

- There was a large variation in how subject leaders describe and identify formative assessment in science.
- No subject leader in the sample expressed regret over the removal of the science SAT in 2009, but the subsequent increased importance of making reliable teacher assessment judgements had caused concern.

[25] Stenhouse L. 1975. An introduction to curriculum research and development: Heinemann.
[26] Getting Practical was a programme of professional development for teachers of science at primary, secondary and post-16 level, launched nationally in 2010 with the aim of improving the effectiveness of learning through practical science lessons. It received DFE funding and was led by the ASE.
[27] *La main à la pâte* is a French educational programme for primary schools, focusing on an investigative approach to learning science, which was launched in 1996.

- Five of the 37 schools in the sample were using SAT papers to confirm children's attainment in science.
- Teachers had seen a benefit in assessing attainment using a broad range of evidence, including regular observation of children working.
- Implementing new assessment tools took time and effort. It also required participation in external and internal professional development, support from senior staff, and commitment from colleagues.
- Twenty-five of 37 of subject leaders welcomed the introduction of APP as an assessment tool and were implementing it in their school.
- Using APP or another framework that focuses on science enquiry skills resulted in some teachers adapting their own lesson planning, particularly to allow for children's increased independence in carrying out classroom investigations.
- Few subject leaders felt that APP was fully established in their schools by the time of making their PSQM submissions.

As part of a PSQM submission, subject leaders reflect on current assessment practice in their school, describing the strategies used and their role in developing and supporting them.

All of the subject leaders in the sample reported that AFL strategies were used in science teaching at their school. These included:

- using KWL grids and concept maps to gauge prior understanding and establish learning objectives
- children using 'talk partners' to share ideas and give feedback
- thumbs up or traffic lighting, used as methods for children to reflect on their understanding
- an emphasis on children being aware of their individual progress and being supported in identifying the next steps in their learning
- giving children formative feedback on their progress, based on their practical work and written evidence of learning.

There is some variation in how and when strategies are used. Usually, subject leaders described using AFL strategies 'all the time' or 'regularly' to inform short-term planning and the pace of lessons and to build up a broad evidence base of individual children's attainment. However, a few descriptions of teachers' planning incorporating an AFL activity once a half-term might indicate a differing understanding of the purpose of this pedagogy.

Subject leaders also use more formal methods for making summative assessments of children's progress in science, including:

- APP (25 of 37)
- purchased commercially produced assessment tools (six of 37)
- locally developed (local authority, cluster, school) assessment frameworks (seven of 37)
- previous SAT papers or questions (five of 37).

These methods are used to monitor and record progress at intervals – whether "all the time", at the end of a unit, mid-unit, termly or annually – and to set subsequent targets. Tracking of individual pupils' progress took place in 23 of 37 schools. Cross-class moderation of teacher assessment judgements took place in six of 37 schools, and one subject leader in the sample reported moderating assessment judgements with teachers from other schools.

Eleven of 37 subject leaders reported confidently on robust, shared processes for summative assessment in science. However, 14 of 37 subject leaders in the sample were concerned that current summative assessment processes were not sufficiently reliable or effective and viewed assessment as an ongoing development. The removal of the SAT had revealed to some an over-reliance on formal tests for ascertaining the levels of attainment required for accountability purposes, but they were unsure how to address this problem. Four subject leaders acknowledged that confidence levels and expertise in teacher assessment of attainment and progression needed to be improved. Demands from Ofsted for clear tracking of children's progress added to subject leaders' concerns in three schools. No subject leader expressed concern about their school being selected to be part of the national sample, in which children sit a standard assessment test so the Department for Education can check standards nationally but results are not reported in league tables. The reflections on assessment submitted by the majority of subject leaders

focused on the problem of filling the gap left by removing the science SAT, resulting in the search for an assessment strategy that is manageable, supports the quality of teaching for which they are aiming, is motivating for colleagues, improves children's learning and meets accountability demands.

Taking part in the PSQM encourages a focus on raising the profile of science and improving the quality of science teaching and learning. It is clear that this offered many subject leaders an opportunity to perform a school-wide evaluation of current science assessment practice. In many cases, this led to the introduction or more thorough embedding of new assessment tools, most notably APP. Many subject leaders focused on this as a key action and reported significant improvement in colleagues' capacity to make consistent assessments of children's progress in science, most notably in Sc 1. Four of 37 subject leaders said that owing to new assessment strategies, teachers felt more confident being creative in their science teaching and were planning more lessons that offered children practical opportunities to demonstrate what they could do.

