EXCELLENCE IN SCIENCE

THE ROYAL SOCIETY

Vision for science and mathematics education 5–19

Call for Views
MEI response

The Royal Society, the UK's National Academy of Science, is undertaking an ambitious new project to set out an evidence-based vision for a future world-class, high-performing 5–19 education system, particularly with respect to science and mathematics.

Using international comparisons, the 'Vision for science and mathematics education 5-19' project will help ensure the UK has a scientifically and mathematically literate population as well as sufficient numbers of scientists and mathematicians to help solve the many challenges the world will face in the coming decades. It will take a fresh approach to tackling concerns widely held or expressed by governments, employers and the science and mathematics communities about the UK's future economic competitiveness and individuals' future prospects.

Five specific areas for inquiry have been identified, all of which are essential considerations for establishing and sustaining a high-performing and well-respected science and mathematics education system:

- teachers (and the wider workforce);
- leadership and ethos;
- skills, curriculum and assessment;
- infrastructure;
- accountability.

This Call for Views covers each of these areas. We would welcome views and evidence from all organisations and individuals, particularly from those with educational expertise and an especial interest in improving science and mathematics education. We want to know what needs to be done to help ensure that all young people have an inspiring introduction to science and mathematics, and that those who wish to pursue these subjects further are enabled to do so.

Please send us your submissions to this Call for Views by Friday 16 March 2012 at the latest to: vision@royalsociety.org . We would particularly welcome any robust data or other evidence to support your views about improving the science and mathematics aspects of the education system and would be grateful if you would reference this fully so that it can be followed up.

Notes for completing the Call for Views

1. Please do not feel a need to answer every question.
2. Where appropriate, please cross-reference your responses.

3. Personal information will be treated as confidential and will only be used for the purposes of the Call for Views.
4. Submissions, or extracts from them, may be published on our website or in other outputs we publish. Please inform us if you do not want to be identified in anything we publish or highlight clearly any particular aspects of your submission that you would wish to be anonymised.
5. If you are submitting a response on behalf of an organisation, please make this clear and include details of the relevant person to contact should we wish to discuss issues raised in your submission.

If you have any queries about the content of this document, please email: vision@royalsociety.org

General questions

1) Science and mathematics education in the UK

a) What is good about UK science and mathematics education?

- *There is an expectation that uses of mathematics should be taught alongside pure mathematics; this is seen in functional aspects of GCSE, in the twin pilot GCSEs and in the structure of Mathematics A Level. It emphasises both the usefulness and the rigour of mathematics in a way that is not seen in all countries.*

b) What aspects of UK science and mathematics education need changing and how may they be improved to meet the challenges of the 21st century?

- *The principal change required is in relation to teaching approaches, which need (in mathematics at least) to include far more opportunities for students to grapple with problems that challenge them to use and apply the mathematics they know, sometimes in unexpected ways. These problems should include the kind that requires the use of simple mathematics in complicated contexts. A greater emphasis on multi-step reasoning should also be introduced.*

- *Our assessment of mathematics learning should also reflect the curriculum changes described above. More will be written about this below.*

c) What, if any, broader educational issues concern you? (These may or may not relate directly to science and mathematics education)

- *There is a lack of equality of opportunity. For example, some state schools do not offer Further Mathematics. Some allow students who achieved grade B GCSE Mathematics to take Further Mathematics, and others require A*. In some state schools triple science is mandatory and in others it is optional. Some schools allow more teaching time for mathematics than others.*

d) How can a science and mathematics education system best meet the needs of employers and higher education?

- *By encouraging students to develop independent learning and problem solving skills, rather than just training them to answer examination questions.*

Other comments:

2) Science and mathematics education internationally

a) Name three countries anywhere in the world where you feel 'high-quality' science and mathematics education are to be found? What are the hallmarks of this 'high quality' science and mathematics education?

b) What specific aspects of other countries' high-performing education systems should we be learning from?

Other comments:

Teachers (and the wider workforce)

An education system can only be as good as the teachers within it. But for many years now shortages of science and mathematics teachers have been recorded in England and Wales and the situation elsewhere in the UK is not entirely clear. Problems have been reported both in recruiting sufficient trainees and retaining qualified teachers.

Please answer these questions without feeling in any way constrained by current or proposed mechanisms in place for recruiting, training and/or professionally developing science and mathematics teachers.

1) Teaching as a career

a) What needs to be done to make teaching a top career choice for trained scientists and mathematicians?

- *It should be emphasised that teaching mathematics is not primarily about teaching techniques and 'rules', but instead is concerned with helping students to think mathematically and gain enjoyment from problem solving, in the way that trained mathematicians do.*

- *The damage done by league tables and teaching to the test needs to be addressed; students who go through this system are not likely to want to become teachers themselves.*

- *Career progression needs to be clear. There must be opportunities for skilled mathematics teachers to have access to similar salaries to senior management, while staying in mathematics teaching.*

- *The esteem in which teachers are held in society needs to be increased to the levels in countries like Germany and Finland.*

2) Initial Teacher Training

a) What should the minimum entry requirements be for entry to primary and secondary science and mathematics teacher training courses? Should diagnostic tests be applied to test the suitability of candidates? If so, what types?

