PERSPECTIVES ON EDUCATION

Primary Science

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Foreword

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> Not everything that counts can be counted and not everything that can be counted counts.
> (Albert Einstein)

The history of primary science in England over the last 50 years has in many ways been a positive one, with postwar concerns about a shortage of scientists leading to science becoming more prominent first in secondary and then in primary schools. Certainly, over the last 30 years most would agree that primary school science has taken great steps forward and benefited from much of the special attention and support that its position as a core subject confers.

Nevertheless, despite this apparently enviable situation, both the rationale behind having a core curriculum and the aims of the science curriculum within it have remained unclear and fears have mounted about the status of (and time allotted to) science being undermined (for example, Boyle and Bragg, 2005). As a core subject, science also finds itself subject to the current national testing regime, whose multiple purposes – at national, local, school and pupil levels – have resulted in a high-stakes system widely criticised across the education world, not least for its inevitable narrowing of the curriculum, where teachers feel bound to 'teach to the test' (for example, Collins *et al.*, 2008).

In this report, the first of a series of perspectives on UK science education, two leading voices in primary science – Wynne Harlen and Peter Tymms and colleagues from Durham University – take a historical look at primary science in England over the 20th century and give their views on its place in the National Curriculum and on the causes and implications of trends in attainment, attitudes and teaching approaches.

The first piece, by Wynne Harlen, considers the purposes of school science education and the position of science in the National Curriculum. The article charts the history of primary science through the 20th century and looks at the arguments presented regarding the advantages and disadvantages of the status of science as a core subject. It examines the extent to which assessment and its uses can alter the quality of primary science education and argues that national tests should be replaced by moderated teacher assessment. The article concludes by suggesting a number of steps that ought to be taken when considering the position of science as an element of the primary curriculum.

The second piece, by Peter Tymms, David Bolden and Christine Merrell at Durham University, draws on a range of indicators relevant to primary science education in England over the last 60 years, and looks at trends in children's attainment levels and attitudes towards science as well as the attitudes of primary teachers. Although statutory test results at the end of Key Stage 2 rose dramatically between 1995 and 2000 (where they reached a plateau and have since remained stable), the article finds that only a much more modest rise is supported by independent data; the authors suggest this may be the result of increased familiarity with tests. They also highlight worrying evidence to suggest that children's conceptual understanding of science has actually decreased since the 1970s.

On attitudes, Tymms *et al.* look at the continuing trend for young people's attitudes to school science to become less positive as they move from primary school to secondary school and for young people to 'like' science less than they used to. While international comparisons suggest that this is not confined to the UK, they also suggest that English pupils' attitudes towards science are below average compared to other participating nations. As highlighted by the Wellcome Trust's *Primary Horizons* study (Murphy *et al.*, 2005) and many others, the authors draw attention to continuing concern about primary teachers' lack of confidence in their knowledge and competence to teach science, although, more positively, there are signs that this is starting to improve.

Recommendations

These perspectives suggest a number of challenges for policy makers and researchers, including:

1. The need for a fundamental review of:
    a. **the concept of a core primary curriculum and the purpose and position of science within it**
    b. **the primary science curriculum,** with a view to providing a broad framework of skills and concepts within which schools have the flexibility to provide experiences that are relevant and interesting to pupils
    c. **the nature and purposes of summative assessment at primary level,** which evidence strongly suggests is currently one of the biggest obstacles to delivering high-quality, engaging education at this level. Recommendations based on this report include replacing national tests with moderated teacher assessment, so that pupils' progress in the full range of skills and concepts can be recorded and reported, and evaluating schools' provision of primary science against a wide range of indicators, including but not limited to the level of pupil achievement.

2. The generation of **more opportunities and support for high-quality initial teacher training and continuing professional development for primary teachers.**

3. The need for **further research**, including a systematic review of well-evaluated different approaches to the teaching and learning of science in primary schools across the world and their impact, and a review of how the National Curriculum in science relates to children's developmental stages.

4. A need for **greater academic rigour in developing policy**, so that education policy is more closely tied to research evidence and existing and new strategies are trialled and properly evaluated before being introduced on a national basis.

References

Boyle B, Bragg J. No science today – the demise of primary science. Curriculum Journal 2005;16(4):423–37.
Collins S, Reiss M, Stobart G. The Effects of National Testing in Science at KS2 in England and Wales: Executive summary. London: Wellcome Trust; 2008.
Murphy C, Beggs J, Russell H, Melton L. Primary Horizons: Starting out in science. London: Wellcome Trust; 2005. www.wellcome.ac.uk/primaryhorizons [accessed 29 August 2008].

Science as a key component of the primary curriculum: a rationale with policy implications

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Introduction

The purpose of this paper is to consider the position of science in the primary school curriculum, taking 'primary' to mean the age range 5–11/12 years. From the start of the National Curriculum in England and Wales, science has been one of the subjects identified as forming the core of the primary curriculum, although a rationale for identifying a core and for selection of its constituent subjects has not been made explicit. In the absence of such a rationale, this paper considers various ways in which the notion of a core might be justified and the pros and cons of including science within it. It considers the aims of primary science and the nature of its contribution to science education for the whole of the 5–16 age range. The achievement of these aims inevitably depends on the content and methods of teaching, but also on what is possible, given the primary school context – particularly the crowded curriculum, the non-specialist teaching force, and the limited experience and maturity of the pupils. These circumstances are to be seen as challenges to be faced rather than reasons for not teaching science in the primary school if the potential benefits to pupils and to society are to be realised.

The first part of the paper briefly charts reasons given for attempts at various times to include science in the primary curriculum throughout the 20th century, culminating in its inclusion as government policy. The next two sections deal with the concept of a curriculum 'core' and how the subjects given this status might be identified. This involves a further look at the reasons given for including science at the primary level, reasons that have changed in the light of research about how children learn, on the one hand, and a greater awareness of the need for a scientifically literate society, on the other. Finally, the last two sections draw together conclusions and policy implications from the earlier discussion.

Why primary science?

Early history

Primary science did not begin in the 1960s, although it was in that decade that the first major developments of note, intended to reach all pupils, took place. Previously, there had been pioneering attempts to introduce some science into elementary schools in the latter part of the 19th century through the 'object' lesson and, in some areas, peripatetic demonstrators (Harlen, 2001). The object lesson was superseded in the early 20th century by observation lessons and nature study (Harlen and Simon, 2001), with support for teachers coming from the School Nature Study Union, encouraging the creation of school gardens and 'nature walks'. Then, foreshadowing events 80 years later, the introduction at the beginning of the 20th century of tests of the '3Rs' to select pupils from elementary schools for transfer to secondary schools was accompanied by a neglect of other subjects and the disappearance of science from all but a few schools. The Hadow Reports of 1926 and 1931 attempted to broaden the curricula of both the elementary – renamed primary – school and the secondary school. However, due to economic circumstances and World War II, it was not until 1944 that many of the Hadow recommendations, and in particular the separation of primary and secondary education, were made statutory.

The 1950s were a watershed in school science education. The demand for scientists and technologists in the postwar years brought about a rapid expansion in the output of scientists from universities. To sustain the flow of university entrants it was necessary to give attention to science teaching in secondary schools. Changes were badly needed in material provision as well as in the curriculum, which, as a result of the speed of scientific developments during and after the War, had become severely dated. So the focus of attention for change started at the top of the secondary school with the many projects funded by the Nuffield Foundation and the Schools Council and gradually worked its way downwards. When it reached the primary school it became clear that the existing practices were highly unsatisfactory in helping children to begin to understand the scientific aspects of their world and as a preparation for secondary science.

At the same time there were moves to broaden the range of 'nature study' to include some physical as well as biological science and to involve children in active investigation. One was a meeting of the Science Teachers' Joint Committee, which resulted in the publication of the pamphlet *Science in the Primary School* (Association of Women Science Teachers, 1959). Another was a conference sponsored by the British Association for the Advancement of Science under the directorship of Nathan Isaacs at the Froebel foundation, *The Place of Science in Primary Education* in 1961, leading to a publication with this title in 1962. In his presentation, Isaacs made it quite clear that he was not advocating teaching of science in any way resembling secondary school science. He also acknowledged that:

> A good many secondary schools science teachers feel in fact that the best service which the primary schools can render to the cause of science education is to leave it alone. (Isaacs, 1962, p. 5)

This was not the last time such a sentiment was expressed. What Isaacs had to say in favour of bringing science into the primary schools was prefaced by concern that science should be understood as a "distinctive set of processes, the basic ways and means, which have brought it [scientific knowledge] into being and are still developing it". He then gave his reasons for "why science in some sense now has claims to form part of the very ABC of education". These were: the need for everyone to be able to relate to the rapid changes that science and technology were making to the world around; the ability to share in understanding and celebrating science as an important human achievement; the need for more scientists; and the generation of a scientific approach to human problems through seeking evidence and basing decisions on evidence.

Nationwide programmes

Two of the points made by Isaacs – about the pre-eminence of 'processes' and the hope that science education could somehow affect people's reasoning in everyday life – reverberated in the large-scale funded primary science projects that began in the 1960s. The first two projects resulted from a meeting in 1961 of a committee that included representatives of the inspectorate, local education authorities (LEAs), institutes and colleges of education, schools, the Nuffield Foundation, and the Science Masters Association and the Association of Women Science Teachers (amalgamated into the Association for Science Education [ASE] in 1963). One project was for research and development in primary science, set up at the Institute of Education of the University of Oxford in July 1963. It is significant to the story of primary science to note the terms of reference for the project:

> An enquiry into the formation of scientific concepts in children under the age of thirteen; the development of teaching material for this age range; and the training of primary teachers in science. (Boyers, 1967)

The second was the Nuffield Junior Science Project, set up as part of the Nuffield Science Teaching Project. It began in January 1964 with the following rather different aims:

1. To encourage children to look on science not as a subject to be 'done' at special times in special rooms, using special apparatus, but as a way of discovering which can be applied anywhere, at any time, with whatever material happens to be available.

2. To produce children who:
    - are keenly observant
    - are questioning
    - are able to devise means of getting answers to their questions
    - are scientifically rigorous – i.e. look at their work rigorously
    - can communicate. (Nuffield Junior Science Project, 1967)

Thus the two projects were significantly different in their aims, reflecting a tension between emphasis on process skills and conceptual development in primary science that persisted in varying forms for the next 30 years or so and still lingers today. In the 1960s, however, developments in primary education were considerably influenced by the Plowden Committee Report (Central Advisory Council for Education, 1967), which favoured 'discovery learning' and reflected the enthusiasm for applying ideas derived from Piaget's work to primary education. So it was not surprising that the approach of the Nuffield Junior Science Project was more influential than that of the Oxford project.

The ASE was active in bringing together ideas for developing science in the primary school through its Primary Science Committee, formed in 1963. One of the Committee's first acts was to prepare a policy statement, which added support to the Nuffield Project approach by stating: "At this level we are concerned more with the developing of an enquiring attitude of mind that with the learning of facts" (ASE, 1963). The benefits of developing what were then described as 'discovery methods' were expected to be:

- a growing understanding in pupils of the nature of science
- an increase in their scientific knowledge
- the training of citizens who are concerned about the possibilities of applying science to human problems.

The last of these points was particularly related to the national need for more technologists.

The project that followed Nuffield Junior Science, Science 5/13*,* had the advantage of being able to learn from the experience of other projects both in the UK and abroad. So during its eight-year life from 1967 Science 5/13 provided a statement of "objectives for children learning science" to help teachers work purposefully ("with objectives in mind"), 26 units for teachers giving ideas for children's activities related to children at three stages of development, and information about the background science for the unit topics. The objectives of the project were concerned with the children's learning rather than value to society or to their later education. They were identified under the broad heading of 'Developing an enquiring mind and a scientific approach to problems' as:

- developing interests, attitudes and aesthetic awareness
- observing, exploring and ordering observations
- developing basic concepts and logical thinking
- posing questions and devising experiments or investigations to answer them
- acquiring knowledge and learning skills
- communication
- appreciating patterns and relationships
- interpreting findings critically.

Worldwide developments

The UK was not alone in responding to the rapidly changing needs of the postwar technological age. In the USA, reform of school science began in high schools in the 1950s and was underway in relation to the elementary science curriculum at the start of the 1960s. The first three elementary school projects to be set up reflected the content–process issue that was emerging in the UK. The Elementary Science Study (ESS, 1966) was funded for ten years from 1961. Its emphasis was upon giving children first-hand practical experience using everyday materials where possible. Science – A Process Approach (SAPA) also received government funding for over ten years from 1962, providing a highly structured programme designed to develop children's process skills. The *Science Curriculum Improvement Study* (SCIS), 1962–74, combined the aims of developing knowledge and understanding, inquiry attitudes and rational thinking skills.

ESS was also the inspiration for the African Primary Science Programme, and similar developments were soon underway in other developing countries, often set up with aid from international agencies and providing help from visiting science educators from developed Western countries. UNESCO was one of the international agencies working to improve science education throughout the world and particularly in developing countries. The report of a meeting of experts involved in primary science programmes worldwide identified the following points as justifying the inclusion of science in the primary curriculum:

- Science can help children to think in a logical way about everyday events and so solve simple problems…
- Science, and its applications in technology, can help to improve the quality of people's lives. Science and technology are socially useful activities with which we would expect young children to become familiar.
- As the world becomes increasingly more scientifically and technologically oriented, it is important that future citizens should be equipped to live in it.
- Science, well taught, can promote children's intellectual development.
- Science can positively assist children in other subject areas, especially language and mathematics.
- Primary school is terminal for many children in many countries and this is the only opportunity they may have to explore their environment logically and systematically.
- Science in the primary school can be real fun. Children everywhere are intrigued by simple problems... (UNESCO, 1983)

Several of these points make specific claims for which there was not at that time, nor has since been created, supporting research evidence. They were aspirations, borne out by the experience of individual cases rather than from research findings, and it was part of the enthusiasm of the time not to question them. Many developing countries, experiencing particularly rapid changes, acted to make science a part of primary education before more developed countries, where there was greater scepticism about unsubstantiated claims (Morris, 1990).

In the UK, the economic downturn in the 1970s saw a reduction in funding and a 'back to basics' trend in schools. Then the 1978 Her Majesty's Inspectorate (HMI) report on primary education in England noted that "the progress in science teaching in primary schools has been disappointing; the ideas and materials produced by curriculum development projects have had little impact in the majority of schools" (Department of Education and Science, 1978). A survey associated with this report showed that only about half of primary classes had any science at all and in only about one in ten was the work developed seriously. Similarly in the USA a study in the same year (Weiss, 1978) reported that 70 per cent of school districts did not use any of the materials of the three major projects (ESS, SCIS and SAPA).

Raising the status of primary school science

One of the reasons for the Government's setting up the Assessment of Performance Unit (APU) in 1977 was to answer questions about what was happening to standards of education as a result of the changes in the expansive 1960s. The APU conducted annual surveys of English, mathematics and science at ages 11, 13, and 15 in England, Wales and Northern Ireland from 1980 to 1985. (Surveys of a similar nature began in Scotland in 1984 and still continue.) The inclusion of science at age 11 confirms the importance being given to primary science despite – or perhaps because of – the failure reported in the 1978 HMI report. It may also have been, as the educational historian Brian Simon (1993) suggested, that school education in the 1970s was being portrayed (in the Black Papers, for instance) as failing in many respects and blamed for Britain's many difficulties in that decade, including low technological and economic development.

In order to develop the APU programme it was necessary to decide what kinds of achievement should be assessed. The lack of consensus at the time about the aims and content of primary science made this no small task. There were objections from those who saw the process as likely to impose uniformity on what was taught – in recognition that what is assessed is inevitably taken as a guide to what to teach – rather than leaving this to schools to decide. With the benefit of hindsight, however, the APU can be seen as having a largely positive impact on primary science. It raised the profile of science in the primary curriculum, putting it by the side of mathematics and English, the only other subjects to be covered systematically by the five years of APU surveys, and perhaps establishing it as a part of the curriculum core. Its framework emphasised skills of collecting and interpreting evidence; knowledge was assessed through applications and not by direct recall.

The APU science survey results provided information about the skills and understandings of children at the end of primary school, pointing to areas of strength and weakness. The results also provided evidence of the interdependence of process and the content used to assess it. There was clear evidence that, for example, in making observations, planning an investigation or interpreting results, the content on which these skills were used made a considerable difference to achievement. This was in direct conflict with the view that the subject matter is unimportant in the use and development of processes. At the same time it was recognised that the dependence is two-way and that the development of understanding (as opposed to knowledge of facts) depends on the use of processes.

