Primary science and mathematics education: getting the basics right

A summary of the key issues in 5–11 education from the Royal Society's 'state of the nation' report on 5–14 science and mathematics education in the United Kingdom

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Foreword

This report considers primary and early secondary science and mathematics education across the United Kingdom. Venturing into this complex area represents something of a first for the Royal Society. Why have we done it?

Clearly future advances in science and technology will be essential to combating the greatest social and environmental challenges we face, and suitably qualified experts are required to tackle these. Evidently, the success of government policies concerning science and innovation depends on the quality of young people's education.

Our work in education policy, like that of many others, has been mostly concerned with the products of the education 'system', focusing on the numbers taking public examinations in science, mathematics and related subjects and pursuing careers in them. On the face of it, this makes good sense given that the subject choices young people make narrow as they progress through the education system, and the extent to which they continue to pursue science and mathematics will increasingly determine the numbers of professional scientists and the overall level of scientific literacy in the population.

However, recent evidence has highlighted how children's initial experiences of education can have profound implications for their future success and well-being. Children are innately curious about the natural world. But, year after year, large proportions are 'turned off' science and mathematics by the time they reach secondary school, with little prospect of that interest being rekindled. Inevitably, those who are most likely to suffer are the under-privileged.

We have sought to understand why this is happening, by sifting through a quantity of the vast array of information available from independent research and national educational records.

It is clear that there are profound issues that will only be solved long term. This will demand a precise understanding of what subject specialism is and should be in relation to primary and secondary education. Finally, as responsibility for education increasingly shifts to local communities, there is a need for private enterprise, educational charities and the learned and professional bodies to give far greater consideration to supporting primary science and mathematics inside and outside the classroom. It is only by concerted action that we will be able to move closer to achieving equality of opportunity for all children.

Martin Rees
President of the Royal Society

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1 Background

The Royal Society's third 'state of the nation' report[1] surveys key indicators of the health of 5–14 science and mathematics education across the United Kingdom, and identifies some critical areas that require urgent attention if we are to ensure that every child has access to a high quality education in these subjects.

The primary and early secondary years of education represent a crucial phase in young people's development. Innately keen, curious and highly impressionable, this is when they are most receptive to exploring and learning about the world around them. It is at this stage, too, that they are at their most vulnerable, where a negative or poor educational experience may easily change their perceptions and potentially switch them off any subject, possibly for life.

While there have been some positive developments in 5–14 education over the past decade, in particular the creation in England of a meaningful infrastructure for providing teachers with continuing professional development (CPD) in science and mathematics, the evidence presented in the main report gives rise to some serious concerns. These may be categorised as follows.

- Teachers: there is a very small number of primary teachers with significant backgrounds in science or mathematics, and poorly defined recruitment strategies for remedying this situation.
- Funding for CPD: the vital role being played by the major providers of science and mathematics CPD in the UK needs to be developed further, but is jeopardised by funding concerns.
- Assessment system: this has very probably contributed to large proportions of young people being 'switched off' science and mathematics, and hastened the departure of many teachers from the profession.
- Policy making: this has been inadequately informed because of issues with data collection and insufficient consideration of research evidence.

1 For more information on the previous 'state of the nation' reports, see http://royalsociety.org/education-policy/projects/, or contact the Society directly.

This summary of the Royal Society's 'state of the nation' report on 5–14 science and mathematics education focuses on the needs of primary pupils in their first distinct phase of school-based learning, before the transfer into secondary education. It explains the key issues, describes the problems the UK will face if these are not addressed and identifies actions that need to be taken.

