



Science education in schools

Issues, evidence and proposals

A Commentary by the Teaching and Learning Research Programme





The future of the United Kingdom lies in knowledge. But our ability to generate new knowledge and use it innovatively depends upon having a scientifically literate population. And although people learn throughout their lives, good science education in schools is a vital preparation for scientific literacy in later life. But despite its importance, science education in schools is threatened from a number of directions, not least by a shortage of well-qualified science teachers.

This Report, the third Commentary from the Teaching and Learning Research Programme, is published during National Science Week 2006 to set out what we know about improving science education in schools. It points to research evidence on key factors such as the recruitment, development and retention of science teachers, the communication of key scientific ideas, the use of assessment to help learning, and the value of science learning outside school. It makes solid, evidence-informed proposals for improving UK science education.

As with other policy-relevant subjects across the social sciences, education is a field in which research-informed evidence can illuminate important national concerns.

A research-based approach to enhancing science education will help to produce more scientific specialists at all levels, for a society that needs technicians as well as world-class researchers. Perhaps more importantly, it will increase the public's ability to engage with scientific knowledge and scientific choices, whether the subject be choosing a healthy diet or thinking about the UK's energy future.

I would like to thank the task group that wrote this report, especially its convenor, Professor John Gilbert of the University of Reading, for their prompt work in its production. I am especially pleased that this Commentary is a joint venture with the Association for Science Education and that Dr Derek Bell, chief executive of the ASE, was able to join the task group.

We would welcome your response to this report via the TLRP's web site, www.tlrp.org

Professor Ian Diamond FBA AcSS
Chief Executive
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The challenge of strengthening science education

There is widespread concern about the outcomes of science education at school. For example, the representatives of industry say that they need more high-grade scientists, technicians, and engineers if the UK is to compete successfully in technology-intensive global markets. Whatever their career intentions, too few young people do much science at school once it ceases to be compulsory. This leads to fewer applications for science degrees and reduces the supply of science graduates. Just as importantly, the number of young people entering non-graduate occupations involving science or technology is reduced, which leads to skills shortages in many sectors.

The Review undertaken by Sir Gareth Roberts in 2002¹ summarised the scale of this problem. It also identified some of its causes. In particular it noted the lack of women choosing to study science-related subjects, reports by students of their poor experience of science education, the shortage of well-qualified and enthusiastic science teachers, and young people's poor image of science-related careers. The Roberts Report led to the government's ten-year 'Science and Innovation Investment Framework 2004-2014'⁶¹.

Yet while the strategy makes some useful references to teacher supply and curriculum issues, it offers little guidance on how its ambitious aims are to be achieved. This TLRP Commentary has been produced four years after the Roberts Review. It reflects concern that whilst some progress has been made, the pace of educational change has been too slow.

This report shows how insights from research and scholarship on secondary school science education can inform our approach to these problems in terms of both policy and practice. The majority of science education research conducted to date has addressed secondary schooling, although research into primary school science identifies similar issues and is referred to where available. We have not reviewed evidence on higher education, recognising that it raises different issues from those that arise at school level.

The Commentary draws on the extensive body of research available and:

- Identifies the broad purposes of science education for all students at secondary school level in the early 21st century, drawing upon academic analysis and scholarship
- Reviews research evidence about current challenges to the provision and attainment of high quality science education
- Considers what actions have been or may be taken on the basis of that evidence
- Proposes research and development that still needs to be done
- Considers how that research and development may take place

The 'Beyond 2000' report⁶⁰ suggested that we need 'science education for citizenship'. It would be designed to develop the curiosity of young people about the natural world around them, and help them acquire a broad appreciation of the important ideas and explanatory frameworks of science and how scientific enquiry works.

The processes and ideas of science are of great importance to everybody in three ways. The first is in their personal lives, for example so that they can validly identify the components of a healthy life-style. The second is in their civic lives, so that they take an informed part in social decisions, for example on future options for electricity supply. The third is in their economic lives, where they need to be able to respond positively to changes in the science-related aspects of their employment.

If the major purpose of science education is to increase the flow of specialist scientists, technologists and engineers, it could be argued that young people with a special talent in science should be identified as early as possible and provided with a separate, specialised, and highly focused science education. We do not agree. Such people share the general need for a broad science education and should not be cut off from it. In any case, there are no valid and reliable ways in which such young people may be identified. Some who show early



promise subsequently fade, whilst the talents of others emerge later on. Young people today show an appetite for a broadly-based education based on themes of proven interest, and developing a range of transferable skills. They would resist any attempt to foreclose their choices.

We believe that the best way forward is to provide the highest grade of 'science education for citizenship' for all students⁶⁰. If that education is sufficiently challenging and interesting, genuine high achievement will become more widespread and will become apparent through students' creativity, lateral thinking, and persistence. The young people who demonstrate such achievement will be increasingly motivated to follow science-related careers.

What analysis and evidence are available to help promote high quality science education for all future citizens? There must be a greater recognition of what students bring to their studies and how different teaching methods engage with their learning. The diversity in students' learning strategies must be met by the use of suitable teaching methods. The curriculum must be closely matched to the purposes of 'science education for citizenship'. The assessment of what has been learned must be closely matched to the purposes of that curriculum. And, central to all of these aims, the supply, development, and retention of high quality teachers must be actively pursued.