Findings from the APU science surveys also led directly to research on children's ideas at the secondary level that revealed that pupils often held ideas about scientific phenomena that were not consistent with the scientific view. These ideas, often held despite science teaching, are ones that seem to make more sense to the pupils than abstract scientific explanations. Research into the ideas of younger children began with studies in New Zealand (Osborne, 1985). In the UK from 1990 to 1998, the Science Processes and Concepts Exploration (SPACE) project revealed a range of ideas about the scientific aspects of their surroundings that children had worked out for themselves on the basis of their limited experience and ways of thinking. It was clear that these ideas could not be ignored: children believed them, had worked them out for themselves, and indeed they had to be the starting-point from which more scientific ideas could be developed. The findings underscored what Piaget revealed about early development of ideas in young children; other research since has shown that babies distinguish different features of objects long before they can talk (Gopnik *et al.*, 1999).

Thus a new argument was added to the case for science in the primary curriculum, that children's ideas about the world are developing throughout the primary years whether or not they are taught science. Without intervention to introduce a scientific approach in their exploration, many of the ideas they develop are non-scientific and may obstruct later learning. Further, research was showing that attitudes towards science develop in the pre-secondary years, earlier than attitudes to some other school subjects (Ormerod and Duckworth, 1975). Thus children need to experience science activity for themselves at a time when these attitudes are being formed. More recent research evidence from the Royal Society (2006) shows that most students develop interests and attitudes towards science well before the age of 14, and many before the age of 11. A further point arising from research is that gender differences, which continue to be of concern at higher levels, have not appeared at the primary stage (Haworth *et al.*, 2008).

Primary science as government policy

By the mid-1980s, the position of science in the primary curriculum appeared to be confirmed in government policy:

> Science should have a place in the education of all pupils of compulsory school age, whether or not they are likely to go on to follow a career in science or technology. All pupils should be properly introduced to science in the primary school, and all pupils should continue to study a broad science programme, well suited to their abilities and aptitudes, throughout the first five years of secondary education. (Department of Education and Science/Welsh Office, 1985)

Thus when the National Curriculum was being planned there was no obvious sign of discussion of whether science should be included at the primary level. Instead, the final report of the working group that produced the first draft of the science curriculum identified the contribution of science to the school curriculum as a whole. This was done under six headings: understanding scientific ideas; developing scientific methods of investigation; relating science to other areas of knowledge; understanding the contribution science makes to society; recognising the contribution science education makes to personal development; and appreciating the nature of scientific knowledge.

It was accepted, then, that there are good reasons based on argument, experience and increasingly on research evidence, for claiming that science education at the primary level has a crucial role to play in realising the value of science in preparing children for their future lives. But why should it be designated part of the primary curriculum 'core'? This is the question to which we now turn.

What defines the curriculum core?

Although not explicit, the notion of the primary curriculum having a 'core' in the form of the 3Rs is deeply rooted in the history of education, persisting throughout most of the 20th century. Core status has been associated with testing, that is, with those subjects that are taken as key indicators of pupils' achievement in learning and the efficacy of teaching. The 3Rs were the subjects tested when selection for admission to secondary schools was introduced. In this sense of the core being tested, the first indication of science having this status was its inclusion in the regular national surveys of achievements carried out by the APU as noted earlier. The status was confirmed in the Education Reform Act of 1988, which required that all pupils in state schools between the ages of five and 16 should follow a National Curriculum, comprising, in England, ten foundation subjects: English, mathematics, science, technology, history, geography, art, music, physical education and (at the secondary school level) a modern foreign language. The first three of these were designated as core subjects. The curriculum in each subject was developed by working groups, whose terms of reference noted that:

> The degree of definition and the requirement to be set out for each of these subjects will of course vary widely, but mathematics, English and science are at the centre of the curriculum and working groups are therefore being established first in these subjects. (Quoted in the Final Report of the National Curriculum Science Working Group, 1988, appendix B.)

Testing is only one way in which subjects can be singled out for special treatment. Following the highly critical 1978 report by HMI about the state of science in the primary school (Department of Education and Science, 1978) there had been a major emphasis on providing support at the school level through a system of local advisory teachers, funded through a Disability Equality Scheme (Department of Education and Science, 1984). As a result of this and other measures, the editorial of the first issue of *Primary Science Review*, the newly established journal of the ASE, had an optimistic tone:

> Primary science has never received as much interest and financial backing as at the present time. Its importance as a central part of the primary curriculum is now widely recognised. *(Primary Science Review*, 1986)

However, the explicit identification in the National Curriculum of content to be covered drew attention again to the low level of content knowledge of the majority of primary teachers. Implying that this was not sufficiently addressed by the advisory teacher scheme, funding was diverted to the provision of extended professional development courses for teachers, of which a specified proportion of time had to be given to upgrading subject matter.

There was some evidence that the attention given to science, through courses, publications and some non-statutory guidance, was having a positive impact. A survey in 1989 of how competent primary teachers felt about teaching the subjects of the National Curriculum and religious education found science to be in eighth position, above only music, ICT and technology (Carré and Carter, 1990). When the survey was repeated in 1991, science ranked third, just behind English and mathematics (Bennett *et al*., 1992). A 2004 survey of primary teachers across the UK found that science remained at the third rank, but only marginally ahead of history (Murphy *et al*., 2005). Of course ranking depends on feelings of competence about other subjects and this apparent rise of science could have been at least partly due to a general reduction in competence across the board, perhaps the result of realising what content was explicitly required by the National Curriculum. At the same time the funds made available for courses in science and the flurry of publications to help teachers no doubt were influential in improving felt competence.

It is interesting that in Scotland, where a similar survey was carried out in 1993, with a follow-up in 1996, the ranking of science in relation to other subjects hardly changed (from being ranked ninth to being ranked eighth). The Scottish *5–14 National Guidelines for Environmental Studies*, which included science, had just been published in 1993. Since other evidence from the surveys showed that teachers' confidence in teaching science significantly improved between 1993 and 1996, it could be argued that concurrent improvement in other subjects left the rank position much the same. However, as in the case of all areas of the curriculum in Scotland, the national guidelines were advisory, not statutory; there were no subjects designated as 'core' and no particular attention or funding given to teaching science. Moreover, the national tests, used to confirm teachers' assessments for the purpose of reporting levels achieved, existed only for English and mathematics. In all other subjects, including environmental studies (of which science is a part), levels were, as now, based on teachers' judgments.

Evidence of the efficacy of the support for primary science in the mid-1990s is somewhat equivocal. A study of primary and secondary teachers found a continued bias towards biological topics and a perception that the curriculum as specified was too difficult for children (Russell *et al*., 1995). However, the reports from Ofsted inspections at that time were more optimistic – that over 80 per cent of lessons were judged to be satisfactory or better. But the news of the other subjects was not good: targets for English and mathematics were not being met. Attention was transferred from science as, in 1998 and 1999, the national frameworks for teaching literacy and numeracy were introduced, with revised frameworks provided in 2006. The time and even the methods to be used in teaching English and mathematics were specified and, although not statutory, schools were strongly advised to follow the frameworks and to show that they were giving priority to government targets in numeracy and literacy. The effect was not only to elevate the status of these subjects and to separate them from other subjects, but also to downgrade others, including science. An ASE survey (1999) confirmed that the time given over for science had declined for 1997 to 1998, that it had been put "on the back-burner" (Murphy, 1999) at Key Stage 1 and that much professional development in science had been postponed. Further help was provided to schools in the form of *A Scheme of Work for Key Stages 1 and 2* (Department for

Education and Skills, 1998). This set out an exemplar of "how the content of the programme of study for key stages 1 and 2 can be divided into units to be taught in years 1–6, and ways in which units might be sequenced across a year and key stage". A second version was published in 2000 following the 1999 National Curriculum revision. However, the much-needed professional development for primary science was then, as since, only sporadically provided. Few primary teachers have visited or even heard of their regional science learning centre (Collins *et al*., 2008).

Pros and cons of core status

The advantages of the special attention afforded to science as a subject within the core have to be weighed against the disadvantages when that core is defined by external testing at the end of key stages. Research shows unequivocally that this testing in science has had a detrimental impact on learning and teaching, particularly in the years when the tests take place. Of course it is important to know what children have achieved, to report this to parents and other teachers, and to keep records that enable within-school evaluation. The negative impact derives not from the summative assessment process as such but as a consequence of the policy of using results to set targets and to judge teachers and schools solely on the basis of test results. The sanctions associated with low levels of test results give the tests 'high stakes' and mean that teachers are under pressure to raise scores. This leads to teaching to the tests, giving multiple practice tests and coaching pupils in how to answer test questions. There is also firm evidence that this results in considerable stress for pupils and harms motivation for learning (Harlen and Deakin Crick, 2003).

The narrow focus of the tests makes this practice even more damaging to children's science education. Tests can only sample part of the curriculum, and only that part where questions can be set that are easily marked as correct or incorrect in order to reduce errors. Consequently the results provide a poor picture of pupils' achievement across the full range of goals (Wiliam, 2001) and equally poor guidance to teachers as to what is important to teach. More valid results would be provided by using teachers' assessments based on information collected during regular work, which, released from the constraints of testing, would include the development of understanding and of inquiry skills and enable them to be assessed (Assessment Reform Group, 2006).

There are, therefore, disadvantages to being designated as part of a core defined by tests. But the likely consequences of science not being part of the core curriculum can be seen in the last decade, when schools were asked to give priority to language literacy and to numeracy. Science was given lower status even within the core. Outside the core it would no doubt revert to the margins of the school timetable, with severe consequences for individuals and for society. But should it be necessary to face the dilemma of either being within a core where testing is influencing the quality of teaching and learning or being outside of the core where science may be treated virtually as optional?

Alternative conceptions of a 'core'

From the discussion so far it is evident that 'core' subjects have been given special attention at various times and are used as measures of the health of the educational provision in primary schools. They are identified by testing, and results are used to set targets both within schools and nationally. However, there is a distinct lack of justification for defining a core and for including science in it. This leaves science in a vulnerable position: the same apparently arbitrary decision to include it may equally become a decision to exclude it from the core. It is important, then, to ask: are there ways of defining a core for which there is a more solid and educationally valid justification?

One way of providing a positive answer to this question is to consider relationships among subjects and to identify as core subjects those that make the greatest contribution to general education. In this view it can readily be seen that reading and writing support learning in most other subject domains. Similarly, mathematics in its broadest sense supports understanding of time, space, measures of physical quantity, manipulation of numbers, etc., which are needed across the curriculum. To use the same justification in the case of science would take us back to the kind of arguments included in the UNESCO list, that science helps children to think logically and can promote children's intellectual development.

As mentioned earlier, it is hard to find evidence for such claims – indeed some might point to certain scientists as counter examples. At the secondary level the evidence of the impact of CASE (Cognitive Acceleration through Science Education) on pupils' GCSE results can be cited (Adey and Shayer, 1990), but we await information about effects of CASE at Key Stage 2.

An alternative to trying to justify science in terms of its impact on general learning is to consider the value of learning science both for the individual learner and for society.

Science in primary school benefits children as individuals by providing contexts for interacting with a variety of natural phenomena, promoting development of:

- skills needed to find out about their environment and tackle problems
- attitudes such as curiosity, which drives their learning, and willingness to consider evidence
- concepts that help them to understanding the world around them
- a language for describing and communicating their observations and ideas.

At the same time these experiences constitute a basis for further learning at the secondary level. Millar and Osborne in their influential report, *Beyond 2000*, express this as follows:

> Such experiences are essential to constructing the basic representations and concepts on which a more sophisticated understanding of science and technology rests – something on which the secondary school attempts to build. It begins the lengthy process of developing the ability to produce and understand scientific arguments using reliable and agreed evidence to support conclusions. It provides a natural opportunity to begin to engage with non-fiction texts and their interpretation. In this way, primary science supports the curriculum priorities of literacy and numeracy, whilst adding an important dimension that would otherwise be lacking; it starts the development of young children's capability in reasoning from evidence, using clearly and precisely defined concepts and ideas. (1998, p. 4)

In relation to benefits to society, beginning science in the primary school also has a key role in developing two of the widely recognised qualities needed by future citizens: the ability to continue learning beyond formal education, and scientific literacy. Current views of what students need to learn emphasise the importance of preparing them for an increasingly technological and scientific – and changing – world. Young people will have to make more choices than did those living in past decades. The ability to continue learning throughout life is acknowledged as essential for future generations and thus it has to be a feature in the education of every pupil. This is underlined by the OECD:

> Students cannot learn in school everything they will need to know in adult life. What they must acquire is the prerequisites for successful learning in future life. These prerequisites are of both a cognitive and a motivational nature. Students must become able to organise and regulate their own learning, to learn independently and in groups, and to overcome difficulties in the learning process. This requires them to be aware of their own thinking processes and learning strategies and methods. (1999, p. 9)

The outcomes of education that are valued in a modern and democratic society also include creativity, enterprise and economic productivity, citizenship, and various forms of literacy (Harlen, 2007). In this context, 'literacy' means being able to engage effectively with different aspects of modern life. So it is common to refer to technological literacy, mathematical literacy, scientific literacy, even political and social literacy. Being literate in these various respects indicates having the knowledge and skills that are needed by everyone, not just those who will be specialists in, or make a career using knowledge in, one of these areas. The emphasis is not on mastering a body of knowledge but on having, and being able to use, a general understanding of the main or key ideas in making informed decisions and participating in society. Scientific literacy, then, can be defined as being comfortable and competent with broad scientific ideas, with the nature, processes and limitations of science, and having the capacity to use these ideas in making decisions as an informed and concerned citizen.

The case for primary science development is strengthened by recognising that scientific literacy must begin from the start of formal education. This is because the 'broad ideas' referred to here cannot be taught directly; they are necessarily highly abstract and indeed meaningless if they do not evoke the many real situations that they link together. For example, if children develop, through investigation and observation, an understanding that there is interdependence among plants and animals in their own environment – their back garden, the park, the stream or the hedgerow – they may eventually understand the reasons for protecting the rainforests. But if the big issues relating to conservation are the starting-points, they may be understood at no greater depth than slogans and the relationships never more than superficially grasped (Elstgeest and Harlen, 1990). So the 'big' ideas (so called because they explain a range of related phenomena) have to be created from 'small' ones, developed through understanding specific events familiar to the children. It is by learning through inquiry that a foundation of understanding can be laid, on which broader ideas are later built.

The case is summarised well by Millar and Osborne:

> It is our view that the enormous impact of the products of science on our everyday lives, and of scientific ideas on our common culture, justify the place of science as a core subject of the school curriculum, studied by all young people from 5 to 16. (1998, p. 4)

It all depends, though, on what is taught and how it is taught, so we must now turn to consider the appropriate methods of learning and teaching science at the primary level.

What pedagogy?

The question now addressed is: what content and what pedagogy facilitate the achievement of the aims of primary science, justifying its position in the curriculum core?

Dealing first with the content: in order to engage children this needs to be interesting to them, linked to their experience and accessible to all. The main complaint of pupils about science is that it is not sufficiently relevant. For activities to be meaningful and engaging they should help understanding of things pupils have encountered directly in their day-to-day experience and indirectly through films and television programmes. It should be possible for children to make a link between new experience and previous experience. There can be a dilemma here in relation to whether science activities should be taken from real-life events – often complex and with several ideas involved – or whether they should be 'tidied up' to demonstrate certain relationships or principles. Some degree of abstraction from real events is generally necessary, but it should always be possible for the children to link what is learned to real events.

A link with other subjects is also important. There was criticism of integrated topic work in the 1980s for trying to cover too many subjects and making rather spurious connections between them (Department of Education and Science, 1989). However, the separation of science from other subjects went too far in the 1990s, and in 2003 the Department for Education and Skills advised that high standards were more likely to be achieved in schools that adopted a flexible approach to curriculum planning rather than separate subject teaching (DfES, 2003).

As important as the content is the way in which the pedagogy enables pupils to engage with it. Defining 'good practice' in teaching is problematic – but we know when we see it. Although the parts do not always make up the intended whole, both theory and practice suggest the following as the main elements of effective classroom practice in science:

- Teachers provide the means for children to collect evidence, which may be through experiment and practical inquiry or from secondary sources.
- Children have the opportunity to express their ideas, to listen to the ideas of others and to build on their existing ideas when faced with new experiences. This means they have shared experiences to discuss, time to do this and, where appropriate, real objects to handle and explore.