2 Issues in primary science and mathematics education

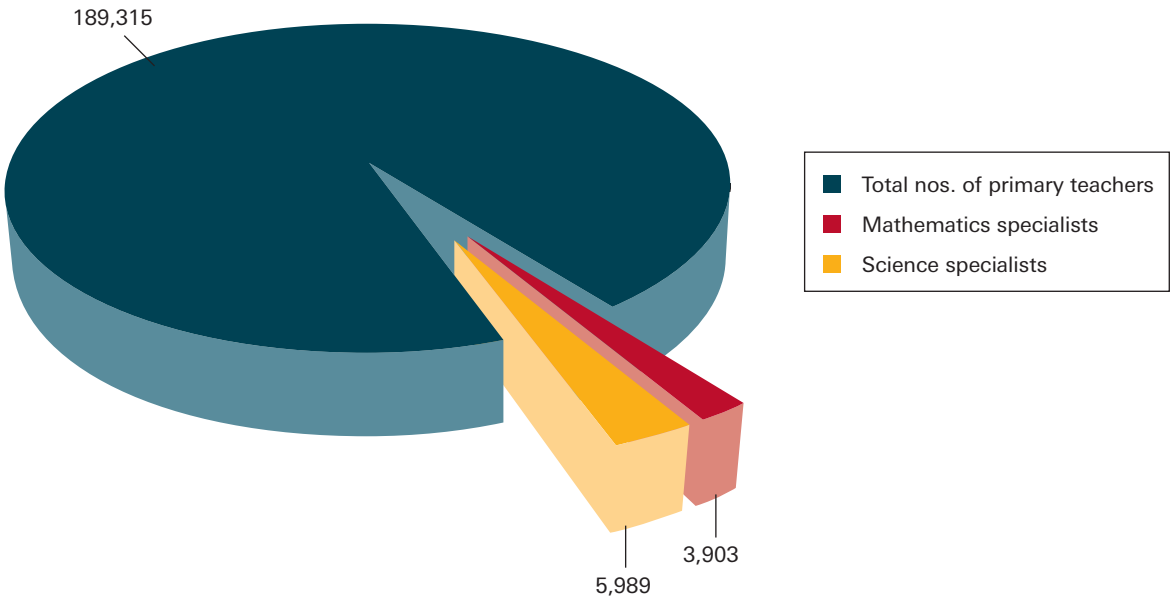
2.1 Teachers

Teachers are the most important factor in determining the quality of education children receive and their attainment. However, teaching specialism in science and mathematics is not generally recorded across the UK, due to the fact that primary teachers are expected to teach all subjects in the curriculum. It is the Society's view that this situation needs to change if children are going to be given the best possible start in these subjects.

The findings of academic research show that primary teachers lack confidence in teaching science and mathematics, and that children are being 'switched off' these subjects at secondary school, quite probably because of inadequacies in conceptual understanding that become exposed in post-primary education. These findings indicate that the attainment trends, which show that children perform comparatively well in assessments in these subjects, are misleading.

Historically, recognition of the value of science or mathematics 'coordinators' or 'leaders' has fluctuated over time in accordance with transient funding initiatives, and the people fulfilling these roles have often not had strong educational backgrounds in these subjects. A rigorous approach to improving the quality of science and mathematics teaching and learning is

Figure 1. Pie-chart showing separately the numbers of in-service primary teachers with specialist degree and initial teacher training qualifications in science and mathematics as a fraction of the total number of registered practising primary teachers in England.



Source: GTCE.

Notes: Data on 'specialists' were obtained from the General Teaching Council for England (GTCE) in April 2010. Information on the total number of in-service registered primary teachers (199,207) was obtained from the GTCE's most recent *Digest* of statistics for 2008/09.

needed across primary and early secondary education. This requires:

- establishing how best to deploy the existing small number of teachers with significant backgrounds in science and mathematics (often referred to as subject 'specialists') and ways to enhance the level of understanding and confidence in delivering these subjects across all teachers;
- initiatives to attract more people with backgrounds in science and mathematics into primary and early secondary teaching;
- providing all teachers with appropriate subject-specific CPD throughout their teaching careers.

But first, there is a need to understand what a subject 'specialist' is. Unfortunately, as the first Royal Society 'state of the nation' report on *The UK's science and mathematics teaching workforce* showed, back in 2007, there is no universally agreed definition or understanding of a 'specialist' at primary (or secondary) level.[2] Indeed, data on science and mathematics 'specialists'—including both trainees and fully fledged practitioners—are not generally collected. Where this information has been collected,[3] it is very evident that 'specialists' in science and mathematics represent tiny fractions (3% and 2%, respectively) of the total numbers of primary teachers (figure 1).

So long as a true understanding of the extent of subject expertise within the primary workforce remains elusive, Government attempts to achieve real improvements in the quality, delivery and effectiveness of primary education (eg through curricula reform) will continue to be blunted.

It is evident that some very careful consideration needs to be given to working out how the population can access the best possible teaching across all areas of the curriculum. While the concerns raised in this report relate specifically to teaching and learning in science and mathematics, they have far-reaching implications across all subjects, in particular in considering the necessity for subject 'specialists' at primary level (beyond Key Stage 1, or P3 in Scotland).

There is an urgent need to find a sustainable way of training and employing sufficient numbers of primary teachers who have specialist backgrounds in science and mathematics. While post-qualification routes to acquiring specialism (such as the Mathematics Specialist Teacher primary programme) have lately been introduced for teachers in England, the focus for long-term viability should be on developing subject 'specialists' through initial teacher training.