For each of these issues, this Commentary identifies the problems which must be solved if high quality 'science education for citizenship' is to take place, what research has to say about each of these concerns, what actions have been or can be taken on the basis of that research, and what research and development now need to be done.





The background to a strengthened science education

Students bring the legacy of their cultural backgrounds to their studies. They have all experienced science learning outside the classroom and can form and express their own views. This means that they have their own attitudes towards science education and attention must be paid to them.

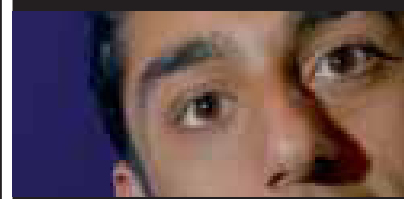
There can be substantial discontinuities between what young people experience in their school science lessons and in the rest of their lives. Aikenhead² has argued that school science expects young people to cross this border, which is more forbidding for some students than for others. Schreiner³ has explored the way in which student attitudes towards science can be seen as expressions of their identity, whilst Reiss⁴ concluded that school science education can only succeed when students believe that the science they are being taught is of personal worth to themselves.

Unless school science explicitly engages with the enthusiasms and concerns of the many groupings that make up today's students, it will lose their interest. Accordingly, it needs to grapple with how it can respond positively to the wide diversity of student concerns. It must think how to better address women, those who hold strong religious views, those who have little cultural capital, and those whose current or recent roots lie outside Western societies. All too little is known systematically about these issues.

A conundrum for science educators is that school students are being turned off school science lessons, yet the same students are often engaged by science outside the classroom. Science in science museums, hands-on centres, zoos and botanical gardens is often seen as exciting, challenging and uplifting. Newspapers and magazines offer rich sources of science information including debates about controversial current issues. Multi-channel television and the internet have spawned sources of high-quality and attractively packaged information about science and issues of relevance to young people⁵. We are also living in a golden age of popular science book publishing, with a wealth of high-quality science books for children as well as adults.

Students of school age spend about two-thirds of their waking lives outside formal schooling. Yet science educators tend to ignore the crucial influences that experiences outside school have on students' beliefs, attitudes and motivation to learn. They often see these influences only as a source of misconceptions.

Out-of-classroom contexts can add to and improve the learning of science in several ways⁶. They can promote the understanding and integration of science concepts. Falk and Dierking⁷ have reviewed studies that show that science museum visits can lead to improved understanding of such classic school science concepts as force and motion, an improvement measured by tests of knowledge before and after visits. They are also an opportunity to engage in science activities that would not be possible in the school laboratory either because of safety considerations or because they are too complex. Examples include launching rockets, performing ecological surveys, observing the night sky, and large scale experiments with combustion. How these activities contribute to students' knowledge of the processes of science is still not clear. And they can provide access to rare material and to 'big' science. Science museums, botanic gardens, zoos and science industries provide opportunities for students to see yesterday's and today's science in use. Artifacts and collections, and the stories associated with them, help teach about the ways in which scientific and technological knowledge has been generated and about the social enterprise in which those who engage in this work operate. Here too, the exact contribution to school science is unclear. Such activities also provide opportunities for science activities which are less constrained by school bells and lesson times. Work can be more extensive and there are more opportunities for students to take responsibility for themselves and others, to work in teams and to consider their effects on the environment.



But there is more to using out-of-school settings to enrich formal science education than taking students on a day trip. The resource has to be evaluated by the teacher in advance and the students must be prepared for the activity they are to undertake. The activity must be purposeful and produce a record, and the work must be followed up later in the classroom. Other important issues that must be addressed include health and safety risk assessments in all cases and in many instances, travel arrangements and staffing levels⁶. The extra effort required to meet these conditions can be considerable and can discourage the use of these opportunities.

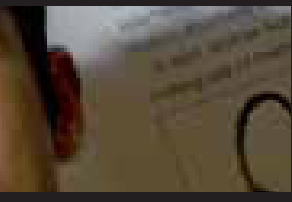
Although out-of-classroom contexts are valuable for learning in science⁸, there is much about them that is under-researched^{9,10}. Further research is needed into the long-term impacts of out-of-classroom learning in science and attitudes to science; how the formal and informal learning sectors can complement one another to maximise their joint contribution to students' learning in science; how out-of-classroom contexts can engage with the full range of students of school age; how school grounds can be used to improve learning in all the sciences, not just ecology; and the particular worth of residential activities.

What students bring to the science classroom, whether from their cultural background or from out-of-school experience, is reflected in their inclination to form and express their own opinions. The notion of 'student voice' emphasises students as active participants in education. Its relevance for science education has been comprehensively reviewed by Jenkins¹¹. He points out that the UN Convention on Children's Rights requires that children be consulted on matters that directly concern them. A recent major TLRP project, Consulting Pupils about Teaching and Learning⁶³, carried this perspective forward. Students' views exhibit diversity, not least between genders, but have provided some indication of the kinds of subject matter which might increase enthusiasm for school science. Students also express definite views on teaching methods, with a dislike of 'writing' and an enthusiasm for practical work, especially where they have some real input into its design and interpretation. Jenkins advises caution in interpreting and generalising across these findings, but argues strongly that students' views are valid and should be explored more completely.