Assessing Pupils' Progress
Twenty-five of the 37 of schools sampled described introducing and using the APP materials during their PSQM year.

The rationale for introducing this particular new strategy (non-statutory, but formally disseminated by the National Strategies in summer 2010) was generally not identified, although some subject leaders referenced building on existing experience in using APP materials to assess maths and English. Fourteen subject leaders identified a need to introduce a systematic teacher assessment tool for science, either because they were dissatisfied with existing processes or because there was no systematic assessment of science learning taking place. APP was available, and in many cases was being promoted by the local authority, and was therefore adopted. Eight subject leaders indicated that APP was being implemented in only a few classes before deciding whether to make it a whole-school strategy. Five of the subject leaders in the sample are Advanced Skills Teachers and were involved in leading the dissemination of APP for science within their local authority.

In most schools it was the responsibility of the subject leader, sometimes with the support of senior management and/or local authority advisors, to decide on the APP implementation strategy for their school. All subject leaders in the sample who introduced APP initially took part in some form of external CPD, usually led by local authority advisory staff. Following this, various dissemination approaches were described:

- The subject leader invited a local authority advisor or Science Learning Centre consultant to introduce materials to staff.
- The subject leader used the materials in his or her own classroom before introducing them to the rest of the staff.
- The subject leader introduced materials to staff in staff meetings and used a negotiated implementation strategy, most frequently asking some or all teachers to identify three or six children to assess at regular intervals using a range of evidence, planning for whole-staff moderation at a later date.
- One subject leader led a staff meeting where teachers and teaching assistants carried out a practical investigation and identified possible assessment opportunities against the APP criteria. She then taught the same lesson in her colleagues' classrooms so they could make observations and assess children's performance.
- One subject leader reported adapting the APP statements into 'child speak' so that children could use them for self-assessment.

One subject leader reported colleagues' reluctance to take on APP, saying that – having adopted APP for maths and English – they were simply too jaded to take on any more new initiatives or were anxious about onerous paperwork requirements. Three subject leaders reported concerns that APP would only assess science Attainment Target One and that they would therefore continue to use other strategies, such as testing children using old SATs papers, commercially published end-of-unit tests or pre-existing knowledge assessment grids. It is clear that subject leaders played a key part in balancing the demands of introducing this new strategy. They adapted their approach depending on their colleagues' expertise and motivation.

By the time they completed their PSQM submissions, 14 subject leaders indicated that APP was still a 'work in progress', and many had clear plans for developing and embedding the strategy further. Where reflections on the impact of implementing this new assessment strategy were made, they were generally positive. Subject leaders were pleased to see teachers developing confidence in assessing children's progress in science using a wider range of evidence than pen and paper tests. Subject leaders saw that using APP was having an impact on teachers' planning as they began to notice that existing schemes of work or short-term plans did not present enough opportunities to collect evidence of children's progress in all areas of science enquiry, typically mentioning Assessment Focus 2 concerning the implications and applications of science. Although some subject leaders described APP as a formative assessment strategy, most were using it to arrive at summative results.

Discussion

An analysis of the reflective statements submitted to meet PSQM C3, 'Teachers are using a range of assessment approaches', suggests common concerns and patterns in assessment practice within the sample group. It should be remembered that schools taking part in the PSQM programme are self-selecting on the basis that they want to increase the focus on science in their schools and have support to do so.

Teacher assessment of science levels at the end of Key Stages 1 and 2 has been reported since 1996 but has historically been considered less important than the SAT result. Teachers often relied on the externally marked SAT results to give them a 'reliable' summative level of children's achievements to report to parents and for accountability purposes. Levels were understood in relation to the knowledge required to write answers to standard SAT questions, rather than what children could be observed to do practically in science. The reflections from the subject leaders in this sample indicate that the removal of the science SAT in 2009 revealed a high level of insecurity in teachers about making reliable assessment judgements. This sample cannot be considered representative of all teachers or subject leaders, but it may be inferred that concerns about confidence in teacher assessment, which were being reported as early as 2003, have now reached a state of urgency.[28] The use of old SAT papers is a clear indication of this. This might suggest that teacher assessment is now seen as a replacement summative process for assigning an accurate level only, rather than a formative process used to aid teaching and learning.