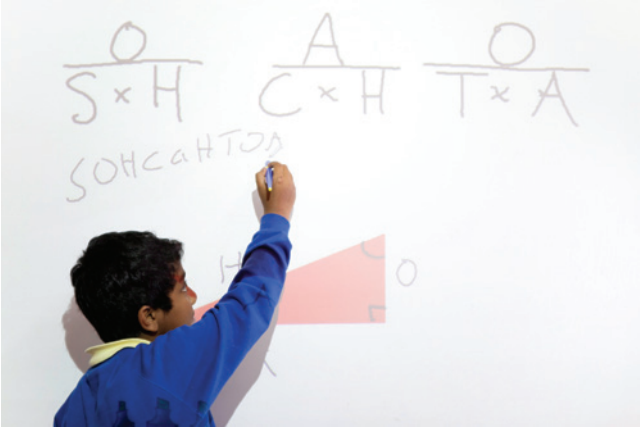
Given, though, that the primary teaching workforce is made up mainly of women, and that fewer women than men take first degrees in mainstream science, mathematics and engineering subjects at university,[4]

2 Royal Society 2007 *The UK's science and mathematics teaching workforce*. London: Royal Society.
3 Such information has only been collected with any reliability in England.
4 Royal Society 2006 *A degree of concern*, figure 5.11, pp. 37. London: Royal Society.

any strategy to attract more graduates into the profession must take account of these gender effects.

Other important factors to consider are the ageing nature of the workforce, the acknowledged need for more male role models in primary schools and a much wider concern that the expectations of written curricula will not be fulfilled so long as there are insufficient numbers of subject 'specialists' involved in teaching them.

The Government should establish, with the support of the science community, an unambiguous definition of a science 'specialist' teacher at primary. It should then formulate both a target for increasing the numbers of science 'specialist' teachers in English primary schools to ensure that every child has access to a high quality science education, and invest in strategies for achieving this. Given that there are currently more than 17,000 primary schools in England, and based on the identification of a 'specialist' used for figure 1, there is potentially a need to triple the numbers of science 'specialists' in the primary teaching population.



2.2 Funding for subject-specific continuing professional development (CPD)

It is vital that qualified teachers are provided with, and enabled to access, opportunities for CPD in science and mathematics throughout their careers. These opportunities should enable them to refresh and update their knowledge and pedagogical skills and thereby re-enthuse and invigorate their teaching.

While CPD should not be seen as some sort of 'silver bullet' that will solve the problem of teacher retention, poor rates of retention compound the difficulties encountered in attracting sufficient numbers of science and mathematics 'specialists' into primary teaching (see § 2.3). This is why the professional recognition and Masters-level qualifications that have been established in England to develop science and mathematics 'specialists' in primary schools need to be sustained.

In England, recent years have witnessed a welcome transformation in the delivery of science and mathematics CPD. The majority of CPD specific to science and mathematics is now provided directly (or guided) by the National Science Learning Centre (NSLC) and its associated network of Science Learning Centres, and by the National Centre for Excellence in the Teaching of Mathematics (NCTEM). Increasingly, teachers from across the UK are able to access courses offered by the NSLC. However, because the NSLC is remitted to devote a greater proportion of its resource into providing CPD for secondary teachers, there is a general lack of CPD opportunities for primary teachers.

In Scotland, too, the Scottish Schools Equipment Research Centre (SSERC) has developed an effective CPD provision for science and mathematics teachers, but provision in Northern Ireland and Wales requires development.

The NSLC, its associated Science Learning Centres, the NCETM and SSERC have become established as major deliverers of science and mathematics CPD in the UK. It is essential that they continue to be appropriately funded and supported.

2.3 Assessment system

Across the UK, there has been a move towards teacher assessment replacing 'high stakes' national tests altogether as the preferred means of measuring and monitoring children's progress.

In England, testing during primary schooling became 'high stakes' when the Government started using it as a tool to compare, and ostensibly drive up, schools' performance. But it appears to have had a limited effect on performance in science and mathematics, with UK Government targets (pertaining only to England) generally being undershot. Such improvement as has been recorded may owe much to teachers becoming increasingly adept at, and focused on teaching to the test. In addition gulfs exist in the performance of children of different ethnic groups or socioeconomic status which, as we demonstrated in our second 'state of the nation' report, affect their success in public examinations at GCSE, A-level and life beyond.[5]

The testing regime appears to have had negative effects on both teachers and children. The pressures on teachers and schools have been so great that much classroom time has been dedicated to drumming the required 'facts' into pupils' heads. This has inevitably stifled creative and innovative approaches to teaching and learning science and mathematics, and severely limited children's experiences of these subjects. Their ability to perform in the tests masks an inadequate conceptual understanding of these subjects that is exposed at secondary level when