- Teachers pose questions that require children to hypothesise, predict and suggest answers.
- Teachers engage children in thinking about and discussing how to test their predictions and see if their ideas 'work'.
- Children are clear about what they are finding out and what they are learning by doing so.
- Children consider the evidence they collect in relation to initial ideas and predictions.
- Children reflect and report on how and on what they have learned.

This series of events, orchestrated by the teacher, is described as inquiry-based science education. Not all learning in science involves inquiry. There are some things, such as conventions, names and the basic skills of using equipment, that are more efficiently learned by direct instruction, as and when they are needed, but it is important to ensure that inquiry is used where it is appropriate.

Managing inquiry during a lesson is only part of what the teacher is doing. The teacher's work must start before the lesson, when he or she decides the ideas and skills to be developed and the activities likely to help this development. Then throughout the lesson the teacher is listening and watching, gathering information about the children's ideas and inquiry skills and how they are responding. The teacher uses this information to decide what help is needed either at the time or later. The teacher also ensures that children know what they are trying to learn and have some idea of how well they are doing it, so that they can identify for themselves what they need to do to improve or move forward. This is assessment used to help learning, sometime called formative assessment or assessment for learning.

Three views of how to foster learning are embedded in the vision of pedagogy (Harlen, in press) that enables primary science to meet its aims:

- Social constructivism – a view that recognises that children are all the time trying to make sense of the world around them and that these ideas have to be taken seriously as the starting-point for further development, and which recognises the impact of others' ideas on the way learners make sense of things (Bransford *et al.*, 1999).
- Inquiry – a view of learning in which children develop understanding through gathering and using evidence from first- or second-hand sources and through argument, dialogue and discussion (National Science Foundation, 1997).
- The formative use of assessment – a pedagogical approach that focuses on ensuring progress in learning and regulation of teaching and learning activities to ensure achievement of particular goals (Harlen, 2006).

All three views have application across the curriculum and it is therefore important to recognise what is special about using them to develop scientific understanding. For example most of the inquiry skills – observation, posing questions, developing hypotheses, making predictions, planning investigations, gathering evidence, interpreting evidence, considering alternative explanations, communicating results and conclusions, critical reflection and review – are generic skills that can be used in other domains, particularly history, geography and social subjects. But the subject matter in these domains does not lend itself to the kind of thinking and manipulation that can be conducted in relation to the subject matter of science. The difference between generic and scientific inquiry lies in the kind of reasoning about evidence that is possible. Thus it requires teachers who themselves understand 'how science works', and ensure that children experience it at an appropriate level through their investigations, and 'fair testing', as they manipulate and explore their world.

Conclusions

School science education as a whole is now recognised as serving two important purposes. First, to educate all children so that they can engage with science-related issues – such as the impact of global warming – that increasingly affect everyday life. The second is to provide a foundation for the education of future scientists, technologists and engineers. The first of these is seen as a priority, certainly in countries of the European Union (Osborne and Dillon, 2008), and it is this purpose that primary science serves. Nevertheless the enjoyment and understanding of science in the primary school is surely a motivation for continuing its study throughout secondary education and beyond.

The discussion in this paper leads to the conclusion that science should continue to be regarded as a core component of the primary curriculum, for reasons falling under the following headings:

- Primary school science enables children to develop ideas about the world around, laying a foundation for scientific literacy, the general grasp of key ideas of and about science that are necessary for effective operation in the modern world.
- Children's experience of undertaking scientific inquiry can develop appreciation of how science works, of the power and the limitations of science, as well as the enjoyment of learning through scientific activity.
- Science can help understanding of scientific aspects of their daily lives that affect their health and safety during the primary years and have wider implications for their and others' future through longer-term affects on the environment.
- Scientific activity and learning about the people and history of science support appreciation of science as an important human endeavour in which reliable knowledge is built up through the systematic collection and use of evidence.
- Involvement in scientific activity leads to the recognition of the importance of reasoning about evidence, which is needed for future learning in science and beyond.

These outcomes are central to the aims of education and unlikely to be achieved if science starts only at the secondary level.

Summary and implications

Main points

The history of science in the primary school curriculum during the 20th century shows, despite some peaks and troughs, a gradual increase in advocacy and security coinciding with the increase in impact that science and technology have on daily life. If education is a preparation for life, it must prepare pupils for life in a world in which science and its applications in technology have key roles. It follows that children need to develop:

- some knowledge and understanding of aspects of the natural environment
- a capacity to reason from evidence
- an understanding of the nature of science and of how scientific knowledge is developed
- the key ideas that will help them to make sensible decisions about how they live their lives and that affect the lives of others.

But why does this development need to begin in primary education? There are several strong reasons why it cannot be adequately achieved through secondary school science alone.

Learning science helps children to begin to understand aspects of the world around them, both the natural environment and that created through the application of science. Primary science gives children the opportunity to begin forming key concepts through exploring a variety of contexts before formal learning at the secondary level. The evidence that children are arriving at their own ideas in the early years, whether or not there is science in the curriculum, is a powerful argument for ensuring that they explore and inquire in a way that promotes the development of reliable knowledge and basic science concepts. There is a considerable body of research evidence that shows that, since children's own ideas are often in conflict with scientific ones, if taken into the secondary school, these can inhibit effective learning. The conflict between children's own ideas and ones that they are taught in secondary education leads many to find science too hard, too confusing and too remote from their real experience.

The consequence is serious for the individuals – since it has implications for their personal choices affecting their health and enjoyment of the environment as well as for their choice of career – and for society through the cost of healthcare, of environmental pollution and so on. But perhaps most important is the division between those who understanding scientific aspects of the world around and those who don't. In purely economic terms we need to ensure that today's young people do not grow up into a throwaway, energy-wasting, planet-polluting society. While we do not want to make children feel guilty about the state of the planet – for it is not they who have brought this about – there is ample evidence that children can develop respect for and understanding of how to care for themselves, other living things and the environment from an early age.

These consequences of science-related decisions underline that it is important for science not to be divided from other school subjects and other parts of life. Science at the primary level is well placed to help children recognise and value the contribution that science makes to other areas of learning, and conversely, how skills, creativity and imagination fostered in other subjects can contribute to science. Beginning to explore the environment at an early age also brings the enjoyment and satisfaction that all of us feel as a result of learning things through our own actions.

The development of reasoning and reflection on learning is an important part of educating young people for a world that is so rapidly changing that we cannot anticipate now what will be regarded as normal in 20 or so years' time. Through developing inquiry skills, science has a key role in this preparation. The worldwide movement towards the implementation of inquiry-based science education in the primary school is an acknowledgement of its value and provides evidence of its effectiveness (Harlen and Allende, 2006).

To achieve the aims of science education at the primary school level it is important to consider not just the subject matter that is suitable for the development of scientific understanding, but also the pedagogy that is required for meeting these aims. This must enable learners to achieve understanding of what is involved in learning and to take increasing responsibility for their learning. It has been argued here that this is best achieved through a pedagogy that takes children's own ideas seriously, helps them to acquire and use inquiry skills in the development of understanding, and uses assessment formatively to ensure that challenges keep pace with progress in skills and understanding. The curriculum and assessment should enable children to experience such teaching throughout the primary years.

Implications

- The concept of the primary curriculum having a core should be reviewed and if retained should be justified and defined in an educationally defensible way.
- The position of science as a key component of the primary curriculum should be justified by its contribution to the development of scientific literacy and its connections with other areas of the curriculum and not by inclusion in national testing.
- The development of science skills and the understanding of key ideas should be seen as interdependent and inseparable aims of science education and represented in the curriculum this way.
- The written National Curriculum should indicate a few points in progression in the development of skills and concepts for which there is firm evidence.
- The curriculum should provide a broad framework of skills and concepts within which schools prepare the programme of study that provides experiences that are relevant and interesting to their particular pupils.
- National tests should be replaced by moderated teachers' assessment, so that progress in the full range of skills and concepts can be recorded and reported.
- There should be no high-stakes use of summative assessment of pupils' progress at the primary level as this distorts teaching and learning.
- Schools' provision for primary pupils' learning in science should be evaluated against a wide range of indicators of quality, of which the levels of pupils' achievement would be only one.
- Teacher education, initial and continuing, should provide the understanding and strategies needed for a pedagogy that combines social constructivism, inquiry and the use of assessment to help learning.

References

Adey P, Shayer M. Accelerating the development of formal thinking in middle and high school students. Journal of Research in Science Teaching 1990;27(3):267–85.

Assessment Reform Group. The role of teachers in the assessment of learning. London: ARG; 2006. http://k1.ioe.ac.uk/tlrp/arg/ASF%20booklet%20English.pdf [accessed 28 August 2008].

Association for Science Education. Policy Statement. Hatfield: ASE; 1963.

Association for Science Education. Science and the Literacy Hour: Executive summary. Hatfield: ASE; 1999.

Association of Women Science Teachers. Science in the Primary School. London: John Murray; 1959.

Bennett SN, Wragg EC, Carré CG, Carter DSG. A longitudinal study of primary teachers' perceived competence in, and concerns about, National Curriculum implementation. Research Papers in Education 1992;7(1):53–78.

Boyers P. Report to the Department of Education and Science on an Enquiry into the Formation of Scientific Concepts in Children 5–13. Oxford: University of Oxford Institute of Education; 1967.

Bransford JD, Brown AL, Cocking RR (eds). How People Learn: Brain, mind, experience and school. Washington, DC: National Academy Press; 1999.

Carré CG, Carter DSG. Primary teachers' self-perceptions concerning implementation of the national curriculum for science in the UK. International Journal of Science Education 1990;12(4):327–431.

Central Advisory Council for Education. Children and their Primary Schools. The Plowden Report. London: HMSO; 1967.

Collins S, Reiss M, Stobart G. The Effects of National Testing in Science at KS2 in England and Wales: Executive summary. London: Wellcome Trust; 2008.

Department for Education and Skills. A scheme of work for Key Stages 1 and 2: Science teacher's guide. London: Qualifications and Curriculum Authority; 1998.

Department for Education and Skills. Excellence and Enjoyment: A strategy for primary schools. London: DfES; 2003.

Department of Education and Science. Primary Education in England. London: HMSO; 1978.

Department of Education and Science. Education Support Grants. London: DES; 1984.

Department of Education and Science. Aspects of Primary Education: The teaching and learning of science. London: HMSO; 1989.

Department of Education and Science/Welsh Office. Science 5–16: A statement of policy. London: HMSO; 1985.

Elementary Science Study (ESS). New York: McGraw Hill; 1966.

Elstgeest J, Harlen W. Environmental Science in the Primary Curriculum. London: Paul Chapman Publishing; 1990.

Gopnik A, Meltzoff AN, Kuhl PK. The Scientist in the Crib. New York: William Morrow & Co.; 1999.

Harlen W. The rise and fall of peripatetic science demonstrators. Primary Science Review 2001;67:9–10.

Harlen W. Teaching, Learning and Assessing Science 5–12. 4th edn. London: Sage; 2006.

Harlen W. Assessment of Learning. London: Sage; 2007.

Harlen W. Constructivism, inquiry and the formative use of assessment in primary school science education. In press.

Harlen W, Allende J. Interacademies Panel on International Issues. Report of the Working Group on International Collaboration in the Evaluation of Inquiry-Based Science Education Programs. Santiago, Chile: Fundacion para Estudios Biomedicos Avanzadosde la Facultad de Medicina; 2006.

Harlen W, Deakin Crick R. Testing and motivation for learning. Assessment in Education 2003;10(2):169–207.

Harlen W, Simon S. Elementary school science and the rise and rise of primary science. School Science Review 2001;82(300):49–57.

Haworth C, Dale P, Plomin R. A twin study into the genetic and environmental influences on academic performance in science in nine-year-old boys and girls. International Journal of Science Education 2008;30(8):1003–25.

Isaacs N. The case for bringing science into the primary school. In WH Perkins (ed.). The Place of Science in Primary Education. London: British Association for the Advancement of Science; 1962.

Millar R, Osborne J. Beyond 2000: Science education for the future. London: King's College London, School of Education; 1998.

Morris R. Science Education Worldwide. Paris: UNESCO; 1990.

Murphy C, Beggs J, Russell H, Melton L. Primary Horizons: Starting out in science. London: Wellcome Trust; 2005. www.wellcome.ac.uk/primaryhorizons [accessed 29 August 2008].

Murphy P. Science and literacy – moving forward? Editorial. Primary Science Review 1999;59:1–2.

National Curriculum Science Working Group. Final Report. London: Department of Education and Science/Welsh Office; 1988.

National Science Foundation. The Challenge and Promise of K-8 Science Education Reform. Foundations 2. Arlington, VA: NSF; 1997.

Nuffield Junior Science Project. Teachers' Guide. London: Collins; 1967.

Organisation for Economic Co-operation and Development. Measuring Student Knowledge and Skills. OECD Programme for International Student Assessment (Pisa). Paris: OECD; 1999.

Ormerod MB, Duckworth D. Pupils' Attitudes to Science. Windsor: NFER; 1975.

Osborne J, Dillon J. Science Education in Europe: Critical reflections. London: The Nuffield Foundation; 2008.

Osborne RJ. Children's own concepts. In W Harlen (ed.). Primary Science: Taking the plunge. London: Heinemann Educational Books; 1985.

Primary Science Review. Editorial. Primary Science Review 1986;1:2–3.

Royal Society. Taking a Leading Role. London: The Royal Society; 2006.

Russell T, Qualter A, McGuigan L. Reflections on the implementation of national curriculum science policy for the 5–14 age range: findings and interpretations from a national evaluation study in England. International Journal of Science Education 1995;17(4):481–92.

Simon B. The Education Reform Act: Causative factors. In P Broadfoot, D Nuttal, B Dockrell, C Gipps (eds). Policy Issues in National Assessment. BERA Dialogues 7. Clevedon: Multilingual Matters; 1993.

UNESCO. New Trends in Primary Science Education. Paris: UNESCO; 1983.

Weiss IR. National Survey of Science, Mathematics and Social Studies Education: Highlights report. ERIC Document ED152 566; 1978.

Wiliam D. What is wrong with our educational assessment and what can be done about it? Education Review 2001;15(91):47–58.

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A founder member of the British Educational Research Association, she was its President in 1993/94. She was a member of the Secretary of State's original working group on the creation of the National Curriculum in science. She was awarded the OBE by the Queen for services to education in 1991 and was given a special award for distinguished service to science education by the Association for Science Education (ASE) in 2001. She edited *Primary Science Review* for the ASE from 1999 to 2004 and serves on the editorial board of three international journals. Her publications include 25 research reports, over 150 journal articles, contributions to 35 books, and 28 books of which she is author or co-author.

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Science in English primary schools: trends in attainment, attitudes and approaches

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Introduction

We review trends in attainment, attitudes and approaches to science education in English primary schools over time. We focus on the primary age range 5–11 years and look at evidence of children's attainment levels and attitudes towards science over the last 50 years. Where possible we develop descriptions of what children know and can do in science as they move through these primary years. This is linked to changes to the curriculum and to the way in which science and science-related activities have been approached in the classroom.

Our review considers the international evidence from the Trends in Mathematics and Science Study (TIMSS) and similar studies that throw light on England's standing against other countries and how that has changed over time. We also review the ways in which teachers perceive science and whether those perceptions have changed over time. Trends of pupils opting for science courses in secondary school are briefly mentioned. We conclude by relating the findings to some government initiatives and discussing implications for the future.

Approach

This review starts with a history of science in primary schools over the last 60 years and looks in detail at the changing fashions and the pressures experienced by schools and teachers. It goes on to assess the evidence surrounding pupils' attitudes to science as well as teachers' attitudes and their perceptions of their own capacity to teach science.

Achievement in science is examined from the perspective of English data as well as international studies and to this is added the evidence concerning the Piagetian levels of primary-aged children.

Finally, the information is brought together with a proposal for a way forward that would build on present knowledge, and develop a firm foundation for structuring our approach to science in primary schools.