Many influences affect the attitudes to science that students develop. Research on attitudes towards school science shows that they become less positive from age 11 to 16¹². Evidence gathered both from focus group studies¹³ and surveys suggests that children are interested in school science^{14,15} but are less interested in science than in other subjects. This trend is not unique to the UK. It is common to all education systems in the developed world including Japan. Thus, whilst UK students perform well on the OECD PISA (Programme for International Student Assessment) tests, coming fourth after Korea, Japan and Finland in 2000, their attitudes towards science, one of the four elements of PISA from 2003, are a cause for concern. More recent evidence suggests that, in England at least, this decline is now beginning in the final year of primary school and that the prime cause is the overemphasis on revision for the KS2 Standard Assessment Tasks (SATs),¹⁶ which place too much emphasis on recall.

Research suggests that the main factor determining attitudes towards school science is the quality of the educational experience provided by the teacher^{12,17}. Part of the explanation for student attitudes toward school science may be a shortage of well-qualified science teachers capable of providing a positive experience. Moreover, many science teachers are required to teach sciences outside their own specialism. This undermines their confidence, leading them to offer a significantly more closed and less stimulating experience¹⁸.

More insights into the nature of the problem come from a recent extensive focus group study¹³. Students complained that school science consisted of too much repetition and too much copying and note taking. They felt that they had been frogmarched across the scientific landscape with no time to discuss any of the ideas or their implications. In addition, the gulf between science as it is taught and science as portrayed in the media made the relevance of school science questionable.



Science is unique among school subjects in that its curriculum aims to create future scientists rather than the future citizen. This produces a foundation curriculum whose coherence only becomes clear for those who stay the distance, and with it the value and meaning of the subject. Moreover, it is dominated by an assessment system whose predominant demand is low-level cognitive recall. Such a system promotes “performance learning,” which is extrinsically motivated, rather than “mastery learning,” which concentrates on the student, to the detriment of student engagement¹⁹. Those who drop by the wayside are left with a few disjointed pieces of knowledge whose salience is difficult to comprehend.

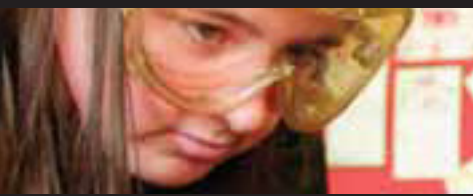
Learning and teaching methods, the curriculum, and assessment, are all highly influential in the formation of student attitudes towards science, as is the quality of the teaching that they experience.

Learning and teaching science

There is now a significant body of knowledge about teaching and learning science. It has been developed through scholarship and empirical studies conducted in many countries around the world. All teachers know that what is taught by teachers is not the same as what is learnt by pupils. As in all acts of communication, learners have to make sense of what they hear, see and read in terms of what they already know. Teachers can make this easier or more difficult for pupils by the way that messages are put together, and the way that pupils’ questions are elicited and answered¹⁹.

This fundamental insight, that learning involves individuals in actively responding to information and its situation, has been developed into several theoretical perspectives which have been used to inform the planning of science teaching. A recent example involves the design and evaluation of short science teaching sequences in the early years of secondary education²⁰. Drawing upon a social constructivist perspective on learning, insights about the treatment of content and patterns of teacher talk were built in to the design of such sequences. Evaluation evidence shows that students’ understanding was significantly better when they followed these teaching sequences than it would have been had they followed their school’s usual teaching programmes.

There is very strong empirical evidence that some of the fundamental concepts on which scientific understanding is built are commonly misunderstood by learners, and that there are patterns in the difficulties that they experience. For example, when first encountering explanations of the behaviour of simple electrical circuits consisting of components connected in series, many learners use a source-consumer model inappropriately, with the result that they can’t accept that the current is the same at any point in the circuit²¹. Several ways of addressing this difficulty have been designed and evaluated, with positive results²⁰. Evidence of this kind is useful in identifying key conceptual difficulties that are likely to be experienced by students at specific points in the science curriculum. Usable tools for addressing those difficulties can be developed. The insights that come from the research do not lead to simple prescriptions of ‘what works’ and what science teachers should therefore be made to do. But research can inform science teachers as they plan how to tackle difficult content in a way that their students understand, and can help guide their conversations with pupils during teaching. There are now materials available for teachers, informed by research evidence, to support them in teaching some of these difficult areas²⁰ – and there is an exciting future agenda in developing and evaluating research evidence-informed approaches to teaching other parts of the science curriculum.



Significant work has also been conducted on the ways in which classroom communication, and particularly talk, can be used to support pupils in coming to understand scientific content^{22,23,24}. This evidence shows how teachers can use different patterns of talk for different teaching purposes. It can be used while working with individuals, small groups or whole classes, and can help achieve aims such as introducing new ideas or supporting learners to use newly-introduced content for themselves.

For teaching to be effective in promoting learning, it must involve interaction between teachers and students. One-way delivery from a teacher does not work for the vast majority of pupils. Assessment for learning (a developed form of formative assessment) is a key element of this interaction. A comprehensive review of the research literature has shown that there is very clear evidence that formative assessment leads to significant improvements in students' test scores, i.e. their attainment as measured by summative assessment²⁵. In the past, science teachers in particular have been discouraged from adopting this approach to assessment.

Formative assessment has been explored and developed with teachers who tried various approaches as part of their normal classroom work²⁶. A two-year programme showed that teachers found it improved their teaching and raised students' test scores. Similar innovations have been the basis of a development programme for the Ministry of Education in Scotland²⁷ and of national programmes of study in science in England for Key Stage 3 and at primary level.