5 Royal Society 2008 *Science and mathematics education, 14–19. A 'state of the nation' report on the participation and attainment of 14–19 year olds in science and mathematics in the UK, 1996–2007*. London: Royal Society.

science is disaggregated into biology, chemistry and physics. This, together with the fact that science in early secondary education is taught by graduates lacking expertise in at least one of the mainstream scientific disciplines, may well be responsible for the progressive disaffection measured in attitudinal research. Indeed, various studies have recorded that many children are switched off science and mathematics following transfer into secondary education,[6] and it is very probable that this is irreversible.

Similarly, teachers should be enthused and enjoy teaching. While factors such as workload and poor classroom behaviour have been cited as reasons for teachers changing careers, it also seems to be the case that teachers have become disaffected as a result of the pressures and constraints they have been under in 'delivering the tests' at the end of Key Stage 2, and this is likely to contribute to the fact that some 20% of primary teachers in England leave the profession after three years.[7,8]

2.4 Policy making

There has been an unprecedented amount of educational reform over the past 12 years, and in England this has been piecemeal, often conducted in haste and without any proper system being established for monitoring and review. Consequently, the impact of any individual changes has been hard to measure, leaving the evidence base for future policy change on an unsound footing.

The main report brings together evidence gained from official statistics and academic research which indicates that better monitoring of the problems with subject-based teaching and assessment may have enabled earlier and more effective intervention.

3 The threat to the future well-being of the UK

For too many years now, there has been persistently low uptake of science, technology, engineering and mathematics (STEM) courses at university. Employers have repeatedly voiced their concerns at the lack of professionals entering the workplace with specialist training and qualifications in these disciplines and, in response, the previous Government introduced a ten year investment framework to boost science and innovation in the UK.[9]

The chronic nature of this 'STEM fatigue'[10] is deeply concerning. Future advances in science and technology are essential to combating the major social and environmental threats to human health and well-being—climate change, creation of vaccines against pandemics, better food supplies, 'clean' energy, ecosystem preservation, etc—and this is why science and innovation merit their central role within the UK's long-term strategy for growth. However, success in meeting these challenges, and thereby sustaining a competitive knowledge-based economy, requires that the UK's education systems nurture sufficient numbers of well qualified science, technology, engineering and mathematics graduates, while at the same time raising the overall levels of scientific and mathematical literacy in the population.

This nurturing begins in earnest at primary school, but it is important to realise the vital role that parents or guardians, and local industry and business have to play in enthusing children about science and mathematics. Here again there is a need to chip away at the ingrained negative attitudes towards science and mathematics. The prevailing view that it is somehow 'cool' to be bad at mathematics is symptomatic of a cultural deficit that needs to be overturned.

While the UK has a proud track record of achievement in science and engineering, this is proving increasingly difficult to maintain owing to (i) fierce competition from abroad, and (ii) the constant struggle to recruit students into science and mathematics courses and employment. If we are to achieve substantial increases in the numbers taking science and mathematics subjects at university, the UK Government and the devolved administrations must invest significantly in improving 5–14 science and mathematics education despite economic pressures to divert funds to other areas of public spending.

6 For instance: Galton, M, Edwards, J, Hargreaves, L & Pell, T 2003 *Transfer and transitions in the middle years of schooling (7–14): continuities and discontinuities in learning*. DfES report no. 443, chapter 3, pp. 43–74; Nardi, E & Steward, S 2003 Is mathematics T.I.R.E.D.? A profile of quiet disaffection in the secondary mathematics classroom. *Br. Educ. Res. J.* **29**, 345–367.

7 Politeia 2009 *Teaching matters: the recruitment, employment and retention of teachers*. The report of the Politeia Education Commission, Appendix D, p. 75. London: Politeia.

8 House of Commons 2010 *Training of teachers. Fourth report of the Children, Schools and Families Committee*, Session 2009–10, volume 2, Ev 180ff (HC 275-II). London: TSO.

9 HM Treasury 2004 *Science and innovation investment framework 2004–2014*. London: The Stationery Office.

10 DENI/DELNI 2009 Report of the STEM Review. Bangor/Belfast: Department for Employment and Learning/Department of Education.

4 Actions

Major changes in primary education are required to help build a thriving society in the UK. These are detailed below.