Sources of evidence

A literature search was undertaken in January 2008 and the following online databases and search engines were used to search for sources of evidence: Educational Resource Information Centre (ERIC), Electronic Collections Online (ECO), WorldCat, British Education Index, Google Scholar and the Current Educational Research in the UK database (CERUK). Other relevant research known to the authors was also included in the list of research to review.

It was necessary to use a variety of search terms in combinations to limit the large number of references returned by searching using single terms, e.g. 'primary science' produced over 5000 references. The following search terms were employed in different combinations: science, primary, pupils, schools, England, achievement, attainment, standards, trends, skills, SATs, attitudes, sex, behaviour, Piaget, levels, knowledge and concepts.

Science in the primary curriculum: a brief history

Pre-National Curriculum

Although some form of primary education has been available since the mid-19th century it was largely the preserve of the more affluent in society. It was the Education Act of 1944 that formally established primary schools as the first stage of compulsory schooling in the UK (Jenkins and Swinnerton, 1998). The Act did not prescribe the curriculum, however, and science education within this new primary phase remained largely limited to 'nature study' and attracted very little curriculum time; some estimates put it at less than 20 minutes per week (Wastnedge, 2001). In the late 1950s there arose a political debate concerning the shortage of scientists and the potential impact this was likely to have on the country's economic prosperity. These concerns led to the establishment of the first Minister for Science. Shortly afterwards, in 1962, the Nuffield Foundation donated £250 000 toward the costs of a programme to improve the teaching of both science and mathematics. Although this was almost entirely aimed at secondary science it was indicative of how the teaching and learning of science in schools was beginning to attract attention. Other projects aimed at extending this early work and improving science in the primary phase soon followed, e.g. the Schools Council 5–13 Science Project in 1967 (see Harlen, 1975; Parker-Jelly, 1983). Science education at this time was viewed more as a method of enquiry than a body of knowledge. This view fitted perfectly with the ideas that, in the 1960s, were just beginning to emanate from the work of Piaget (Conran, 1983; Jenkins and Swinnerton, 1998).

Piaget's theory of cognitive development suggested that children's thought processes developed through qualitatively different stages[1] (linked to age) and that their learning and intellectual growth matured as they actively engaged and interacted with the environment. The implication of Piaget's central idea was that children are unable to acquire any conceptual understanding beyond their current stage of cognitive development. In terms of primary school children this meant that they could only learn from concrete situations. In the 1960s and 1970s the work of Piaget began to be a key topic of conversation within in-service courses for primary teachers and his ideas inevitably began to influence teaching practice. This philosophy of 'learning by discovery' was not new but was to gain wider acceptance when it was firmly endorsed by the Plowden Report (Central Advisory Council for Education, 1967).

From 1970s onwards the amount of science taught in primary schools gradually increased but it was still regarded as an 'optional extra', delivered in an ad hoc manner and concerns about the quality of the teaching were still expressed. A survey of primary schools carried out by Her Majesty's Inspectorate (HMI) in 1978 highlighted the lack of primary teachers' subject knowledge as the major obstacle to good-quality science provision. It stated that:

> The most severe obstacle to the improvement of science in the primary school is that many existing teachers lack a working knowledge of elementary science appropriate to children of this age. (Department of Education and Science, 1978, para. 5.83)

The same report also identified the primary science infrastructure as a major weakness:

> Few primary schools…had effective programmes for the teaching of science. There was a lack of appropriate equipment; insufficient attention was given to ensuring proper coverage of key scientific notions; the formulating of hypotheses, experimenting and recording was often superficial. (ibid., p. 58)

This was a period when there was no requirement for initial teacher training courses to offer primary science and there was little or no training for student teachers. At this time, would-be primary teachers were expected to first gain a sound theoretical understanding of teaching via courses provided by specialist colleges or higher education institutions, often being taught learning theory by psychologists. Alexander describes the situation for training teachers at the time:

1 The identification of stages does not imply a series of abrupt changes in cognitive development. Rather they are useful descriptions of broad areas that merge seamlessly from one to another.

> By the 1960s the content of education courses increasingly reflected the intellectual preoccupations of education theorists and researchers rather than the needs of intending teachers. (Alexander, 1984, p. 115)

This ‘model’ of teacher training changed in the 1990s when the Government shifted the emphasis of teacher training from a theoretical understanding of education to training in statutory competencies to teach. Schools also took on much more of a leading role in the training process (Jenkins and Swinnerton, 1998).

The 1980s was a period of major growth as well as change in primary science. In 1980, the Assessment of Performance Unit (APU) conducted the first of five annual surveys in the UK of 11-, 13- and 15-year-old children’s performance in science. These surveys were significant because of the substantive data that they produced.

In 1985, the Government released *Science 5–16: A statement of policy,* which set out its objectives and the content of the science curriculum. Its principles of breadth, balance, differentiation, equality of opportunity, continuity and progression, teaching methods, and assessment were the forerunners of the prescribed National Curriculum to come (Carré and Carter, 1990). In the same year the Government began funding science advisory teachers in local education authorities via Education Support Grants. Their job was to support teachers in schools, offer courses, and develop curriculum and teacher support materials. By 1990, at a crucial point in the development of primary science, the grants had ceased and the number of advisory teachers rapidly declined (Ritchie, 1996). These advisory teachers played a significant role in helping teachers to manage the demands of teaching primary science and some see the impact of their work even today (de Boo and Randall, 2001).

With respect to the many changes primary teachers had to contend with in the lead-up to the introduction of the National Curriculum in 1989, a report by the National Union of Teachers (NUT) in 1992 stated:

> Reforms imposed by the Government since the mid 1980s have been characterised by a lack of consultation with teachers, unacceptable pace and a total disregard for the needs for resources to support their implementation. (NUT, 1992)

Post-National Curriculum

The 1988 Education Reform Act set out the National Curriculum and heralded the arrival of science as a ‘core’ curriculum subject in primary schools in England and Wales. The arrival of science in the primary curriculum was also the catalyst for other science changes. For instance, in 1990 the Department of Education and Science (DES) introduced 20-day courses for primary science teachers through the Local Education Authority Training Grant Scheme (LEATGS). The programme aimed to enhance teachers’ subject knowledge in readiness for the demands of the National Curriculum. The Government at the time also changed the status of primary science in initial teacher training courses from an optional module to a compulsory 150 hours. In general, it sharply increased the need for in-service training in primary science (Feasey, 2001). At around the same time, the Government began to view higher education teaching courses as programmes of training in the competences needed to succeed in the classroom rather than a theoretical understanding of teaching.

Although the work of Piaget was still widely known by teachers in the 1980s, there was a general decline in the belief in fixed stages of development, and his influence on pedagogy and education more generally was much less pronounced. Constructivist notions of children’s learning, i.e. the idea that learning is acquired through the process of active construction via experience, became increasingly more prominent (see, for example, Richardson, 1996; Fox, 2001). This general acceptance that knowledge is socially constructed has meant more recently a greater focus on inquiry-based learning in science and the importance of developing the skills in children required for greater conceptual understanding, e.g. effective discussion and group work, cognitive conflict, metacognition, etc. (see for example Black and Harlen, 1993; Adey and Shayer, 2002; Mercer *et al.*, 2004; Howe *et al.*, 2007; Maloney, 2007).

Research at the time of the Education Reform Act (1988) suggested that primary teachers were less than prepared to the meet the demands of the new National Curriculum. Wragg *et al.* (1989) and Carré and Carter (1990) set out the concerns expressed by many primary teachers about the implementation of science and other subjects in the National Curriculum. As part of the Leverhulme Primary Project, conducted at the University of Exeter, findings from over 900 teachers across 152 schools were reported. Teachers were asked to rate their competence to teach ten different subjects using a four-point Likert scale (1 = competent to 4 = not competent[2]). Overall, science was rated eighth out of the ten subjects, with only 34 per cent of teachers perceiving their competence as a '1'. A follow-up study of nearly 450 primary teachers reported conducted in 1991, two years after the introduction of the National Curriculum, found that primary teachers' perceived competence had improved slightly, with 41 per cent now perceiving their competence as a '1'. Consequently, science was rated third behind English and mathematics (Carré and Carter, 1993).

Other surveys of primary teaching conducted around the same period suggested that the teaching of science had improved since 1978. A report of a survey of practice in primary schools conducted for the DES in 1992 stated that:

> …there have been improvements in the quality of teaching in, for example, science… (DES, 1992, p. 1)

However, primary teachers' subject knowledge in science at that time was still perceived to be weak in some areas (Newton D, 1992; Newton L, 1992; Summers and Kruger, 1992; Webb, 1992). Research that sheds light on teachers' knowledge of science and scientific concepts is discussed later in this review and so will not be expanded on here. Suffice to say there is a general consensus that since the introduction of the National Curriculum and science as a 'core' subject there has been considerable progress made with primary science (Murphy *et al.*, 2007).

The National Curriculum is set out in Key Stages, with Key Stage 1 including children aged 5–7 years and Key Stage 2 including children aged 7–11 years. The statutory assessments that were set out in the 1988 Education Reform Act and first reported in 1991 are conducted at the end of each key stage. They were originally conceived of as providing formative and diagnostic information to guide teachers' practice as well as providing summative information about the levels of attainment reached (National Curriculum Task Group on Assessment and Testing, TGAT, 1988). But this rapidly shifted and tests became an accountability tool. The data enabled comparisons between children, schools and local authorities to be made and were in the public domain. At about the same time the inspection system was reformatted into a body (Office for Standards in Education) with quite a different purpose from its predecessor. It fed into the accountability model with the expressed purpose of monitoring the quality of teaching, management and children's attainment. The newly formed Ofsted was not without its commentators and critics (see for example Fitz-Gibbon, 1995, 2001; Dunford, 1998; Dunford *et al.*, 2000).

The Department for Education and Skills's primary national strategy in 2003 set out as one of its priority targets to "extend the sort of support provided by the literacy and numeracy strategies to all the Foundation subjects" (DfES, 2003).[3] This was followed a year later by the DfES's *Five Year Strategy for Children and Learners*, which stated:

> We face a challenge to make sure that every subject is taught well in primary schools and that every child gets the benefit of a rich, well-designed and broad curriculum. (DfES, 2004, p. 34).

2 The complete scale was: 1 = "Yes, I feel I am competent with my existing knowledge and skills", 2 = "Yes, I feel competent with some help from my colleagues", 3 = "Maybe, I'd feel competent with in-service help from colleagues", and 4 = "No, I feel I would not be competent without substantial in-service support".

3 The National Literacy Strategy (NLS) and the National Numeracy Strategy (NNS) were introduced in schools in 1998 to increase standards in primary education. Among other things, these strategies produced a range of teaching and learning resources to support teachers in the classroom.

Despite this rhetoric, there is increasing evidence to suggest that science is being undermined as a 'core' primary subject (Association for Science Education, 1999; de Boo and Randall, 2001; Boyle *et al.*, 2004, 2005; Boyle and Bragg, 2005, 2006). Some have suggested that the Government's use of policy initiatives were simply 'levers' to hike cohort percentages towards their own attainment targets. The resulting narrowing of the taught curriculum not only impacted on the other foundation subjects but also on the 'core' subject of science. For instance, Boyle *et al.* (2004, 2005) reported findings from a longitudinal study of a nationally representative sample of primary teachers, which showed that between 1996 and 2004 only three subjects at Key Stage 1 showed an increase in the amount of time allocated to their teaching; English, mathematics and the cross-curricular subject of ICT. The time allocated to science, which was a 'core' subject, had decreased over the same period by more than any other subject. A similar decrease in science teaching was also found across Key Stage 2 (down from 11.4 per cent in 1997 to 9.8 per cent in 2004), despite science being a tested subject at the end of Key Stage 2 (Boyle and Bragg, 2005, 2006).

Much more recently, Ed Balls, the new Secretary of State in charge of the Department for Children, Schools and Families (DCSF), announced a ten-year Children's Plan, which will include a "root-and-branch" review of what is taught in the primary curriculum to allow "more time for reading, writing and maths". Balls has asked Sir Jim Rose, the former director of inspection at Ofsted, to carry out the independent review. In his brief, Balls set out the key objectives:

> A key objective of your review is to enable schools to strengthen their focus on raising standards in reading, writing and numeracy. I also want pupils to be introduced to a broad range of subjects in primary school, including languages… Your review is focused on the curriculum and is not considering changes to the current assessment and testing regime. (Balls, 2008)

The letter also refers explicitly to the possibility of whether "pupils' interests might be better served by studying fewer subjects during primary education, particularly in Key Stage 1" (ibid.). The lack of any reference to science suggests a threat to the continuing existence of science as a 'core' primary subject.

Summary

To summarise, immediately after World War II there was very little science taught in primary schools. Since that time, teachers and pupils in English primary schools have been subjected to changes in curriculum and assessment with respect to science. Following concerns expressed in the 1950s about a shortage of scientists and the potential impact this was likely to have on the country's economic prosperity, science in the primary curriculum became more prominent. In the 1960s and 1970s the work of Piaget began to have a considerable influence in primary education; this was encouraged by the involvement of psychologists in the education of teachers. During the 1980s there was a general decline in the belief in fixed stages of development but the idea that children develop their own ideas was preserved in the notion of constructivism (which incorporates some Piagetian principles). At about the same time there was a shift in the focus of teacher education from a theoretical understanding of pedagogy to competence in practical skills. Psychologists were less involved in teacher education, while practising teachers and schools became much more involved. The introduction of the National Curriculum in September 1989 heralded science as a 'core' subject backed up with statutory assessments and a rigid inspection system. Despite the status of 'core' subject, the evidence suggests that the amount of time devoted to science in the primary phase has actually declined. Policies that emphasise attainment targets have contributed to a move from an emphasis on children's thinking to their capacity to pass tests (cf. Reay and Wiliam, 1999; Hall *et al.*, 2004; Harlen, 2007; Collins *et al.*, 2008).

Attitudes to science

It should be noted at the outset that the term 'attitude' has suffered from inconsistent operational definitions in the literature. This is partly because the term 'attitude' does not refer to a unitary construct but a number of sub-constructs, all of which contribute in some way to an attitude toward science. Gardner distinguishes between 'attitudes towards science' and 'scientific attitudes' (Gardner, 1975). He defines attitudes toward science as "the feelings, beliefs and values held about an object that may be the enterprise of science, school science, the impact of science on society or scientists themselves" (quoted in Osborne *et al.*, 2003. p. 1053). Scientific attitudes are "the complex mixture of longing to know and understand, a questioning approach to all statements, [and] a search for data and their meaning" (ibid.).

The following sections discuss a number of research studies on attitudes towards science. Unless stated otherwise, these refer to attitudes towards school science.

i) Pupils' attitudes

It is well established that children become less positive towards school and academic subjects as they age, and science is no exception. For instance, the First International Science Survey (FISS), organised by the International Association for the Evaluation of Educational Achievement (IEA) in 1971, reported that pupils' attitudes to science showed a significant decline over the secondary school years. This finding has since been supported by other research (Breakwell and Beardsell, 1992). However, there is also some evidence to suggest that pupils experience a decline in enthusiasm for science even earlier, i.e. at the end of primary school. For example, a study by the Institute of Electrical Engineers (1994) reported a decline in interest in science among pupils in England between the ages of 10 and 14 years (see also Osborne *et al.*, 1998; Pell and Jarvis, 2001; Osborne *et al.*, 2003). In contrast, more recent research has found pupils' interest in science at 9–10 years of age to be high (Haworth *et al.*, 2008, cited in Osborne and Dillon, 2008).

Murphy and Beggs (2001, 2003) have conducted a number of surveys into children's attitudes to science. Their findings suggest that older pupils (10–11 years) tend to have significantly less positive attitudes to science than younger pupils (8–9 years). This finding is also in common with attitudes to both reading and mathematics, which are also found to decline with increasing age (Epstein and McPartland, 1976; Albone and Tymms, 2004; Sainsbury and Schagen, 2004).