These developments have involved four main changes. The first has been in classroom dialogue. If teachers are to communicate effectively with students, they must set up activities and questions that help students to formulate and express their own ideas and then listen to what students say. On the basis of this assessment, teachers must fashion the next steps, challenging students and leading them towards ideas which will be more fruitful. Such two-way interaction can happen several times during a lesson as learning progresses. A crucial aspect of such dialogue-based teaching is to give students a voice, and help them realise that their teacher wants to know what they think, so that they will feel free to express even half-formed or confused ideas.

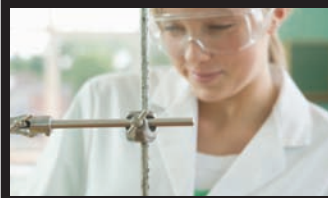
A second change requires interactive feedback on written work. Teachers have to annotate students' work with comments designed to guide them in making improvements, and then provide opportunities for them to use this guidance. Students then come to see their work as a step in improving their learning. Existing practices emphasise marks, so that pupils see the exercise merely as a test.

A third change is to involve students in working in small groups to assess each other's work. The point here is not to trust students with generating marks, but to help them help each other so that they are better able to understand the aims of their work and the criteria by which its quality may be judged. Self-assessment is essential if students are to carry on being effective learners in their adult lives.

The fourth change makes use of the formal tests that teachers regularly apply to add extra value to learning. Students may learn from trying to design test questions or from marking test papers in groups so that they can be more objective and realistic in appraising their own performance and in understanding how tests are marked. Working in this way has led students to become more active participants in their learning and to become more motivated to take it seriously.

The implementation of 'assessment for learning' has used particularly careful strategy in Scotland. It started with the selection of about 10 schools distributed across the country to carry out a pilot programme, on the basis of a project at King's College London and with the help of staff from King's. At the close of the two-year project, a group from another university department conducted an independent evaluation. As this revealed very positive outcomes, a large programme of implementation across all local government districts in Scotland was then mounted. Details can be found on the web-site of Learning and Teaching Scotland²⁹.

The learning and teaching that takes place is framed by the curriculum being addressed and it is to this that we now turn.