- *Trainee primary teachers should have at least a grade B in GCSE Mathematics and should continue with mathematics post-16 at beyond GCSE level, to ensure that they are confident with basic mathematics and that there is not too long a gap between their learning mathematics and teaching it. Moreover, the content of primary PGCE courses should ensure trainees have a clear understanding of the development of number, algebra and shape at KS3.*

- *For secondary mathematics teaching, degree classification is not a good indicator of ability as a teacher. However, sound subject knowledge is vitally important for mathematics teachers. Candidates for training with third class degrees should be able to train if they are able to convince course providers of their suitability. For candidates who do not have a mathematics degree, or a degree in a strongly mathematics-based subject such as physics or engineering, a minimum of a grade C in A level Mathematics, or equivalent, should be required for entry to a subject conversion course. Candidates would need to successfully complete a conversion course before proceeding with further training.*

b) Should inducements be offered to attract entrants into science and mathematics teacher training? If not, why not? If they should be offered, then why and what might they be?

- *Potential trainees with exceptional promise could be offered a deal whereby a proportion of their student loan is paid off in the year of training, and in each of their first five years in teaching, assuming that certain criteria are met.*

c) What is good about initial teacher training programmes in science and mathematics in the UK?

- *A key strength is the balance between time in university, with access to research findings into effective pedagogy, and time in school to practise. It should be noted that teachers in school do not have the perspective that PGCE tutors should have, so the university has an important role to play in improving the pedagogical knowledge of successive generations of teachers.*

d) What changes to these programmes (e.g. philosophy, content, or emphases) are needed?

- *It is important that teachers of mathematics at both primary and secondary level have had the experience of doing mathematics for themselves and enjoying the experience. Teacher training programmes should include such opportunities, to enthuse trainee teachers mathematically and encourage them to pass on their enthusiasm to their students.*

e) How can the standard of science and mathematics initial teacher training programmes be of a consistently high quality across the UK?

- *A core training framework should be developed for all courses and trainers should share good practice and resources.*

f) What types of courses (full and/or part-time) should be provided for training new science and mathematics teachers. Why?

g) In what sort(s) of institution(s) should science and mathematics teacher training take place? Why?

- *See (c) above*.

h) How much of this training should be spent gaining experience in the classroom?

- *About half.*

i) How long should courses be for training (i) primary; and (ii) secondary science or mathematics teachers to become fully qualified?

- *In view of the responsibility of primary school teachers to develop their students' understanding across the whole curriculum, it is difficult to see how a one year PGCE course following a degree can be adequate preparation. For secondary teachers, one year is sufficient, recognising that support is needed in the NQT year and beyond.*

- *For secondary mathematics teachers, if trainees do not have a mathematics degree, or a degree in a strongly mathematics-based subject such as physics or engineering, an extra sixth month conversion course is required to develop their subject knowledge. At least a grade C in A level Mathematics, or equivalent, should be a minimum requirement for entry onto this conversion course.*

Other comments:

3) Continuing Professional Development (CPD) for teachers

a) What are the benefits of subject-specific CPD for science and mathematics teachers?

- *Being challenged to rethink their views about the subject and to consider different pedagogical techniques, considering questions such as: Is the way you were taught and the way you have acquired an understanding the best/only way? Is it appropriate for all learners? What practices are proving effective in other classrooms?*

- *Supporting teachers in learning about the use of new digital technologies in teaching.*

- *Supporting teachers to improve their subject knowledge.*

- *Supporting teachers in teaching at a higher level for the first time.*

- *Exposing experienced teachers to ideas related to pedagogy that they might not have had access to since initial teacher training and which they might not have been ready for at that time; allowing them to reflect on these ideas in the light of their own experiences.*

- *Sharing ideas with other mathematics teachers.*

b) How should science and mathematics teachers best keep up with their subject and with new approaches to teaching, assessment and the curriculum?

- *Face-to-face CPD in their region*
- *On-going CPD courses, rather than one day courses*
- *The option of live on-line courses and support should be available – MEI's work, particularly through the FMSP, shows what can be achieved*
- *Departmental or individual membership of subject associations should be encouraged*
- *Support through the NCETM and the National Science Learning Centre*

c) At what times throughout their teaching careers and with what regularity should teachers undertake subject-specific CPD?

- *Approximately three years into their careers, teachers should undertake structured reflection on their experiences and areas for development. No single model of CPD is appropriate for all but access to funding for CPD should be available to all teachers.*

d) Should CPD be voluntary or mandatory? Why?

- *Voluntary, but linked to career progression – CPD courses need to be populated by teachers wanting to undertake that development. Line managers will be in a position to strongly encourage colleagues who need specific CPD. Chartered Mathematics or Science Teacher status, carrying a requirement to undertake regular CPD, should be encouraged.*

e) Are there key obstacles preventing science and mathematics teachers from accessing subject-specific CPD? If so, how can these be overcome them?