Another strong message from the subject leaders' reflections is that, despite the removal of the SAT, current assessment processes still do not reflect or support the quality of teaching and learning to which they aspire.

APP was adopted by many PSQM schools as a possible solution to these concerns. However, the subject leaders' reflections show various interpretations of the purpose and use of APP, including:

- using the framework to annotate and assess evidence from all children in the class at varying intervals
- assembling a portfolio of the annotated work for three or six representative children
- setting up assessment tasks for groups or the whole class on a periodic basis
- using the framework only to make assessments of Sc 1 and using other tests to assess Sc 2-4
- using the framework to assess four children's performance in Sc 1, 2, 3 and 4.

This is of little surprise when considered in light of the 'hole-and-corner' way in which APP was introduced shortly after the coalition government had been elected and their ambivalence to it as an assessment strategy. There was limited or no support for schools adopting the strategy, and shortly after its launch in June all materials were removed from the Department for Education website. However, as demonstrated by the reflections from the subject leaders who fully engaged with APP (especially those who were part of the Qualifications and Curriculum Development Agency pilot project), there were some positive developments in practice as a result of working with the framework.

Further questions

- What types of assessment are schools using? How are they evaluating them?
- Can and should a shared agreement be established among all stakeholders of the purposes and agreed processes of science assessment in primary schools?

[28] Parliamentary Office of Science and Technology POSTnote;2003:202 (primary science).

- Can the developing practice and expertise in ongoing formative assessment be used more effectively to inform summative judgements?
- What further professional support do subject leaders need to ensure that confidence in teacher assessment grows, and who should provide this support?

How are primary schools resourced for science?

Summary

- Plentiful, up-to-date resources had a positive impact on the perceived quality of science teaching and learning.
- Managing an accessible collection of science resources was a challenge for subject leaders.
- Ensuring that science resources are accessible and sufficient required regular investment.
- Subject leaders made good use of free and borrowed resources.

A mixed picture emerged from the subject leaders' reflections on science equipment in primary schools. Six subject leaders reported having very few resources and a limited or non-existent science budget. They identified this as a significant problem that affected the quality of science teaching and learning.

However, many of the subject leaders indicated that the increased focus on science that had resulted from PSQM participation had facilitated the acquisition of new resources. In particular, the use of new ICT equipment in science lessons is frequent in the submissions sampled.

The requirement for high-quality and plentiful resources is forcefully articulated in the subject leaders' reflections. Subject leaders clearly recognise that the responsibility for meeting this need falls to them. They monitor equipment need and use in several ways, including:

- Auditing the implementation of resources in lessons – do teachers know what is there and how to use it? Do they identify resources and equipment in their planning?
- Gauging children's attitudes to resources (e.g. enjoyment, preferences, quantity and quality).
- Responding to teachers' requests.

The exact mechanism by which resources are purchased is rarely clearly stated; however, the sample of subject leaders' reflections suggests that two main methods are employed: subject leaders have a delegated budget to maintain and enhance resources, or subject leaders present a bid to the senior management team for approval. In terms of consumable resources, as opposed to larger items, some subject leaders have an (additional) allocated budget to independently procure such items.

Science subject leaders are resourceful and make good use of external, usually free, sources of equipment. Nine of 37 subject leaders describe borrowing equipment from secondary schools, universities and Science Learning Centres. Fourteen of 37 subject leaders describe collecting free resources from local organisations and national initiatives for schools run by large organisations, such as the Wellcome Trust Great Plant Hunt and supermarket voucher schemes.[29]

The management and organisation of science resources was identified as a significant challenge by eight of 37 subject leaders. There are many references in the reflections to recent restructuring and reorganising of resources, the majority of which are stored centrally. The use of regularly updated inventories and labelling resources are both frequently described. Having sufficient storage space, keeping resources tidy and accessible, and monitoring usage are all frequently mentioned as being difficult in schools.

Discussion

Subject leaders within the study often focused initially on 'tidying the science cupboard' as a priority task. However, by supporting a reflective approach to science leadership, the PSQM is enabling subject leaders to become more evaluative about this part of their role and about the purpose and value of resources in developing quality in science teaching and learning.