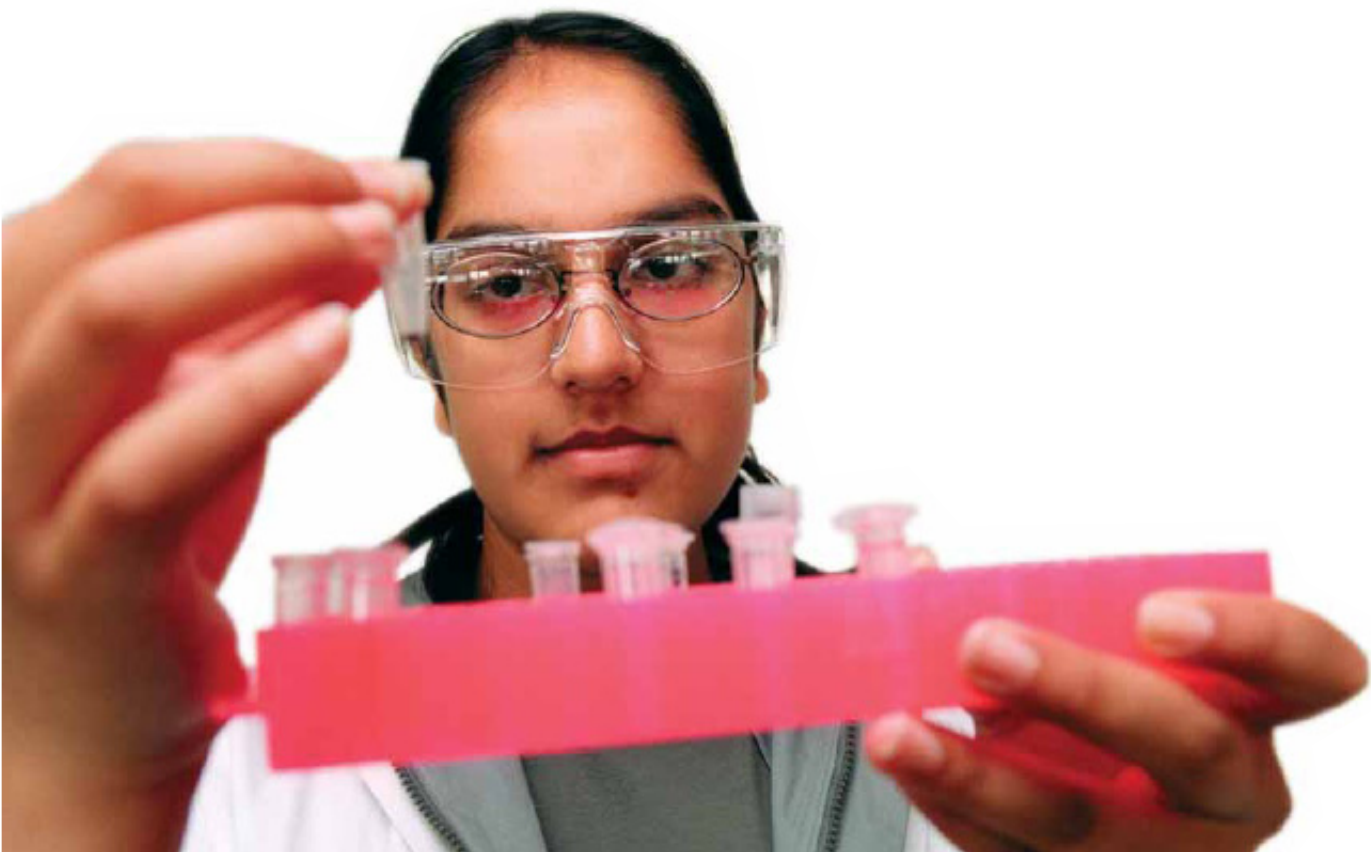


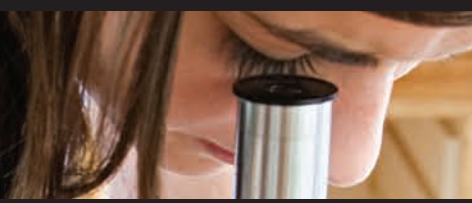
Curriculum content and structure

The science curriculum at any level is a statement about the elements of science we choose to teach, selected from a much larger set of possibilities. These choices, for example about the purpose of education, about what is of most value to individuals and to society, and about the balance between intrinsic and instrumental reasons for learning, all embody values. Empirical evidence may inform these choices, but it cannot determine them. Important insights, for example into the nature of scientific knowledge and its implications for learning, have come from scholarship and analysis. Research on the curriculum should include more such work.

Science educators have realised that major trends in 20th century scholarship on science itself, in particular the work of Popper and Kuhn, are important for science education. But much science teaching seems not to have absorbed this lesson. Some writing on science education has acknowledged that there is a tension between inducing students into a structure of agreed and essentially impersonal knowledge and the personal and social values associated with education and schooling. But this insight has been sporadic and has not influenced teaching significantly.

Changes in the UK science curriculum since the 1960s have largely reflected a growing acceptance that science is a subject for all students up to age 16 rather than one chosen by a minority as a preparation for more advanced study. Research and scholarship have made important contributions to exploring the limitations of such trends and enthusiasms as 'guided discovery learning', and 'process science'. The worldwide growth in interest in STS (Science Technology Society) approaches in the 1980s reflected continuing concerns about students' engagement with science. A review of the research³⁰ suggests that context-led courses lead to greater student interest, a greater appreciation of the relevance of learning to everyday life, and no measurable decrease in student understanding of science content. The evidence that this approach results in an increased uptake of more advanced courses is less strong.





More recent analyses have focused on the tension within the science curriculum between enhancing all students' scientific literacy and providing a foundation for more advanced study. Rather different approaches, it is argued, are needed to do each of these effectively. Emerging evidence from the *Twenty First Century Science* pilot (and from an evaluation of *AS Science for Public Understanding*³¹) suggests that clearer links between school science and science as it is encountered out of school lead to greater student interest and involvement. It also suggests that teachers can be supported to manage the changes in pedagogy required by an increased emphasis on dialogue and discussion in class.

Practical work is a distinctive feature of science education. External stakeholders often regard it as critical to improved student attitudes to science and to the uptake of more advanced science courses. Research evidence consistently shows that students like practical activity in class, often contrasting it with 'writing,' which is unpopular. There is, however, less evidence of the effectiveness of small-group practical work, as currently used, in promoting learning. One factor may be the very wide – but often unrecognised – variation in intended learning outcomes and in the cognitive demands of different practical tasks³².

The growing international interest in scientific literacy as a curriculum aim has increased recognition of the centrally important role of text. Norris and Phillips³³ argue that science depends on written forms of communication, so that text is a component of scientific practice just as empirical enquiry is, and that the ability to analyse and present an argument based on data is an important, though currently under-emphasised, goal of the science curriculum. The same can be said of mathematics, although there has been little research work specifically linking science and mathematics in recent years.

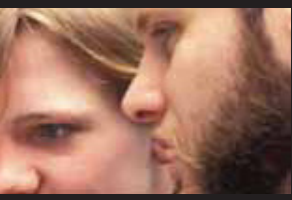
Summative assessment

At intervals during, and especially at the end of, a science curriculum, summative assessment takes place in order to evaluate what has been learnt and to provide guidance on future choices.

Summative assessment has a strong influence on the curriculum and on classroom teaching and learning. Students experience summative assessment conducted by teachers for internal school purposes, and in external tests, such as National Curriculum tests and Certificate examinations. These external assessments have much greater impact than internal ones because of the high stakes attached to the results and because of their influence on teachers' own assessments. There is ample evidence that internal assessment tends to mimic external summative assessment.

Research into current summative assessments has exposed many serious problems^{26,62}. They include the excessive burden of assessment procedures and their failure to assess the full range of skills and competencies that should be the goals of science education. This applies not just to students aged 14-19 but at all levels. Current assessment methods narrow students' learning experiences, in sharp contrast to the broad view of learning goals endorsed in many government documents.

The preference for tests for summative assessment is underpinned by the common assumption that they provide reliable data. However, there is evidence^{25,34} that around 30 per cent of students are given incorrect grades or levels by external tests and examinations. These incorrect grades may lead to wrong decisions that affect student progress within and beyond school. Furthermore, the internal tests that teachers devise for practice for the external tests, or to give end of year grades, are frequently of low quality and dubious reliability. And the impact of frequent testing extends beyond the consequences of inaccurate results. For many students



it reduces the motivation for learning³⁵. The self-esteem of low achieving students is particularly affected, reducing their willingness to put effort into their learning and increasing the gap between higher and lower achieving students.