Other research shows that science is not the most popular of primary school subjects. Pollard (1996) interviewed the same 54 children from nine schools during the first four years of their primary schooling and asked them to identify their 'best liked' and 'least liked' subjects. In Years 1, 2 and 3 science was ranked tenth out of the top 12 and in Year 4 it had dropped out of the top 12 altogether.[4] It should be noted that while having longitudinal importance, the sample size of that study was very small. Pell and Jarvis (2001) found that children preferred practical activities over non-practical activities in science, and Murphy *et al.* (2004) found that increasing the amount of practical, investigative work in primary science increased enjoyment of science experienced by pupils. In contrast, attitudinal data from the Performance Indicators in Primary Schools (PIPS) Project based at the University of Durham's Curriculum, Evaluation and Management (CEM) Centre shows Year 6 pupils' attitudes to science to be remarkably stable and quite positive over time. PIPS is a UK-wide curriculum-based monitoring project that enables teachers to judge their school's performance within the context of thousands of other schools taking part in the same assessments.[5] Pupils' attitude to science is assessed using a five-point Likert scale (1 indicating a very negative attitude and 5 a very positive attitude). An analysis of Year 6 attitudinal scores from pupils from the same 54 schools between 1999 and 2007 shows that average scores have changed very little during that time. Those pupils' attitudes were assessed in the January of the academic year, probably prior to the start of the period of intense preparation for the statutory assessments. The details are shown in Table 1. The samples in this study, although cross-sectional, are much larger than the study by Pollard.

4 This approach to assessing attitudes is problematic since it is based on comparisons. A pupil may like science but prefer other subjects. This is quite different from 'not liking'.

5 See www.cemcentre.org/RenderPage.asp?LinkID=22210000 [accessed 29 August 2008].

Table 1: PIPS Year 6 attitude to science scores over time

	1999	2000	2001	2002	2003	2004	2005	2006	2007
PIPS Year 6 attitude to science	3.9	3.9	3.9	3.9	3.8	3.8	3.8	3.8	3.9
***n* pupils**	1316	1869	1781	2081	1902	2082	1851	1896	1739

(Scores on a Likert scale from 1 = very negative to 5 = very positive.)

A recent scoping study of research into primary science in the UK conducted by Murphy and Beggs (2005) identified the following themes concerning pupils' attitudes to science:

1. Many children experience a decline in interest in school science, which seems to start at around the age of 10
2. There is little relationship between attitudes to school and attitudes to science, i.e. attitudes towards school are more positive and this difference becomes greater as children get older (Morrell and Lederman, 1998).

Recent international studies (Third International Mathematics and Science Study, and Trends in Mathematics and Science Studies, both abbreviated to TIMSS), which were conducted by the IEA, have also reported on pupil and teacher attitudes towards science. TIMSS 2003 surveyed children aged 9–10 years (Year 5 in England) across 26 countries, including a comparison group of 11 'similar' countries. It reported that 54 per cent (1.4)[6] of English pupils had high self-confidence in their ability to learn science, compared with the international average of 59 per cent (0.2). This placed England 18th out of 26 countries in the league table for self-confidence in ability to learn science. The value that pupils place on science was measured in 1995 and 2003 by the extent of their response to the statement 'I enjoy learning science'. Only 39 per cent (1.4) of English pupils agreed 'a lot' with that statement in 2003, down from 41 per cent (1.1) in 1995. The international averages in 2003 and 1995 were 55 per cent (0.3) and 44 per cent (0.4) respectively, suggesting declining attitudes towards science are not confined to the UK but represent a global phenomenon.

Research studies have identified a number of factors relating to pupils' attitudes to science: gender, environmental factors (socioeconomic status, parental and peer support) and curriculum factors (classroom environment and teacher).

Gender

There is a large degree of consensus in the research that suggests that boys tend to have more positive attitudes to science than girls (Harvey and Edwards, 1980; Harding, 1983; Kahle and Lakes, 1983; Erickson and Erickson, 1984; Schibeci, 1984; Smail and Kelly, 1984; Johnson, 1987; Robertson, 1987; Becker, 1989; Breakwell and Beardsell, 1992; Colley *et al.*, 1994; Weinburgh, 1995; Sjøberg, 2000). Certainly, girls remain in the minority when it comes to pursuing careers in science (Woodward and Woodward, 1998; Osborne and Dillon, 2008). However, recent international data from the Programme for International Student Assessment (PISA) suggest that that few participating countries show entrenched gender inequalities in 15-year-old pupils when it comes to performance or attitudes towards science (OECD, 2006a).

A meta-analysis covering the available literature between 1970 and 1991 found 31 effect sizes suggesting that boys have more positive attitudes towards science than girls (Weinburgh, 1995). This meta-analysis appears to have included both primary- and secondary-aged cohorts, and reported an effect size of about 0.20: a small difference.

6 Standard errors in parentheses.

Osborne *et al.* (2003) suggest possible explanations for such gender differences in attitudes to science. One prominent speculative explanation suggests that such differences are a consequence of the cultural socialisation that offers girls far fewer opportunities to engage in science and scientific activities (Kahle and Lakes, 1983; Kelly *et al.*, 1984; Whyte, 1986; Johnson, 1987; Jones *et al.*, 2000). Another possible explanation lies with the content of extant curricula and the finding that it is of far less interest to girls than boys (see the review in Osborne and Dillon, 2008).

Environmental factors (socioeconomic status and parental and peer support)

The evidence for the effects of socioeconomic status and parental and peer support on attitudes to science is largely limited to secondary-aged cohorts, and the available evidence is conflicting. The interested reader is pointed towards Osborne *et al.* (2003), who give a good summary of the evidence.

Curriculum factors

Again, much of the research here is limited to secondary-age cohorts. However, there is some evidence from the USA to suggest pupils' attitudes to science are associated with a high level of involvement and personal support, positive relationships with classmates and the use of a variety of teaching strategies and learning activities (Brown, 1976; Myers and Fouts, 1992; Piburn and Baker, 1993).

The relationship between attitude and achievement

The research here is inconclusive. Shibeci (1984) cites studies that show correlations of 0.3–0.5 between attitudes and achievement but he also cites studies that show no relationship at all. Weinburgh's (1995) meta-analysis of the research from 1970 to 1991, mentioned earlier, suggests only a moderate-strength relationship exists between attitude and achievement.

Data from the PIPS Project based at the University of Durham shows virtually no correlation between Year 6 pupils' attitudes to science and science achievement. The correlations between attitude to science and science achievement over time can be seen in Table 2. The data span the same years and come from the same 54 schools described earlier in the report (see Table 1).

Table 2: Correlation between Year 6 attitude to science and science achievement over time

	1999	2000	2001	2002	2003	2004	2005	2006	2007
PIPS Year 6 correlation (attitude to science and science achievement)	0.02	-0.01	0.03	0.03	0.05	0.04	0.04	0.08	0.06
***n* pupils**	1316	1869	1781	2081	1902	2082	1851	1896	1739

One possible reason for this extremely low correlation may lie in the way that teachers' work in primary schools aims to maintain children's self-esteem even when achievement is low. One other caveat should be noted when considering these findings: all the research investigating a link between attitudes and achievement suffers from the problem of 'cause' and 'effect'. That is, there is disagreement in the literature on whether attitude or achievement is the causal variable in any relationship between the two.

ii) Teachers' attitudes

The research mentioned earlier by Wragg *et al.* (1989) and Carré and Carter (1993) suggested that primary teachers' perceived competence to teach science was low in 1989 and only slightly improved in 1991. In 1989, science was rated eighth out of the ten subjects with only 34 per cent of teachers perceiving their competence to teach science as a '1' (using a four-point Likert scale from 1 = competent to 4 = not competent). In 1991, primary teachers' perceived competence had improved, with 41 per cent now perceiving their competence as a '1'. This improvement is likely to be linked to the teachers' increased experience of delivering science during two years since the introduction of the National Curriculum in 1989.

A few years later, Tymms and Gallacher (1995) asked primary teachers to respond to a series of questions about their training, confidence and knowledge of teaching English, mathematics and science. They found that primary teachers were considerably less confident about their teaching and knowledge of science than they were about their teaching and knowledge of other curricular subjects such as reading and mathematics.

Murphy and Beggs (2005) also identified the lack of teacher confidence, knowledge and expertise in science teaching as the most significant issue currently facing primary science. This research, reported more recently by Murphy *et al.* (2007) involved a telephone survey of 300 primary teachers. Teachers were invited to indicate their confidence in their ability to teach primary science (using a five-point Likert scale from 1 = low confidence to 5 = high confidence). The authors report that 50 per cent of all teachers questioned as part of the telephone survey highlighted lack of knowledge, expertise, confidence and training in science as the main issue currently facing primary teachers in their science teaching.

Despite this, 80 per cent of primary teachers in the sample also rated their confidence to teach science as 'high' (as measured by 4 or 5 on the Likert scale). This level of confidence to teach science was higher than for teaching history (79 per cent), geography (68 per cent) and ICT (56 per cent) but lower than for teaching maths (95 per cent) and English (88 per cent). It was also reported that younger teachers were less likely than older ones to highlight lack of confidence in primary science as a major issue. There were no appreciable differences in the responses of female and male teachers, teachers of different year groups or from teachers spending more time teaching science. There was however a difference between teachers who had received or who had not received professional development in science, with those experiencing some professional development being more confident. Teachers from larger schools were also found to be more confident in teaching science.

The authors suggest this result indicates that teacher confidence in science teaching relative to other subjects had improved compared with earlier research findings reported in Harlen *et al.* (1995), in which science was rated the eighth most difficult subject to teach out of 11 subjects (Murphy *et al.*, 2007). Despite including a question requesting teachers' highest science qualification, Murphy *et al.* seem not to have reported the impact of qualifications in science on teachers' subsequent confidence to teach science. Many teachers who came into teaching before the introduction of the National Curriculum (i.e. older teachers) never expected that they would have to teach science as a 'core' subject, and this is perhaps one factor that explains their findings.

Summary

To summarise, there appears to be a continuing trend for young people's attitudes to school science to become less positive as they move from primary school and into secondary school. Results from TIMSS surveys of 1995 and 2003 also suggest a trend for young people to 'like' science less than they used to. However, the same research suggests this is not confined to the UK but represents a wider phenomenon. The same research suggests English pupils' attitudes towards science are below average in comparison with other participating nations. There is also a large degree of agreement concerning primary teachers' attitudes towards the teaching of science. In particular, primary teachers have been characterised by a lack of confidence in their knowledge and competence to teach science, although there is some evidence that this has recently started to improve slightly.

Achievement in science

UK studies with a focus on England

The Assessment of Performance Unit (APU) carried out surveys of pupils' performance in science at ages 11, 13 and 15 in each year between 1980 and 1984. The science surveys were carried out on behalf of the APU by teams based at King's College London and the University of Leeds. The question bank was primarily structured to assess children's performance in terms of their understanding of science processes. The annual surveys used practical tests to gain information about the children's ability to perform investigations, make observations and use simple measuring equipment. Written tests were used to gain information about children's ability to plan investigations, interpret and explain presented information, hypothesise, and use graphs, tables and charts.

The APU findings suggested that *most* 11-year old children in primary schools could:

- set about practical investigations in a relevant manner
- observe the broad similarities and differences between objects
- read the scales of simple measuring instruments correctly
- classify objects on the basis of observed properties
- read information from flow charts, tables, pie charts and line graphs.

However, *few* 11-year olds could:

- repeat measurements or observations to check results
- control variables necessary to obtain good quantitative results
- record the observations of fine detail of objects
- observe the correct sequence of events
- produce an adequate plan for simple investigations
- give good explanations of how they arrived at predictions
- describe patterns in observations or data in terms of general relationships (from Harlen, 2001).

Generally, pupils' absolute performance remained largely stable over the five-year period. The authors state that:

> As regards changes in pupils' absolute levels of performance over the period of this first series of surveys [1980–84], it can be inferred with some confidence that there has been no change in the period 1982 to 1984, and it is likely that there was no change either between 1980 and 1982. (Russell, 1988, p. 30)

The results also showed that only rarely were there statistically significant differences between boys and girls at age 11 years. Some of these differences included: using graphs, tables and charts; making and interpreting observations; interpreting presented information; and planning parts of investigations.

Some suggest that the way primary science is assessed views science learning as a body of facts to be recalled in a test and so only serves to constrain children's science learning (Ponchaud, 2001; Campbell, 2001). Indeed, very recent research by Collins *et al*. (2008) suggests that the recent abolition of testing in science at Key Stage 2 in Wales is having a beneficial effect on the development of Year 6 children's knowledge and understanding of science.

Murphy *et al*. (2001) suggested that the introduction of science as a 'core' subject in the National Curriculum has increased the 'scientific literacy' of the pupils who have experienced it. They compared science test scores of a cohort of teacher trainees who had experienced a compulsory science education with a cohort of trainees who had not and found the former to have significantly higher scores.

There are a number of governmental sources of data on primary science achievement. For instance, the Department for Children, Schools and Families (DCSF) website[7] holds science results for children sitting statutory end of Key Stage tests at age 7 and 11 years, i.e. end of Key Stage 1 and Key Stage 2 respectively. The test data are reported as the percentage of pupils achieving level 2 or above at Key Stage 1 and level 4 or above at Key Stage 2, which are the expected levels of attainment at the end of the two Key Stages. These percentages are shown in Table 3.

Table 3: Percentage of pupils reaching level 2 at Key Stage 1 and level 4 at Key Stage 2 in science, 1995–2007

	95	96	97	98	99	00	01	02	03	04	05	06	07
KS1 (teacher assessment)	84	84	85	86	86	88	89	89	89	90	90	89	89*
KS2 (test)	70	62	69	69	78	85	87	86	87	86	86	87	88

(Source: DfES, 2006) * The 2007 data are provisional.

The figures indicate that the percentage of children reaching the desired level 4 at the end of Key Stage 2 rose steeply, by 15 percentage points, between 1995 and 2000. This steep rise then levelled off, with only a more gradual and modest gain of three percentage points between 2000 and 2007. Up until the year 2000, government sources were keen to cite such increases as real improvements in standards in primary schools, but the veracity of such figures has been called into question (Tymms and Fitz-Gibbon, 2001; Tymms, 2004). Tymms (2004), although working predominantly with mathematics and English scores, showed that the dramatic rises seen in these subjects at the same time overestimated the extent to which standards were increasing in primary schools. This finding was subsequently confirmed by the Statistics Commission and other independent experts (Statistics Commission, 2005). The Commission wrote that:

> Overall there was support for the [Tymms] paper and its conclusions. In particular, there was general acceptance of the idea that standards had not risen as much as the KS2 test scores suggested. (Statistics Commission, 2005, p. 3)

A much more modest increase in standards over time is further supported by statistics from other independent sources. For instance, the PIPS Project based at the University of Durham shows only a modest increase. An analysis of PIPS Year 6 science data from the same 54 schools between 1999 and 2007 shows that average raw scores rose by only 0.14 of a standard deviation. The details are shown in Table 4.

Table 4: PIPS Year 6 science test scores over time

	1999	2000	2001	2002	2003	2004	2005	2006	2007
PIPS Y6 science	28.9	28.9	28.4	29.3	29.1	29.9	29.7	29.9	29.9
Standard deviation	8.05	7.70	7.95	7.82	8.21	7.88	7.34	8.03	7.77
***n* pupils**	1316	1869	1781	2081	1902	2082	1851	1896	1739

Further evidence is provided by the findings of work commissioned by the Qualifications and Curriculum Authority (QCA) from the Research and Evaluation Division of the University of Cambridge Local Examinations Syndicate (Massey *et al.*, 2003). The authors were asked by the QCA to study the equivalence of standards in the statutory tests over several years. The study covers statutory test results at the ends of the first three key stages but only those relating to science at the end of Key Stage 2 will be discussed here. Data were collected in several ways. Firstly, statutory tests from 1996 and 2001 were administered to equivalent groups in 18 Northern Ireland primary schools (n = 952). Secondly, the same schools also provided their statutory end of Key Stage 2 assessments in mathematics to check that groups were equivalent (there being no such Key Stage 2 assessments in science in Northern Ireland).

7 See www.dcsf.gov.uk/rsgateway/DB/SFR/ [accessed 29 August 2008].

The findings from the Northern Ireland cohort showed that more pupils in the study reached the required level 4 on the 2001 test than on the 1996 test, a difference that the authors found to be statistically significant. Overall, they state:

> If we take these data as a fair test of the null hypothesis this suggests that the 2001 form of the test confers an advantage over the 1996 form… We can therefore regard our reservations regarding the validity of the experiment as conservative with respect to the outcomes, making us more, rather than less, certain that there is a difference in test standards between the 1996 and 2001 versions of the KS2 science test. (Massey *et al.,* 2003, p. 79)

A recent study by Shayer *et al.* (2007) also casts doubt on the idea that children leaving primary schools are able to cope with science. This research will be discussed in more detail later in the report so will not be expanded on further here.