[29] The Great Plant Hunt was a kit of practical resources sent to every primary school in the country as part of the Darwin 200 initiative (2010). It was produced by The Wellcome Trust in partnership with Kew Royal Botanic Gardens.

Further questions

- Should a minimum resource list for science equipment and budget allocation for schools be recommended?[30]
- Which organisation can fill the need for easy access to affordable science resources, which was once met by local authority science bases?

[30] Science Community Representing Education (SCORE) is preparing a submission to the government on resourcing for practical science both in primary and secondary schools with the aim of providing a benchmark for schools.

Concluding remarks

The report reveals a strong consistency of attitudes and behaviours among committed, active science subject leaders in primary schools in England and among the factors that influence their capacity to lead and manage science teaching and learning in their schools. These can be summarised as follows:

Subject leaders' commonly shared attitudes and behaviours are to:

- promote science enquiry
- encourage cross-curriculum links
- foster and build upon children's curiosity
- make science visible within the school
- ensure accessible resources
- monitor teaching and learning
- improve teacher assessment of science.

Factors commonly influencing leadership capacity include:

- level of senior management support
- participation in CPD
- engagement with networks beyond school.

Since writing the first draft of this report early in 2012, there have been several policy-level interventions that will have an impact on science teaching in primary schools in both the short term and the long term: the Department for Education has published the first and second drafts of the Programme of Study for Science for Key Stages 1 and 2 as part of the coalition government's review of the National Curriculum, the reduction in local authority support for schools has continued, and primary science specialist courses for in-service teachers are being developed by the Wellcome Trust. It is interesting to consider these interventions in light of the findings from this scoping study.

Subject leaders in the sample had focused considerable energy on raising the profile of science in their schools. In doing so, they were responding to the detrimental effect (reported elsewhere) of the school improvement focus on English and maths and the perception that science was of less importance in the primary curriculum.[31] The publication of the draft programme of study for science at Key Stages 1 and 2 makes the position of science clear: it is one of the three core subjects in the National Curriculum for primary schools. Will this be enough to secure its profile, or will subject leaders still need to fight to secure budget and time to monitor and lead it effectively? Will 'science weeks' still be required to raise the profile of science, or will every week be a 'science week'?

The draft programme of study for science at Key Stages 1 and 2 is a specification of scientific concepts and knowledge, with notes and guidance that comprise background information and suggestions for lessons, including practical activities to demonstrate concepts. Scientific enquiry is re-designated as 'working scientifically', and the draft programme of study emphasises that it 'is not to be taught separately' and 'must be delivered through substantive subject content'. However, the subject leaders in this sample reported a need to prioritise science enquiry skills to raise attainment and engagement in science, and many had spent considerable time and effort to support their colleagues in doing so. Notably, the subject leaders had focused on developing children's skills in considering prior knowledge, raising questions and independently planning how to gather evidence to answer them. In doing this, they may be responding to studies going back to 1985 into how children learn science most effectively.[32] More recently, in a study for the Wellcome Trust in 2005, Collette Murphy and colleagues reported:

"Teaching that supports children in expressing and following their own ideas and curiosity, which encourages practical involvement with the stuff of the real world, and which engages children as individuals and in collaboration with others in genuine enquiry and problem solving is motivating and stimulating for teacher and learner alike."[33]

[31] Primary Science Survey Report, Wellcome Trust, 2011.
[32] Harlen W (ed). 1985. Primary Science Taking the Plunge. London: Heinemann.
[33] Murphy C et al. 2005. Primary Horizons: Starting out in science. London: Wellcome Trust.

The subject leaders in the sample reported an awareness of this, developed from their own practice and enhanced by CPD, but did not reference the research base. However, as the research base has had a profound influence on initial teacher training and CPD in science over the past two decades, it is not surprising that it is reflected in practice. The subject leaders indicated that an enquiry-based approach is still an innovation in most of their schools and that there is more work to be done in developing a robust use of evidence to test ideas and answer questions.

How will this still-developing professional assurance of the appropriateness and efficacy of an enquiry-based approach to science learning withstand the demands of a new curriculum? The evidence suggests that a constructivist approach to learning science, which emphasises the importance of teachers first gaining access to children's thinking and then supporting a reorganisation of their ideas to accommodate more accepted explanations, is yet to be fully embedded. Will subject leaders have the confidence to continue on this path, or will they and their colleagues embrace the didactic model where children are taught to 'name or explain', rather than taught how to find out?