An additional serious problem with external summative assessment results from its use as important data for evaluation of the performance of teachers and schools. The resulting pressure drives teachers to an over-use of transmission teaching and highly structured activities, in contrast with what is needed for students to enjoy and be motivated to learn science.

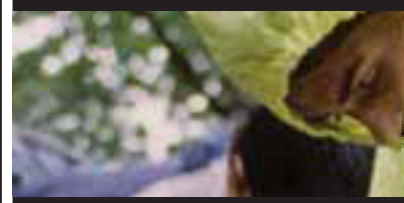
Despite this evidence, assessment policy, in England at least, has been driven by an assumption that testing drives up standards. There is no convincing evidence for this belief. Indeed, research points to the contrary. Increased scores on tests which students have been trained to pass, rather than being used to develop understanding, do not indicate better standards of learning. And over time, even these scores cease to rise year on year³⁶.

Development and research are needed to find alternative ways of providing information about students' learning. Such new methods should be demonstrably fair, should be conducted through transparent procedures, should encourage learning beyond formal education and informed citizenship, and should be compatible with the use of assessment to help learning. There is evidence that greater use of teachers' judgements in summative assessment³⁷ could allow it to cover the full range of student learning goals and improve its reliability. However, such improvement would have to be based on appropriate professional training for teachers, and on the identification of criteria that indicate progress in students' learning of the key aspects of the subject. There is also a need for further research and development on how teachers can combine formative and summative assessment.

The supply, development and retention of high quality science teachers

The teacher is the single most important source of variation in the quality of learning³⁸. The supply, development, and retention of good science teachers is therefore of paramount importance.

Research on teacher supply has tended to focus on how to attract potential applicants, and thus on their intentions and judgments. Undergraduates have been the main target, perhaps because potential mature entrants are more difficult to reach^{39,40,41,42}. Studies show that the proportion of undergraduates willing to consider teaching seriously has broadly declined over the last decade. Despite this decline, potential teachers' judgments on the character of the job are comparatively stable. Students are often central to the attraction of becoming a teacher. The possibility of 'making a difference', of enthusing students and of working with people, rather than with money or things, are important motivations to teach. Undergraduates often cite the influence of their own teachers on them as students. This shows that there is a large pool of goodwill available. But potential teachers are often concerned about their ability to control classes, and that they will be unsupported in doing so.



The sources of these judgments are diverse (the press, hearsay or, sometimes, their own experience), and altering them is not easy. Experience of life in a successful school and with effective trainee teachers and Newly Qualified Teachers (NQTs) has been influential for some undergraduates. Others express reservations about teachers' workloads and the stress of teaching. Potential teachers also express fears about government intervention, including direct control over teachers and interference in the curriculum⁴¹.

Teacher training targets in the sciences have been missed regularly, but since figures are not differentiated across the disciplines, and published figures on vacancies are somewhat uninformative, the impact is difficult to trace^{43,44}. The story on supply clearly varies between schools, regions and disciplines. Schools in challenging circumstances often have greater difficulty in recruiting and retaining specialist teachers⁴⁵. The impact of this differentiation on teaching quality is likely to be negative. Polarisation is particularly visible in physics, the major 'shortage' subject, but extends more broadly. While 44 per cent of specialists in science departments have qualifications in biology and 25 per cent in chemistry, only 19 per cent have qualifications in physics⁴⁶ while the remainder are generalists. It is clear that physics is increasingly taught by non-specialists across the system⁴⁷. Moreover, the level of specialist qualification of the teacher has been found to be the second most effective predictor of pupil performance in physics, after pupil characteristics⁴⁷. This shortage is self-feeding. A small pool of physics undergraduates means fewer and less well-qualified teachers, which leads to lower-attaining students and reduced recruitment to higher education. Across science as a whole the class of degree obtained by PGCE students is somewhat skewed to the lower end⁴¹ although the educational impact of this effect is unknown. There is more to teacher quality than academic qualifications, and Ofsted data presents a positive picture about trainees⁴⁸.

Teachers of science usually start their career with good subject knowledge in one or more areas of the school science curriculum. A first stage in professional development is to help trainee teachers translate this knowledge into good 'pedagogical content knowledge' (PCK) – the best ways of teaching specific science content and concepts to particular groups of students.

A second stage in professional development is often the development of PCK in a less familiar area, such as when biology graduates teach physics. Here subject knowledge and PCK may be developed in tandem. This is particularly difficult because the degree-level education of future science teachers is often highly specialised. Although there are some generic skills in teaching, preparation to teach specific content is important. For example, the nature, processes and practices of science have traditionally been implicit rather than explicit in professional development. Research evidence⁴⁹ suggests that effective teaching to address these important features of scientific literacy is part of a long-term process of professional development. The period of initial training from which individual teachers can develop is very brief. PGCE students have the equivalent of seven weeks' systematic introduction to all aspects of school science education⁵⁰.

There is a wealth of research evidence concerning effective professional development for teachers. To implement new PCK and curriculum change in a sustainable manner, a well-planned professional development programme is needed⁵¹. Such a programme is best implemented over a reasonably long time-scale. It should involve coaching by experts, with opportunities for teachers to reflect in collegial settings on changes in classroom practice^{52,53,54}. Excellent professional development should improve teachers' knowledge of science, science processes and research, and encourage them to demonstrate competence in a tangible way. Such professional development requires providers who are capable of facilitating varied experiences and who know about both science and teaching⁵⁵.