The international context

Information on England's primary science performance in relation to other countries was, until quite recently, sparse. Pre-1990, international surveys suffered from methodological flaws and/or did not include primary-aged pupils (Beaton *et al.*, 1999). For instance, the First International Science Survey (FISS), conducted in 1971, did not include primary-aged pupils. However, more recently, several international organisations have established more regular and more methodologically sound surveys, and more often involving primary-aged pupils (Whetton *et al.*, 2007).

There are two main sources of international survey datasets that throw light on primary science in England:

1. Those conducted by the International Association for the Evaluation of Educational Achievement (IEA). There are three surveys relating to science: the 1984 Second International Science Survey (SISS), the Third International Mathematics and Science Survey (TIMSS) in 1995 and the renamed Trends in International Mathematics and Science Survey (TIMSS) in 2003 (data from TIMSS 2007 are not reported until December 2008).
2. Those conducted by the USA's Educational Testing Service, and known as the International Assessment of Educational Progress (IAEP). Two were conducted, in 1988 and in 1991, but only the second includes data from primary-aged children.

Currently there are four surveys on which to draw comparative information on primary science:

The Second International Science Study (SISS) 1984

This survey targeted all pupils aged 10 years in Year 5 on the day of testing in participating schools in 23 different countries. The average age of pupils tested in England was 10.3 years, a little younger than children from other participating countries. On all the measures England was outperformed by eight countries (Japan, Korea, Finland, Hungary, Italy, Australia, Canada and the USA) and failed to outperform any of the developed countries in the survey (Postlethwaite and Wiley, 1992; Keys, 1987). In fact, England only outperformed three countries: Slovenia, Ireland and Portugal. The interpretation of the results from this early survey is a little more difficult in that no statistical significance between the scores from different countries were presented. However, Whetton *et al.* (2007, p. 16) argue that the results from this survey "do not suggest a high level of performance in science in England at that time".

The International Assessment of Educational Progress Survey (IAEP) 1991

This survey targeted nine-year-old pupils. Comparisons with the earlier survey in 1984 are problematic, largely because of the lack of countries taking part on both occasions. England was again outperformed by Korea and Taiwan but performed at a similar level to Hungary, Scotland, Spain, the Soviet Union, Israel, Canada and the USA (the last two of which outperformed England in 1984).

The Third International Mathematics and Science Survey (TIMSS) 1995

In 1995, TIMSS surveyed two adjacent primary-aged pupil cohorts in 26 countries (in England these were Year 4 pupils aged 8–9 years and Year 5 pupils aged 9–10 years). England outperformed 13 of the 26 participating countries (Hong Kong, Hungary, New Zealand, Norway, Latvia, Israel, Iceland, Greece, Portugal, Cyprus, Thailand, Iran, and Kuwait) and was only outperformed by three (Japan, Korea and the USA) but performed at a similar level to the remaining nine (Austria, Australia, Netherlands, Czech Republic, Canada, Singapore, Slovenia, Ireland and Scotland) (Martin *et al.*, 1997; Keys *et al.*, 1997; Shorrocks-Taylor *et al.*, 1997).

This survey also showed that boys scored higher than girls on science, although this difference was not statistically significant (Shorrocks-Taylor *et al.*, 1997). Reviewing the results of this survey, Whetton *et al.* (2007, p. 17) argue that "overall, the level of performance demonstrated by English students was high".

The Trends in International Mathematics and Science Survey (TIMSS) 2003

The TIMSS 2003 survey, mentioned earlier, set out the relative achievement of pupils in both science and mathematics at grade 4 (Year 5 in England with pupils aged 9–10 years) and grade 8 (Year 9 in England with pupils aged 13–14 years) across 26 countries. This survey allows an investigation of England's primary science achievement not only in relation to all other countries participating in the survey but also in relation to a comparison group formed from those countries viewed as England's economic competitors, from the English-speaking world and from Western Europe (e.g. Australia, Hong Kong, Hungary, Japan, New Zealand, Singapore, USA, Belgium, Italy, Netherlands and Scotland) (Ruddock *et al.*, 2004).

The results of this survey showed that England's score of 540 was significantly higher than the international mean of 489 and significantly higher than the mean score of 530 for the comparison group just described. England's 2003 score of 540 was also significantly higher than its 1995 score of 528. The scores were scaled and the international average was set to be close to a mean of 500 in earlier surveys, with a standard deviation of 100. Consequently, England's score of 540 is approximately one-half of a standard deviation higher than the international average.

The results also showed that only Singapore and Taiwan significantly outperformed England. England was now performing at a similar level to Japan, Hong Kong and the USA. Martin *et al.* (2004) state that the results clearly showed that England's performance had significantly increased between 1995 and 2003.

The use of scale points to define international benchmarks was adopted in TIMSS 2003 in order to make easy comparisons over time. These were set at 625 (advanced), 550 (high), 475 (intermediate) and 400 (low). The proportions of English pupils reaching all but the highest benchmark increased between 1995 and 2003, as can be seen in Table 5.

Table 5: Proportions of pupils reaching each benchmark, grade 4 science

	Advanced International Benchmark	High International Benchmark	Intermediate International Benchmark	Low International Benchmark
England 2003	15%	47%	79%	94%
Comparison group average	10%	41%	78%	94%
International average	7%	32%	65%	84%
England 1995	15%	42%	72%	90%

(From Ruddock *et al.*, 2004)

Overall, Whetton *et al.* (2007) summarise England's trend in primary science thus:

> The international surveys provide clear evidence of a rise in Year 5 performance for science from 1995 to 2003. The 1995 level of performance was already high, amongst the highest in the participating countries, and this good performance in primary science has continued. Before 1995 it is more difficult to make comparisons with other countries. The available data are sparse and few countries participated in several of the surveys undertaken. It does, however, seem that England's performance in science in the surveys carried out before 1995 was not outstanding. (Whetton *et al.,* 2007, p. 18)

In relation to the other 'core' subjects in England, mathematics and English, they conclude that "primary science represents something of a success story for England" (ibid, p. 19).

International comparative surveys of educational achievement such as those of TIMSS are prone to methodological weaknesses and are not without their critics. One such criticism relates to the samples of students used, with suggestions that they may be less than representative of the countries from which they originate. Winter (1998) has argued that international studies do not take sufficient account of sampling problems when comparing different countries. Sampling can be difficult in countries where the educational experience is more variable than in the UK either because of the absence of any standard curriculum or because of some fundamental social inequality that leads to inequitable access to education. Another criticism relates to the insufficient account these studies take of input variables such as school entry age, the amount of allocated teaching time and the opportunities for pre-school education. For instance, in some countries children begin school at the age of seven years whereas in England they begin at the age of five years. There is additionally an issue to do with the number of schools that are prepared to take part in surveys and the dates when the surveys are conducted. All this means that the data from international comparative studies need to viewed with caution.

Summary

To summarise, the statutory data supplied from the end of Key Stage 2 assessments suggested a steep rise in the science attainment of pupils between 1995 and 2000, when it reached a plateau and has since remained stable. This large rise was not supported by independent data, although a more modest rise was supported. International studies indicate that the attainment of pupils in English primary schools has increased relative to other countries. However, international comparative surveys of educational achievement are prone to methodological weaknesses that raise concerns regarding the reliability and validity of the findings.

Teachers' confidence and knowledge of scientific concepts

Few would disagree with the assertion that teachers themselves need to have a good understanding of their subject matter if they are to teach that subject well. HMI (Department of Education and Science, 1978) identified primary teachers' science subject knowledge as the major obstacle to good-quality science provision in primary schools. Similar concerns were also being expressed in light of research findings from the 1990s. For example, research by Newton D (1992), Summers and Kruger (1992) and Smith and Peacock (1992) suggested that primary teachers lacked knowledge of the processes of science, energy, and gravity and air resistance respectively. The work of Wragg *et al*. (1989), Carré and Carter (1990) and Harlen *et al*. (1995) previously mentioned set out the concerns of many teachers about the implementation of science and other subjects in the National Curriculum at that time. The study by Tymms and Gallacher (1995) referred to earlier in the report also showed that primary teachers were considerably less confident about their knowledge of science than about their knowledge of other curricular subjects like reading and mathematics.

Murphy *et al*.'s (2007) UK-wide survey of over 300 primary teachers suggests that primary teachers' confidence to teach science has improved during the intervening period, and there is now consensus that this is the case. Despite this, the authors state that half of the primary teachers surveyed still cited lack of confidence and ability to teach science as the issue of major concern in primary science.

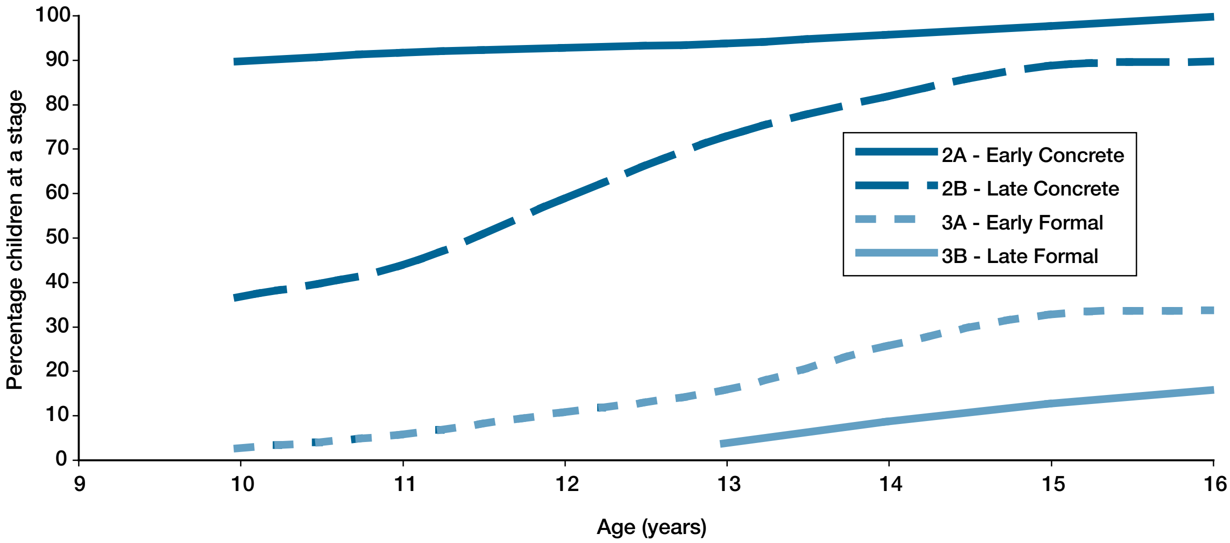
There is also evidence to suggest that some of the science taught in primary schools is too difficult for the teachers themselves. This lack of subject knowledge leads teachers to display a closed pedagogy where the presentation of unrelated facts take precedence over conceptual understanding (Osborne and Simon, 1996; Harlen, 1997; Murphy *et al*., 2001).

Piagetian levels

Some have argued that there is a serious mismatch between the conceptual demands of the science curriculum on the one hand and pupils' cognitive reasoning abilities on the other (Shayer and Adey, 1981; Johnson, 2000, 2005). This mismatch has prompted attempts to illustrate how children's ability to think often lags behind the requirements of the curriculum by linking children's thinking to Piaget's levels of cognitive development. One significant implication of this work is the development of teaching methods to accelerate cognitive development, as in the Cognitive Acceleration through Science Education (CASE) (see for example Adey and Shayer, 1994; Shayer and Adey, 2002; Adey *et al.*, 2003). As part of the earlier Concepts in Secondary Mathematics and Science (CSMS) project started in 1974, Adey and Shayer developed a number of tasks that purported to assess pupils' current stage of cognitive development. In the 1970s, they surveyed a representative sample of the late primary and secondary school population in England and Wales, totalling 12 000 pupils.

Figure 1 shows the proportion of children aged from 9 to 16 years who were at or above each named stage of development.

Figure 1: Proportion of children at different Piagetian stages in a representative sample of pupils from England and Wales



(From Shayer and Adey, 1981, p. 9)

Figure 1 shows that only 40 per cent of 10-year-olds were at or above the stage of late concrete operational thinking whereas nearly 90 per cent of children had reached this stage by the age of 15 years. After analysis of mostly secondary science curricula, Shayer and Adey wrote that:

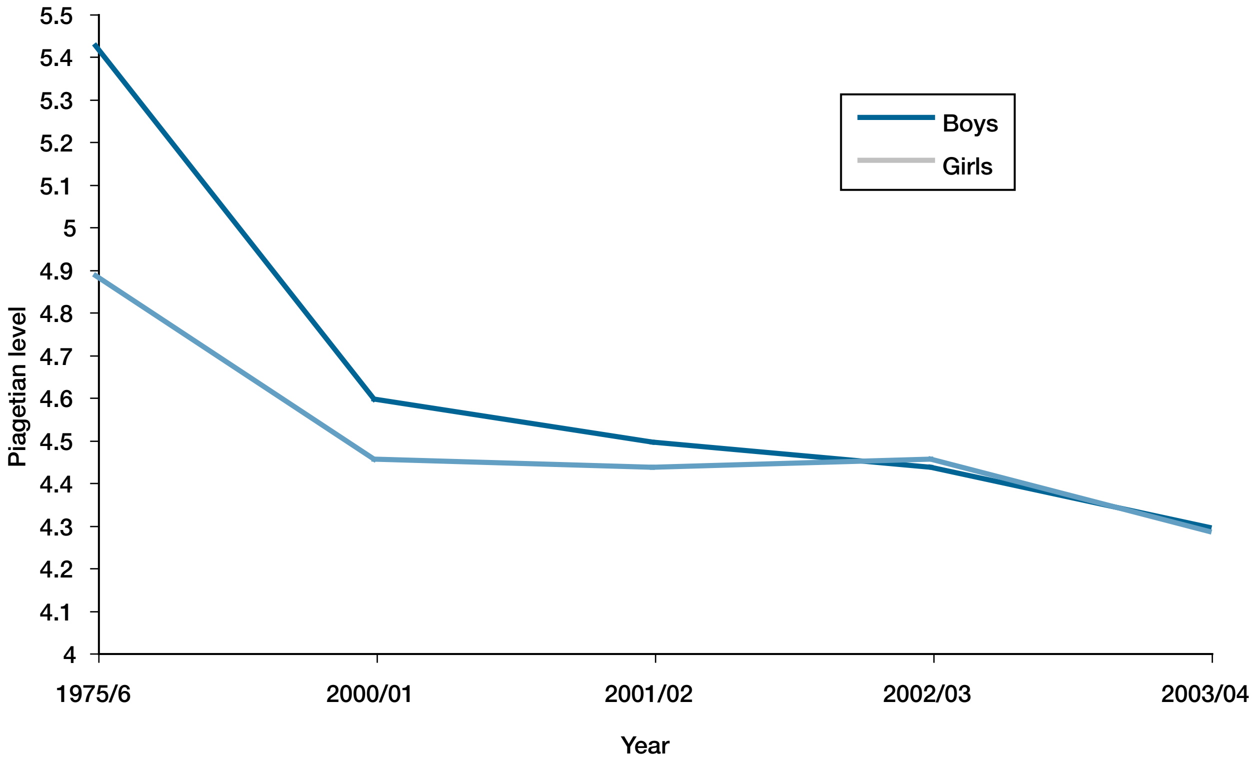
> …it is the daily experience of many science teachers that the demands are unreasonable, that there is a chasm set between the expectations expressed in curriculum objectives and the cognitive skills of many pupils (Shayer and Adey, 1981, p. v)

A recent question in a Key Stage 2 Standard Assessment Task (SAT) test suggests this may be true for primary-aged children, too. Question 2(a) in the 2006 KS2 Science (Paper A) test assesses children's understanding of 'forces'. It is questionable whether most primary-aged children would have a sufficiently deep understanding of 'forces' to enable them to answer this question correctly.

One of the tasks that Shayer and Adey used to assess children's current stage of cognitive development was the Volume and Heaviness Test, which includes many of the best-known conservation tasks devised by Piaget and Inhelder (Inhelder and Piaget, 1958). The task is designed to assess children's cognitive development within the late pre-operational to early formal operational range. The task, like all the Science Reasoning Tasks (as they became known), is designed to be performed by teachers at the front of the class while pupils observe the teacher and write their answers to the teacher's scripted questions. As such, pupils' performance on any task is likely to be influenced by a variety of teacher and classroom variables.