4.1 Teachers

Definitions of subject 'specialists' should be developed that recognise specialism from Key Stage 2 (and equivalent) upwards. A coordinated approach to recording and maintaining consistent records of the specialisms of teachers on registers should be developed and such records should be monitored in a systematic way. This should extend to the creation of a mechanism that allows specialism, and the development of expertise through teaching experience and subject-based and other CPD to be tracked and recognised throughout a teacher's career. In addition the role of subject 'specialists' should be reviewed so that they may be deployed in the most effective way.

There is an urgent need to:

- clarify the type(s) of qualifications that should be included in recognising subject specialism;
- categorise first degree course subjects for the purpose of identifying science or mathematics 'specialists';
- develop and implement a recruitment and retention programme specifically for primary teachers with science and mathematics expertise;
- recruit more graduate science and mathematics 'specialists' into teaching Key Stage 2/3 (or equivalent);
- invest in strategies for improving recruitment and retention of subject 'specialists' within the profession.

As previously mentioned, given that there are currently more than 17,000 primary schools in England, and based on the identification of a 'specialist' used for figure 1, there is potentially a need to triple the numbers of science 'specialists' in the primary teaching population.

4.2 Funding for subject-specific continuing professional development (CPD)

Subject-specific CPD for teachers of primary science and mathematics must be developed and supported through the NSLC and the network of regional Science Learning Centres in England, the NCETM, the SSERC and the professional bodies. Similar capacity for providing teachers in Northern Ireland and Wales with subject-specific CPD needs to be built.

In addition, long-term commitment to the following programmes is required.

- Development of a cross-disciplinary 'science for non-specialists' course for Key Stage 2/3 (and equivalent) teachers and higher-level teaching assistants in line with the courses currently available for secondary teachers, which should be taken forward with support from government and the professional bodies.
- An ongoing commitment to the Mathematics Specialist Teachers (MaST) primary programme in England for qualified in-service practitioners.

Finally, the wider science and mathematics communities need to match Government efforts by providing appropriate subject and professional expertise in primary and early secondary science and mathematics education. Where necessary, they should step in to balance out centralised provision by offering a more tailored, localised approach that better aligns with students' learning requirements as perceived by themselves and those who advise them.

4.3 Assessment system

As it has done for science, the Government should dispense with Key Stage 2 tests in mathematics in England. While teachers should have responsibility for assessing children's progress, there is a need to review how progression during primary and early secondary schooling might better be measured and monitored, through a system geared more to assessment for, as opposed to of, learning. Trends in performance at national level are more accurately measured by regular sample surveys than by the central collection of individual pupil achievement data.

More generally, curricula and assessment systems must be engineered so as to optimise children's experiences and enjoyment of science and mathematics. Moreover, the sort of articulated approach to educational planning adopted of late in Northern Ireland, Scotland and Wales, involving a continuous curriculum from preschool to the end of secondary schooling, should be replicated in England. Efforts must be focused on ensuring that all children have access to a high quality education that is geared more towards supporting and encouraging their progress than to measuring it. As a result, we recommend:

- a review of the way that children are taught and tested in science and mathematics at primary level. Science is a practical subject and it needs to be taught and assessed as such;
- greater emphasis is placed on building understanding of how science and mathematics work than on

rote learning of 'facts'. Achieving this depends on developing a workforce that is confident in teaching these subjects.

4.4 Policy making

The individual education authorities in England, Northern Ireland, Scotland and Wales should take a more evidence-based approach to 5–14 science and mathematics education policy, ensuring that reforms are based on careful consideration of available and newly required independent sources of quantitative and qualitative advice in order to minimise the chances of causing unintended and potentially harmful effects. In part, this requires investment in and better use of research over a longer timescale in order to track changes to individual cohorts of pupils as they develop and progress.

5 In conclusion

The recommendations set out in this report represent significant challenges for, in particular, the UK's Governments and Assemblies, their agencies and associated non-governmental organisations, schools and their local communities and the science and mathematics communities. All of these key stakeholders will need to collaborate in a much more joined-up manner to ensure that children have access to the best possible education in science and mathematics, with considerably more of them being motivated and enabled to study these subjects at higher levels than has historically been the case.

The detailed recommendations arising from this study are included in the main report to be found at http://royalsociety.org/education-policy/

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The Royal Society
6–9 Carlton House Terrace
London SW1Y 5AG
Tel +44 (0)20 7451 2554
Fax +44 (0)20 7930 2170
Email education@royalsociety.org
Web royalsociety.org

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- **Influence** policymaking with the best scientific advice
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For further information

The Royal Society
6–9 Carlton House Terrace
London SW1Y 5AG

T +44 (0)20 7451 2554
F +44 (0)20 7930 2170
E education@royalsociety.org
W royalsociety.org

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