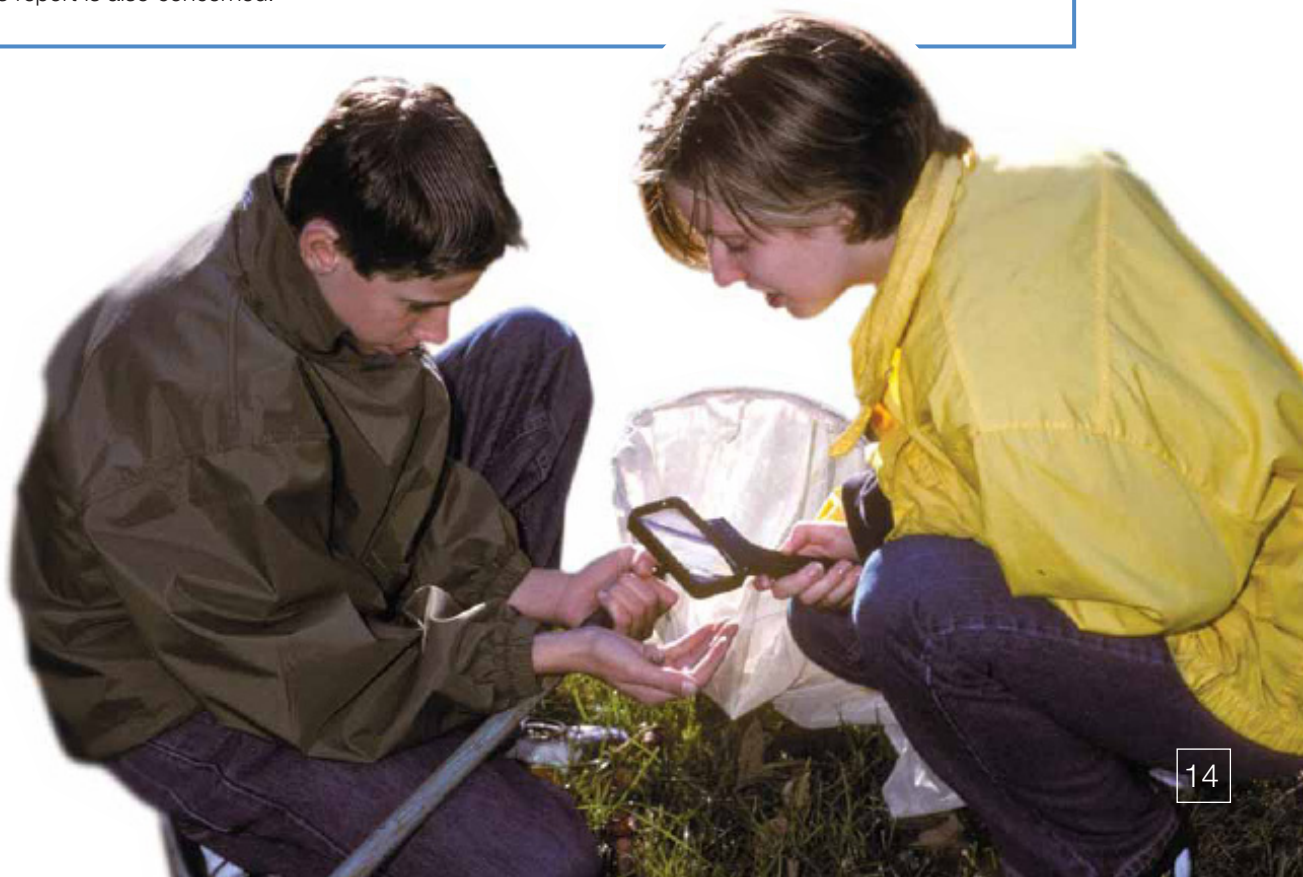


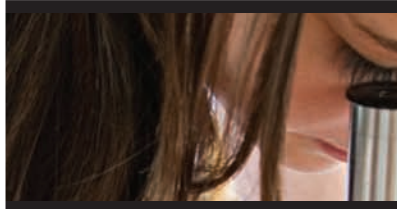
Professional development which fulfils some of these important criteria is now being offered through initiatives such as the National Network of Science Learning Centres, the Secondary National Strategy and a range of other providers. However, teachers' access to professional development, particularly that which assists development of the PCK important to teaching a curriculum rich in contemporary science, is currently limited by time, funding and lack of priority by managers^{56,57}. One recent study has shown that half of all secondary science teachers surveyed had had no subject-knowledge professional development in the past five years, although science teachers are more likely than other teachers to seek subject knowledge updates⁵⁷.

Although the effectiveness of professional development is usually evaluated at a surface level, development and research which focus on the retention of science teachers and their needs in long-term curriculum change would be invaluable.

For the problems in teacher supply do not end with recruitment. Retention is also critical, and in the long term it too is related to quality. In evidence to the House of Lords Committee on Science and Technology, the Council for Science and Technology has claimed that 30-40 per cent of new science teachers leave before their fifth year, and this broadly conforms to Smithers and Robinson's per annum estimate⁴⁵. Longitudinal studies suggest that retention of teachers is positively related to support and development and a sense of progression in the early years⁵⁸. As a corollary, environments where NQTs are left to their own devices, and not given development opportunities, can only increase the likelihood that they will leave the profession.