Recent work by Shayer *et al.* (2007) suggests that children's performance on this task has shown a marked decline in recent years, and certainly since 1976 when they first started the project. Figure 2 shows the age-corrected mean developmental level for both boys and girls aged 11 years in 1976 and then between 2000 and 2004. The data are reported on a Piagetian scale of 4 = middle concrete, 5 = mature concrete, 6 = concrete generalisation, 7 = early formal.

Figure 2: Mean Piagetian levels seen in boys and girls in 1976 and 2000–04



(From Shayer *et al.*, 2007)

As can be seen, the performance of both boys and girls on the Volume and Heaviness Task has declined over time. Moreover, the advantage that boys showed over girls on the task in 1976 had completely disappeared by 2002. The effect size of this decline is in the region of 1.04 (very large) for boys and 0.55 (modest) for girls (Shayer *et al.*, 2007).

Shayer *et al.* suggest that:

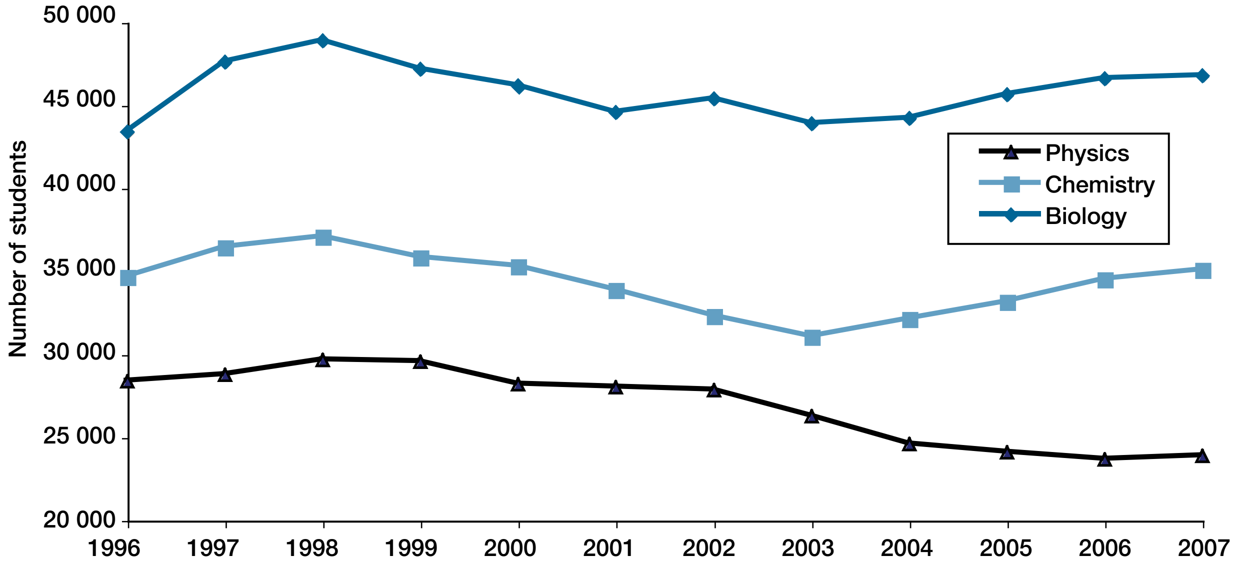
> Perhaps the next major government objective in education should be to address the question: in focusing teachers' attention on the specifics of the 3Rs only, what has been lost from the earlier primary practice of attending to the development of the whole person of the child? (Shayer *et al.,* 2007, p. 38)

How are we to interpret this trend? One interpretation is to agree with Shayer *et al.* and suggest that since the introduction of science as a 'core' subject in the primary National Curriculum, its teaching has become more formal and beyond the developmental level of many pupils. If we add to this what we know about the unease that many primary teachers feel in relation to their ability and confidence to teach science then it is perhaps no surprise if we get rigid, to-the-test, surface-level teaching. However, we must be very cautious given that this is the only source of such evidence and the less than objective way in which the tasks are delivered – they are dependent on the teachers' presentations. But if the cause of the fall in scores is due to less skilled presentations by teachers then that is almost as worrying as lower scores by the pupils. Whatever the cause, the Shayer *et al.* work must not be ignored.

Changes beyond primary schools

The 'swing away from science' can be seen in the declining number of young people opting to pursue science subjects in secondary schools. For instance, the Roberts Review states that between 1991 and 2000 the number of students taking A-level physics fell by 21 per cent (Roberts, 2002). Figure 3 shows the numbers of students between 16 and 18 years of age in schools and further education opting to take A levels in physics, chemistry and biology between 1996 and 2007 (Department for Children, Schools and Families, 2008).

Figure 3: Data for numbers of GCE A-level examination entries in physics, chemistry and biology from 1996 to 2007 in England



(Source: Department for Children, Schools and Families, 2008)

Until quite recently the proportion of pupils taking A-level examinations in science had been in decline. The numbers sitting A levels in biology and chemistry have only begun to increase again since 2003 after showing a general decline since 1998. The numbers sitting physics A levels show a year-on-year decline since 1998 (although numbers seem to have stabilised in 2007). This decline was set against the background of a generally increasing trend in the proportion of students gaining two or more A-level passes (Tymms *et al.*, 2005). However, it should be noted that any interpretation of trends in A-level attainment is complicated by the introduction of Curriculum 2000 reform. This led to the modularisation of A-level courses and subsequently a greater number of pupils taking A-level examinations.

The decline in the proportion and, for physics, the absolute number of students opting for science during the period described has been recognised as a major threat to the future economic prosperity of the UK (Dearing, 1996; Roberts, 2002). The trend would however seem not to be confined to the UK alone but represent at least a pan-European phenomenon (see for example European Commission, 2004; OECD, 2006b). On the same issue, Michael Reiss wrote very recently:

> Good school science education is expensive. It requires specialist teachers, laboratories, equipment, technicians and consumables. Many countries have made a substantial investment in school science, yet there is growing evidence that by the time students get to the age of 15, most of them have been turned off science. (Reiss, 2007)

Many argue that part of the problem lies in the way in which the results of the current assessment procedures in schools in England are used. Published in the performance league tables in the national media, the results of SATs tests are used to hold teachers and schools accountable, which means results represent 'high stakes' and pressurise teachers to teach to the test rather than encourage them to teach for conceptual understanding. This view was underlined by this recent comment in the *New Scientist:*

> None of the correspondents who have rightly been bemoaning the failures of science education in the UK and elsewhere…has mentioned one well-tried alternative. The high point of UK science education was reached in the 1960s, with the Nuffield science project. This emphasised investigation over lists of facts, and understanding rather than rote learning. Then along came the national curriculum with its prescriptive lists. The inevitable consequences were tests, and teachers teaching only what can be tested. Our schools are now being filled with a generation of science teachers themselves taught under this sterile regime. If some genuine science teaching remains, it is in spite of the national curriculum, not because of it. (Holmes, 2008)

On a different but related note it is also worth recording that despite the pass rates in public examinations, published research suggests that few students acquire a proper understanding of the science curriculum (see for example Krnel *et al.*, 1998; Johnson, 2000, 2005; Talanquer, 2006).

Summary

The key points to come out of this review are as follows:

The amount of science in the primary curriculum has increased over time, jumping abruptly in 1989 when the 1988 Education Act came into effect and made science a 'core' subject in the statutory curriculum in state schools. There was also more emphasis on a Piagetian approach to the teaching and learning of science that placed a focus on ways to develop the thinking skills of young children. More recently there has been mounting evidence to suggest that science is being undermined as a 'core' primary subject and the time allocated to it is decreasing.

Further:

1. There is concern about the scientific background of primary teachers and about their perceptions of their capacity to teach science. While these do seem to be improving, this may simply be the result of increased familiarity with science as a 'core' subject.
2. The levels of attainment in some science tests have remained fairly constant although there is evidence of some increase over the last few decades. This increase has been small and may be the result of increased familiarity with tests.
3. There is evidence to suggest that the conceptual understanding of children has decreased to an alarming extent since the 1970s. This evidence comes from Piagetian tests and, if correct, is of serious concern. With only one source of evidence, using data that was less objective than one would hope, there is reason to be cautious. If it is correct then it seems that there are two possible explanations:
    a. One is that the National Curriculum and statutory assessments have restricted the rate of growth of children's scientific insight.
    b. The other is that it may be a consequence of the way that society is evolving. It is conceivable that the lack of opportunities children have for open play, involvement with mechanical objects and nature has decreased. As the child's world becomes more constrained by urban living and man-made items that cannot easily be taken apart and manipulated, so the development of a scientific mindset may decrease.

Whichever interpretation we favour, we are faced with a fundamental problem with the data: we are looking backwards and trying to explain trends, some of which are global and some of which appear to be specific to the UK. All of the relationships that we see are correlational; none has involved deliberate interventions. Despite this we suspect that the current approach in schools is not fostering scientific thought and curiosity to the extent that may be possible. Two of the major problems are league tables of results from Key Stage assessments and a harsh accountability system. These, like it or not, encourage working towards test outcomes and even if the tests themselves are designed to encourage clear thinking, the tactics used by teachers under stress are likely to be at a surface rather than a deep level. We therefore think that there is an argument for a very careful consideration of the approach to science in English primary schools.

Recommendations

Considering the findings of the review as a whole and the future developments of science in primary schools leads us to recommend a four-stage strategy. Initially there needs to be a debate about the purpose of science in primary schools. In the second stage, data and information need to be collated about what is known about primary schools' science. This includes the various approaches to teaching and learning science and scientific thinking in primary schools as well as how the National Curriculum in science relates to children's developmental stages. Thirdly, new well-informed approaches to science in primary schools need to be developed. Finally, the existing and new approaches need to be evaluated using scientific methodology to estimate the extent to which they fulfil the aims that have been established for the programmes. Each of these is taken in turn.

The purpose of science in primary schools

Some might say that science is about a body of knowledge and an established way of investigating, but we suggest that the purpose of science in primary school should be to foster a sense of curiosity and positive attitudes in the young child. It should also guide the child in solving problems to do with the physical, natural and human worlds. This would involve systematic investigations. We do not see science in primary schools as establishing a body of knowledge in the sense that degree courses or GCSEs seek to cover a body of knowledge. Rather science in primary schools should deal with 'Little Ideas' such as: 'Why does ice float on a pond?' (Newton, 1988). We hypothesise that science that aims to cover a body of knowledge, as it is conceived in secondary schools and colleges, can be counterproductive especially when linked to summative testing. We do see assessment as being vital but as feedback to the teacher and to the pupils.

Establishing the evidence base

This comes in three parts:

1. There can be little doubt that there are a number of interesting projects relating to science in primary school running in different parts of the world. We therefore recommend a systematic review of the well-evaluated approaches. This systematic review would start with a search for projects that exist and a look at the ways in which they have been evaluated.
2. We recommend a systematic review of those projects aimed at enhancing scientific thinking. The review should also investigate whether there is an overlap between thinking skills in science with other subject domains or whether scientific thinking is a separate domain.
3. The third part of the review process concerns science in the National Curriculum as it exists at the moment and whether it is suitably matched to the knowledge of children's cognitive development levels. This requires two separate investigations: one of the programmes of study and their application in classrooms (the way science is presented), and the second of the Key Stage 2 tests.

Curriculum development

It is unlikely that the evidence base will lead to a well-defined way forward. There will be a variety of possibilities and we recommend that there be a call for proposals for the development of a primary science curriculum. Promising and very different methods (perhaps three) would be selected. They would have to take cognisance of the systematic reviews and be specific about their aims. They would be well financed and they would run in several schools for two years initially. The two years would be seen as a developmental period and subject to formative evaluation only.

It is worth emphasising that it would be useful to select proposals to reflect a variety of different approaches. Diversity is essential in any healthy educational system: systems must evolve and evolution is dependent on variation.

Without wishing to pre-empt the bids, one can imagine a series of possible approaches. One might specifically focus on encouraging curiosity through directed play. The curriculum could be organised to create wonder and awe in the natural and man-made world. Another might involve links between writing, reading and sciences, as in the Science IDEAS Online project, led by Nancy Romance, Michael Vitale and Jerry Haky.[8] Another might focus on science through its relevance and meaningfulness. Yet another might be to look at the ways in which one solves problems using the concept of variables and the relationships between them in a thinking-skills programme similar to CASE (Adey *et al.*, 1995). And yet another might take the view that what we need to do is to develop those children with an aptitude for science in special ways, perhaps by creating units just for them. Another might be to say that what we need is specialist science teachers in our primary schools. Finally, we think that Newton's (1988) 'Little Ideas' approach could form the basis of a science programme.

There are numerous possible ways forward and the thoughts above simply set out some ideas. It is anticipated that new ideas will come from the proposed research and that great plans will appear following a call for tenders.

Evaluation

At the end of two years of development, the programmes would be investigated summatively using a clustered randomised control trial with the current National Curriculum approach acting as a fourth approach. The programmes would be run over two years and judged against the established aims. This would be followed by clear recommendations for the way forward. These are not envisaged to recommend a single monolithic structure for the primary science curriculum but perhaps two or three different ways of working, with built-in mechanisms to improve and refine each one. As the selected projects grow and develop, it is expected that parts will be found to be working well and parts not so well. This will inform changes as elements are dropped and others added. In order words, the whole venture should become a number of design experiments (Brown, 1992; Cobb *et al.*, 2003; Lobato, 2003). This approach assumes that solutions are not found in a single investigation but rather are approached in an iterative, dynamic process involving randomised controlled trials.