All of the subject leaders in the sample described the importance of linking science with other curriculum areas, most frequently maths, ICT and literacy. This is also described as innovative: moving away from how science has been taught before and towards a more creative way that is relevant to children's interests and builds on other learning. Subject leaders were enthusiastic about the impact of this in terms of pupil and teacher motivation and how it enables children to make sense of the science they are learning. They also acknowledge the need to ensure that creative science teaching still fulfils National Curriculum expectations and, consequently, are developing skills in robust curriculum design. Will the draft programme of study permit such curriculum reorganisation and design, or will teachers feel forced to return to separate subject teaching?

For the majority of subject leaders in the sample, developing confidence in teacher assessment in science was a priority. Many valued the opportunities that teacher assessment offered to use a broader range of evidence to make assessment decisions, sometimes using formative assessment outcomes to inform summative judgements. Most subject leaders admitted that expertise in this area was still developing and described high levels of evaluation of assessment frameworks and processes. The draft programme of study does not give a clear indication about expectations for assessment beyond noting that by the end of each Key Stage, pupils are expected to have the knowledge, skills and understanding of the matters taught in the relevant programme of study. It is therefore important to raise a question about whether – and how – subject leaders will be supported to maintain the development of expertise in a teacher assessment that builds on current good practice in formative assessment.

All subject leaders in the sample had participated in science-specific CPD to some extent, and some had a role in providing CPD for colleagues beyond their own school in their role as an Advanced Skills Teacher.[34] CPD was described as crucial to developing leadership capacity and the introduction of new pedagogies, whether through attending courses or by participating in regional and local network meetings. The two main CPD providers identified were local authorities and the network of Science Learning Centres. Attending ASE events and reading ASE journals were also referred to in descriptions of CPD participation. Subject leaders reported a reduction in local authority capacity to support science in 2010, and that situation has since worsened; few local authorities now employ primary science advisory staff. However, the need for high-quality, specialist local professional support for all teachers of science in primary schools has not diminished. The implementation of a new Programme of Study for science in 2014 will raise demand. Science Learning Centres have developed considerable expertise in this area, often collaborating with existing or displaced local authority staff members and increasingly with Teaching Schools and other school-based clusters. The capacity to offer professional development to primary teachers, facilitate networks and support action research is vital. How can we guarantee the continuing provision of science-specific CPD for primary teachers?

The argument for science specialists in primary schools has been made loudly.[35] Learned bodies, the government and other stakeholders have demanded that the supply of science subject specialists to primary schools should be increased. Evidence from the sample analysed for this study indicates that it is

[34] Advanced Skills Teachers are expected to take a leadership role in developing, implementing and evaluating policies and practices that contribute to school improvement.
[35] The Royal Society 2010 Science and mathematics education, 5-14.

enthusiasm for science that motivates leadership activity and that this is not always coupled with a science background. However, the importance of CPD in developing confidence in science teaching and subject leadership is clearly stated. Science subject leadership is often the first step on the leadership ladder for primary teachers, and they do not often remain in that post for more than a few years. The discussion about what makes a primary science specialist and what their role should be has been thoughtful and wide ranging, and the Wellcome Trust developed a definition recently.[36] Recent developments in science specialist programmes for trainee and in-service teachers will be monitored closely to inform this debate and any subsequent policy-level initiatives. What can the findings derived from PSQM subject leaders in this study add to the evidence base?

As stated in the introduction to this report, this study's intention was to scope the possibilities of the data held within the hundreds of PSQM submissions that have been made since 2010. This initial analysis of less than 7 per cent of the total submissions made to date, looking only at teachers' reflective writing and not at supporting evidence, has highlighted the richness of the data and its pertinence to current debates and developments in primary science. Stakeholders and researchers should contact the PSQM team if they wish to have access to the data for further research.

[36] www.wellcome.ac.uk/Education-resources/Education-and-learning/Our-work/Teacher-training/WTS052326.htm

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Wellcome Trust
Gibbs Building
215 Euston Road
London NW1 2BE, UK
T +44 (0)20 7611 7221
F +44 (0)20 7611 8254
E education@wellcome.ac.uk
www.wellcome.ac.uk

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