What messages does research offer about teacher recruitment, development and retention? Above all, it says that there are no quick fixes. Most potential teachers are sceptical about advertisements on the sides of buses, and about short-term financial incentives. They, and those just emerging from training, will need to be convinced that the environment in which they will work is comparable with other professions in a range of ways including professional development and support, salary, and the manner in which work will be evaluated and governed. This is a long-term challenge for government and others. It cannot be separated from those wider challenges of cultural background, improving curriculum, pedagogy and assessment methods with which this report is also concerned.





The way forward

We have identified ways in which science education could be strengthened in the light of existing research. We have also identified some avenues for additional research that must be explored if the process of reform is to be progressive. Our conclusions are that:

- The provision of a high quality 'science education for citizenship' for all students should continue to be energetically addressed. Its establishment would, we hope, help more students to see the intrinsic worth of a career in science-related fields.
- Every incentive should be given to science graduates to become school teachers. In particular, we suggest that those who remain as full-time science teachers for four or more years should have their student debt written off.
- Science graduates need a systematic and formal introduction to the complexities of teaching science in order to provide a basis for their actions and reflections. The time allocation within the PGCE course for such activities is in practice limited to seven weeks and for school-based trainees even less. The balance of time-use in initial teacher training should be reconsidered.
- A national structured programme of continuing professional development should be provided as an entitlement for all science teachers in post. The successful completion of stages in this programme should be recognised by incentives such as salary increments and teaching-related sabbatical leave.
- Increased delegation of significant curriculum decision-taking to schools would enable able teachers to see their profession as an enterprise in which they can exercise their creativity.
- Systematic scholarship is needed into the relationship between the purposes of the science curriculum and the content of that curriculum.
- Efforts are needed to forge links between science and other subjects, especially English and mathematics.
- Research is needed to establish clear links between curriculum goals and the assessment methods used.
- A range of valid and reliable items that can be used in both the formative and the summative assessment of the whole range of knowledge and skills that the science student encounters should be developed.
- More research, development, and teacher education are needed on how to increase students' engagement in science education. Priorities include classroom organisation, a changed approach to written work, and an increased focus on the on-task talk that is part of the core of learning science. There should be a strong emphasis on 'assessment for learning'.
- Systematic efforts must be made to increase the use of out-of-school activity in the learning of science. In addition, we must know more about the value of different contexts and types of experience. Administrative changes should facilitate this increased use.
- Much more must be found out about how the gender and cultural backgrounds of students interact with their learning of science in school. Unless these can be brought into harmony, it is very likely that science that will continue to be rejected, by many with disadvantages for students and for the UK economy.
- Strategies for linking research, policy formation, classroom practice, and teacher education must be developed.



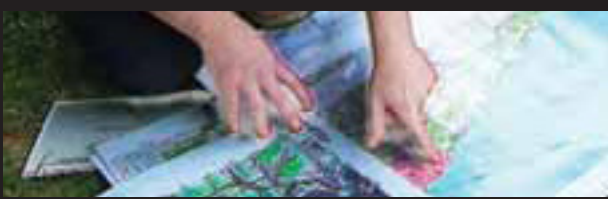
We believe on the basis of the evidence that if these conclusions are implemented, the quality of science education for all students will improve substantially.

How can the research and development that we recommend be brought about? There are six types of research, which in order of impact from the immediate to the long term are:

- Action research, intended to achieve improvement in a particular context of science education and to provide insights into possible improvements in related areas
- Research into the consequences of existing policies or practices
- Research intended to identify practices that help achieve particular educational goals
- Research to inform policy or practice in a specific aspect of science education
- Research undertaken from particular psychological or sociological perspectives
- 'Blue skies' research aimed at generating new knowledge whose impact on practice is uncertain, diffuse, or long-term⁵⁹

Each of these types of research implies a particular relationship between policy-making (as reflected in the design of curricula), classroom practice (as reflected in the development of materials and pedagogic strategies) and teacher education (as reflected in the design of professional development structures). The type chosen must be compatible with the relationship intended. It is vital that a strategy be devised that links research much more firmly with the formation of policy, its implementation in practice, and implications for teacher development. There are all too few examples of this tripartite linkage taking place in science education. The *Cognitive Acceleration in Science Education Project*⁵⁴ started out as a research project, evolved into a specific approach to teaching and learning that has proved very successful in the classroom, and has been influential in teacher education, yet has not become official policy. The *Beyond 2000* project⁶⁰ started out as a multi-faceted enquiry. It has led to the 21st Century Science project which has strongly influenced policy on the structure of the suite of specifications available for 14-16 year olds in England and Wales.

The concerns of the Roberts Report¹ can be successfully addressed. However, a coherent plan of research, policy formation, curriculum development and trialing is needed, alongside a reconceptualisation of teacher education. Unless action is taken very soon, the consequences, for individuals, society, and the economy, are likely be serious.



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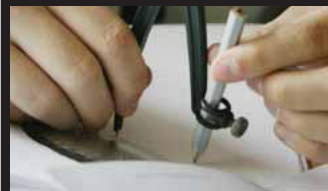
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About this publication

This is the third in a series of TLRP Commentaries designed to make research-informed contributions to contemporary discussion of issues, initiatives or events in UK education. The first and second in the series, on Personalised Learning and on Improving Teaching and Learning in Schools, are available from the bookshop at the Institute of Education (ioe@johnsmith.co.uk). This publication is a joint venture with the Association for Science Education.

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