8 See www.scienceideas.org [accessed 29 August 2008].

References

Adey P, Shayer M. Really Raising Standards: Cognitive intervention and academic achievement. London: Routledge; 1994.
Adey P, Shayer M. Cognitive acceleration comes of age. In M Shayer, P Adey (eds). Learning Intelligences. Buckingham: Open University Press; 2002.
Adey PS, Nagy F, Robertson A, Serret N, Wadsworth P. Let's Think Through Science! Windsor: NFER-Nelson; 2003.
Adey PS, Shayer M, Yates C. Thinking Science: Student and teachers' materials for the CASE intervention. 2nd edn. London: Nelson; 2005.
Albone S, Tymms P. The impact of the national numeracy strategy on children's attitudes to mathematics. British Educational Research Association Annual Conference. Manchester: UMIST; 2004.
Alexander RJ. Primary Teaching. London: Holt, Rinehart and Winston; 1984.
Association for Science Education. ASE survey on the effect of the National Literacy Strategy on the teaching of science. Hatfield: Association for Science Education; 1999.
Balls E. Letter to Sir Jim Rose. Department for Children, Schools and Families; 2008.
Beaton AE, Postlethwaite TN, Ross KN, Spearritt D, Wolf RM. The Benefits and Limitations of International Education Achievement Studies. Paris: International Institute for Educational Planning/UNESCO; 1999.
Becker BJ. Gender and science achievement: a re-analysis of studies from two meta-analyses. Journal of Research in Science Teaching 1989;26:141–69.
Black P, Harlen W. How can we specify concepts for primary science? In P Black, AM Lucas (eds). Children's Informal Ideas about Science. London: Routledge; 1993.
Boyle B, Bragg J. No science today – the demise of primary science. Curriculum Journal 2005;16(4):423–37.
Boyle B, Bragg J. A curriculum without foundation. British Educational Research Journal 2006;32(4):569–82.
Boyle B, Lamprianou I, Boyle T. A longitudinal study of teacher change: what makes professional development effective? Report of the second year of the study. Journal of School Effectiveness and School Improvement 2005;16(1):1–27.
Boyle B, While D, Boyle T. A longitudinal study of teacher change: what makes professional development effective? The Curriculum Journal 2004;15(1):45–68.
Breakwell GM, Beardsell S. Gender, parental and peer influences upon science attitudes and activities. Public Understanding of Science 1992;1:183–97.
Brown AL. Design experiments: theoretical and methodological challenges in creating complex interventions in classroom settings. Journal of the Learning Sciences 1992;2(2):141–78.
Brown S. Attitude Goals in Secondary School Science. Stirling: University of Stirling; 1976.
Campbell B. Pupils' perceptions of science education at primary and secondary school. In H Behrendt, H Dahncke, R Duit, W Graeber, M Komorek, A Kross, P Reiska (eds). Research in Science Education – Past, present and future. London: Kluwer Academic Publishers; 2001.
Carré C, Carter D. Primary teachers' self-perceptions concerning implementation of the National Curriculum for science in the UK. International Journal of Science Education 1990;12(4):327–41.
Carré C, Carter D. Primary teachers' self-perceptions concerning implementation of the National Curriculum for science in the UK – revisited. International Journal of Science Education 1993;15(4):457–70.
Central Advisory Council for England. Children and Their Primary Schools. The Plowden Report. London: HMSO; 1967.
Cobb P, Confrey J, diSessa A, Lehrer R, Schauble L. Design experiments in educational research. Educational Researcher (theme issue: The role of design in educational research) 2003;32(1):9–13.
Colley A, Comber C, Hargreaves D. School subject preference of pupils in single sex and co-educational secondary schools. Educational Studies 1994;20:397–86.
Collins S, Reiss M, Stobart G. The Effects of National Testing in Science at KS2 in England and Wales. London: Wellcome Trust; 2008.
Conran J. Primary Science 1950–82: A personal view. In C Richards, D Holford (eds). The Teaching of Primary Science: Policy and practice. London: The Falmer Press; 1983.
Dearing R. Review of qualifications for 16–19 year olds. London: Schools Curriculum and Assessment Authority; 1996.
Department for Children, Schools and Families. GCE/VCE A/AS and equivalent examination results in England, 2006/07 (revised). 2008 9 January. www.dcsf.gov.uk/rsgateway/DB/SFR/s000769/ [accessed 29 August 2008].
Department of Education and Science. Primary Education in England. London: HMSO; 1978.
De Boo M, Randall A (eds). Celebrating a Century of Primary Science. Hatfield: Association for Science Education; 2001.
Department for Education and Skills. Excellence and Enjoyment: A strategy for primary schools. London: HMSO; 2003.
Department for Education and Skills. GCSE and Equivalent Results and Associated Value Added Measures in England 2004/05 (Revised). 2006 18 January. www.dcsf.gov.uk/rsgateway/DB/SFR/s000631/ [accessed 29 August 2008].
Department of Education and Science. Primary Education in England. London: HMSO; 1978.
Dunford J, Fawcett R, Bennett D (eds). School Leadership: National and international perspectives. London: Kogan Page; 2000.
Dunford JE. Her Majesty's Inspectorate of Schools Since 1944: Standard bearers or turbulent priests? London: Woburn Press; 1998.
Epstein JL, McPartland JM. The concept and measurement of the quality of school life. American Educational Research Journal 1976;13(1):15–30.
Erickson G, Erickson, L. Females and science achievement: evidence, explanations and implications. Science Education 1984;68:63–89.
European Commission. Europe Needs More Scientists: Report by the High Level Group on Increasing Human Resources for Science and Technology. Brussels: European Commission; 2004.
Feasey R. Primary science arrives. In M De Boo, A Randall (eds). Celebrating a Century of Primary Science. Hatfield: Association for Science Education; 2001.
Fitz-Gibbon CT. Ofsted, schmofsted. In T Brighouse, B Moon (eds). School Inspection. London: Pitman Publishing; 1995.
Fitz-Gibbon CT. The future of inspection. Education Review 2001;14(2):82–4.
Fox R. Constructivism examined. Oxford Review of Education 2001;27(1):23–35.
Gardner PL. Attitudes to science. Studies in Science Education 1975;2:1–41.
Hall K, Collins J, Benjamin S, Nind M, Sheehy K. SATurated models of pupildom: assessment and inclusion/exclusion. British Educational Research Journal 2004;30(6):801–18.

Harding J. Switched Off: The science education of girls. New York: Longman; 1983.
Harlen W. Science 5–13: A formative evaluation. London: Schools Council Research Studies, Macmillan Education; 1975.
Harlen W. Primary teachers' understanding in science and its impact in the classroom, Research in Science Education 1997;27(3):323–37.
Harlen W. The Assessment of Performance Unit: extracts from the results of the APU surveys of children at age 11. In M De Boo, A Randall (eds). Celebrating a Century of Primary Science. Hatfield: Association for Science Education; 2001.
Harlen W. The Quality of Learning: Assessment alternatives for primary education (Primary Research Review Survey 3/4). Cambridge: University of Cambridge Faculty of Education; 2007.
Harlen W, Holroyd C, Byrne M. Confidence and understanding in teaching science and technology in primary schools. Edinburgh: Scottish Council for Research in Education; 1995.
Harvey TJ, Edwards P. Children's expectations and realisations of science. British Journal of Educational Psychology 1980;50:74–6.
Haworth C, Dale P, Plomin R. A twin study into the genetic and environmental influences on academic performance in science in nine-year-old boys and girls. International Journal of Science Education 2008;30(8):1003–25.
Holmes N. Skills supply. New Scientist 2008;2649:20.
Howe C, Tolmie A, Thurston A, Topping K, Christie D, Livingston K, Jessiman E, Donaldson C. Group work in elementary science: towards organisational principles for supporting pupil learning. Learning and Instruction 2007;17:549–63.
Inhelder B, Piaget J. The Growth of Logical Thinking from Childhood to Adolescence. London: Routledge & Kegan Paul; 1958.
Institute of Electrical Engineers. Views of science among students, teachers and parents. In Osborne *et al.* (1998).
Jenkins EW, Swinnerton BJ. Junior School Science Education in England and Wales Since 1900: From steps to stages. London: Woburn Press; 1998.
Johnson P. Children's understanding of substances, part 1: recognizing chemical change. International Journal of Science Education 2000;22(7):719–37.
Johnson P. The development of children's concept of a substance: a longitudinal study of interaction between curriculum and learning. Research in Science Education 2005;35(1):41–61.
Johnson S. Gender differences in science: parallels in interest, experience and performance. International Journal of Science Education 1987;9:467–81.
Jones G, Howe A, Rua M. Gender differences in students' experiences, interests, and attitudes towards science and scientists. Science Education 2000;84:180–92.
Kahle JB, Lakes MK. The myth of equality in science classrooms. Journal of Research in Science Teaching 1983;20:131–40.
Kelly A, Whyte J, Smail B. Girls into Science and Technology: Final report. Manchester: Department of Sociology, University of Manchester; 1984.
Keys W. Aspects of Science Education in English Schools. International Studies in Pupil Performance Series. Windsor: NFER-Nelson; 1987.
Keys W, Harris S, Fernandes C. Third International Mathematics and Science Study: First national report part 1. Slough: NFER-Nelson; 1997.
Krnel D, Watson R, Glazar SA. Survey of research related to the development of the concept of 'matter'. International Journal of Science Education 1998;20(3):257–89.
Lobato J. How design experiments can inform a rethinking of transfer and vice versa. Educational Researcher (theme issue: The role of design in educational research) 2003;32(1):17–20.
Maloney J. Children's roles and use of evidence in science: an analysis of decision-making in small groups. British Educational Research Journal 2007;33(3):371–401.
Martin MO, Mullis IVS, Beaton AE, Gonzalez EJ, Smith TA, Kelly DL. Science Achievement in the Primary School Years. IEA's Third International Mathematics and Science Study (TIMSS). Washington, DC: National Science Foundation/Arlington, VA., National Center for Education Statistics; 1997.
Martin MO, Mullis IVS, Gonzalez EJ, Chrostowski SJ. TIMSS 2003 International Science Report: Findings from IEA's Trends in International Mathematics and Science Study at the fourth and eighth grades. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College; 2004.
Massey A, Green S, Dexter T, Hammet L. Comparability of national tests over time: KS1, KS2 and KS3 standards between 1996 and 2001. Final feport to QCA of the Comparability over Time Project. Cambridge: Research and Evaluation Division of the University of Cambridge Local Examinations Syndicate; 2003.
Mercer N, Dawes L, Wegerif R, Sams C. Reasoning as a scientist: ways of helping children to use language to learn science. British Educational Research Journal 2004;30(3):359–77.
Morrell PD, Lederman NG. Students' attitudes toward school and classroom science: are they independent phenomena? School Science and Mathematics 1998;98(2):76–83.
Murphy C, Beggs J. Pupils' attitudes, perceptions and understanding of primary science: comparisons between Northern Irish and English schools. Paper presented at the annual conference of the British Educational Research Association, Leeds, 2001.
Murphy C, Beggs J. Children's attitudes towards school science. School Science Review 2003;84(308):109–16.
Murphy C, Beggs J. Primary Science in the UK: A scoping study. London: Wellcome Trust; 2005.
Murphy C, Beggs J, Hickey I, O'Meara J, Sweeney J. National Curriculum: compulsory school science – is it improving scientific literacy? Educational Research 2001;43(2):189–99.
Murphy C, Beggs J, Carlisle K, Greenwood J. Students as 'catalysts' in the classroom: the impact of co-teaching between science student teachers and primary classroom teachers on children's enjoyment and learning of science. International Journal of Science Education 2004;26(8):1023–35.
Murphy C, Neil P, Beggs J. Primary science teacher confidence revisited: ten years on. Educational Research 2007;49(4):415–30.
Myers RE, Fouts JT. A cluster analysis of high school science classroom environments and attitude toward science. Journal of Research in Science Teaching 1992;29:929–37.
National Curriculum Task Group on Assessment and Testing. A Report. London: Department of Education and Science; 1998.
Newton DP. Making Science Education Relevant. London: Kogan Page; 1998.
Newton DP. Children doing science: observation, investigation and the National Curriculum for England and Wales. In LD Newton (1992).
Newton LD (ed.). Primary Science: The challenge of the 1990s. London: Multilingual Matters Ltd; 1992.

National Curriculum Task Group on Assessment and Testing. A Report. London: Department of Education and Science; 1998.
National Union of Teachers. Primary Issues: Our great expectations. London: NUT; 1992.
Organisation for Economic Co-operation and Development [2006a]. PISA 2006: Science competencies for tomorrow's world volume 1: Analysis. Paris: OECD; 2006.
Organisation for Economic Co-operation and Development [2006b]. Evolution of Student Interest in Science and Technology Studies Policy Report. Paris: OECD; 2006.
Osborne J, Dillon J. Science Education in Europe: Critical reflections. London: King's College London; 2008.
Osborne J, Driver R, Simon S. Attitudes to science: issues and concerns. School Science Review 1998;79(288):27–33.
Osborne J, Simon S. Primary science: past and future directions. Studies in Science Education 1996;27:99–147.
Osborne J, Simon S, Collins S. Attitudes towards science: a review of the literature and its implications. International Journal of Science Education 2003;25(9):1049–79.
Parker-Jelly S. Science 5–13: Reflections on its significance. In C Richards, D Holford (eds). The Teaching of Primary Science: Policy and practice. London: The Falmer Press; 1983,
Pell A, Jarvis T. Developing attitude to science scales for use with children of ages from five to eleven years. International Journal of Science Education 2001;23:847–62.
Piburn MD, Baker D. If I were the teacher... qualitative study of attitude toward science. Science Education 1993;77:393–406.
Pollard A. Playing the system? Pupil perspectives on curriculum, pedagogy and assessment in primary schools. In P Croll (ed.). Teachers, Pupils and Primary Schooling: Continuity and change. London: Cassell; 1996.
Ponchaud B. Primary Science: Where next? Surrey: Association for Science Education; 2001.
Postlethwaite TN, Wiley DE. The IEA Study of Science II: Science achievement in twenty-three countries. Oxford: Pergamon; 1992.
Reay Y, Wiliam D. 'I'll be a nothing': structure, agency and the construction of identity through assessment. British Educational Research Journal 1999;25(3):343–54.
Reiss M. Bottom of the science class. New Scientist 2007 1 December;2632:36–7.
Richardson V. From behaviourism to constructivism in teacher education. Teacher Education and Special Education 1996;19(3):263–71.
Ritchie R. Science in the National Curriculum. In D Coulby, S Ward (eds). The Primary Core National Curriculum: Policy into practice. London: Cassell; 1996.
Roberts G. SET for Success: The supply of people with science, technology, engineering and mathematics skills. Final Report of Sir Gareth Roberts' Review. London: HM Treasury; 2002.
Robertson IJ. Girls and boys and practical science. International Journal of Science Education 1987;9:505–18.
Ruddock G, Sturman L, Schagen I, Styles B, Gnaldi M, Vappula H. Where England Stands in the Trends in International Mathematics and Science Study (TIMSS) 2003. National Report for England. Slough: NFER-Nelson; 2004.
Russell T (ed.). Science at Age 11: A review of the APU survey findings 1980–84. London: HMSO; 1988.
Sainsbury M, Schagen I. Attitudes to reading at ages nine and eleven. Journal of Research in Reading 2004;27(4):373–86.
Schibeci RA. Attitudes to science: an update. Studies in Science Education 1984;11:26–59.
Shayer M, Adey P. Towards a Science of Science Teaching: Cognitive development and curriculum demand. London: Heinemann Educational Books; 1981.
Shayer M, Adey P (eds). Learning Intelligences: Cognitive acceleration across the curriculum from 5 to 15 years. Buckingham: Open University Press; 2002.
Shayer M, Ginsburg D, Coe R. Thirty years on a large anti-Flynn effect? The Piagetian test volume heaviness norms 1975–2003. British Journal of Educational Psychology 2007;77:25–41.
Shorrocks-Taylor D, Jenkins E, Curry J, Swinnerton B, Laws P, Hargreaves M, Nelson N. An Investigation of the Performance of English Pupils in the Third International Mathematics and Science Study (TIMSS). Leeds: Assessment and Evaluation Unit; 1998.
Sjøberg S. Interesting all children in 'science for all'. In R Millar, J Leach, JF Osborne (eds). Improving Science Education. Buckingham: Open University Press; 2000.
Smail B, Kelly A. Sex differences in science and technology among 11 year old schoolchildren: II – affective. Research in Science & Technology Education 1984;2:87–106.
Smith R, Peacock G. Tackling contradictions in teachers' understanding of gravity and air resistance. In LD Newton (1992).
Statistics Commission. Measuring Standards in English Primary Schools: Report by the Statistics Commission on an article by Peter Tymms. London: Statistics Commission; 2005.
Summers M, Kruger C. Research into English primary teachers' understanding of the concept of 'energy'. In LD Newton (1992).
Talanquer V. Commonsense chemistry: a model for understanding students' alternative conceptions. Journal of Chemical Education 2006;83(5):811.
Tymms P. Are standards rising in English primary schools? British Educational Research Journal 2004;30(4):477–94.
Tymms P, Coe R, Merrell C. Standards in English Schools: Changes since 1997 and the impact of government policies and initiatives. A report for the Sunday Times. Durham: University of Durham; 2005.
Tymms P, Fitz-Gibbon CT. Standards, achievement and educational performance: a cause for celebration? In J Phillips, J Furlong (eds). Education, Reform and the State. London: Routledge Falmer; 2001.
Tymms P, Gallacher S. Primary science: an exploration of differential classroom success. Research in Science and Technological Education 1995;13(2):155–62.
Wastnedge R. A revolutionary project: the Nuffield Junior Science Teaching Project, 1964–1966. In M de Boo, A Randall (eds). Celebrating a Century of Primary Science. Hatfield: Association for Science Education; 2001.
Webb P. Primary science teachers' understandings of electric current. International Journal of Science Education 1992;14:423–9.
Weinburgh M. Gender differences in student attitudes toward science: a meta-analysis of the literature from 1970 to 1991. Journal of Research in Science Teaching 1995;32(4):387–98.
Whetton C, Ruddock G, Twist E. Standards in English Primary Education: The international evidence (Primary Review Research Survey 4/2). Cambridge: University of Cambridge Faculty of Education; 2007.
Whyte J. Girls Into Science and Technology. London: Routledge Education Books; 1986.
Winter S. International comparisons of student achievement. Education 3–13 1998;26(2):26–33.
Woodward C, Woodward N. Girls and science: does a core curriculum in primary school give cause for optimism? Gender and Education 1998;10:387–400.
Wragg EC, Bennett SN, Carré CG. Primary teachers and the National Curriculum. Research Papers in Education 1989;43(3):17–37.

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Next issue

Perspectives on Education: Primary–Secondary Transfer

The next issue in the 'Perspectives on Education' series will look at the dips in interest, enthusiasm and attainment often associated with the transfer from primary to secondary school, their particular relevance to science education, and what improvements can and are being made to better support students through this transition.

The authors will be **Anne Diack** from the Innovation Unit and **Keith Topping** from the University of Dundee.

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