- *Key obstacles are funding and the ability to take time out of the classroom. Online CPD can help to overcome both of these, as can ring-fenced funding in schools and colleges for subject specific CPD (this should be sufficient to cover supply costs as well as course fees).*

f) Should subject-specific CPD be linked to broader CPD development strategies within schools and colleges, for example in areas such as leadership and assessment?

- *Yes, in the sense such CPD should have ring-fenced funding. If Ofsted reports suggest areas for development and schools subsequently choose not to offer related CPD then they should be held accountable.*

g) Should CPD be accredited (eg through the awarding of Masters-level credits)?

- *We would not like to see the requirements of Master level accreditation interfering with CPD which teachers need to develop their classroom practice; sometimes CPD will deal with things which are not at Masters level. However, if teachers choose to work towards a Masters degree, it should be possible to apply for bursaries and it may be possible to include their CPD in the accreditation. Subject-specific Masters degrees in Teaching Science or Mathematics would be more useful than general M Ed degrees. Plymouth University, in partnership with MEI and the Royal Statistical Society Centre for Statistical Education, has just developed a Masters degree programme in Teaching Pre-University Mathematics (and Statistics).*

Other comments

Some interdisciplinary CPD would be helpful, enabling science teachers and mathematics teachers to work together to encourage cross-curricular understanding.

4) The wider workforce

a) How and where should we be training laboratory technicians?

b) What CPD needs will laboratory technicians have and how will these best be accommodated?

c) Will there be a role for teaching assistants in science and mathematics classes? If so, what should this be? How and where should they be trained?

- *This is best left to individual schools. Teaching assistants must not have responsibility for any whole class mathematics teaching.*
- *Teaching assistants supporting mathematics and science classes should be offered opportunities to improve their mathematical skills and understanding; this includes achieving at least grade C in GCSE Mathematics if they do not already have such a qualification.*

d) Who should be responsible for providing advice on careers in or related to science, technology, engineering and mathematics (STEM)? (Do we, for instance, need a national network of careers advisers with specialist knowledge and understanding of careers in science, technology, engineering and mathematics?)

- *Specialist knowledge is essential. The advice currently offered is often inaccurate. Up-to-date and accurate information could be held on line, which would reduce the need for a national network of advisers. Such guidance should allow teachers, parents and students to access clear, easy to find information about the range of careers, demand, opportunities, financial assistance available, courses post-16 and in HE and which subject choices are most desirable.*

Other comments

Leadership and ethos

Leadership and ethos are complex concepts within education, but are considered to be significant in affecting the overall performance of individual schools and colleges, and the education system as a whole.
Much less is known about the leadership characteristics of those science and mathematics teachers who successfully introduce innovative teaching and learning practices. This implies a culture of initiative and collegiality for developing, as well as delivering, the curriculum. However, systematic evidence is also lacking in respect of the effect of such leadership on student performance and progression in science and mathematics.

a) What impact do teachers' leadership qualities have on the quality of science and mathematics education, and on the performance of science and mathematics departments within schools and colleges? What evidence exists for this impact?

- *The Ofsted report, Understanding the Score, shows that effective subject leaders improve the quality of mathematics education. 'They used the outcomes of monitoring and analysis of test results to inform approaches to teaching and learning and the development of the curriculum. They also used professional development opportunities to disseminate and build on good practice and to tackle areas of inconsistency and weaknesses. Effective practitioners helped colleagues to develop aspects of their work. Occasionally, this included developing teachers' knowledge of mathematics, as well as how it might be taught. Teachers' readiness and commitment to giving and receiving such support was a hallmark of the school or department's ethos. Such an approach was seen not simply in high-achieving schools but also often in those working hard and effectively to improve, sometimes in challenging circumstances.'*

- *However, increasing pressure to achieve A*-C GCSE grades in mathematics is making it harder for subject leaders to focus on improving teaching and learning for all students. The DfE report, Early Entry to GCSE Examinations (2011) shows the increase in early entries to GCSE Mathematics, particularly for students who are expected to get grade C. There is often little attention given to their mathematical progression once they have obtained grade C.*

- *In some schools the proportion of students progressing from achieving a high grade in GCSE Mathematics to taking A Level Mathematics is much higher than in other schools. It would be helpful to investigate why this happens with a view to disseminating best practice.*

b) What kinds of leadership skills should science and mathematics teachers be able to acquire?

c) How can school and college leaders encourage leadership among science and mathematics teachers?

- *Teachers of mathematics need to be encouraged to focus on effective teaching and learning, rather than concentrating their efforts largely on improving examination grades. Training students to pass examinations, rather than enabling them to develop mathematical thinking skills and become mathematically fluent, makes it harder for them to progress to using mathematics effectively after the examinations are over.*

d) How can leadership pathways for experienced teachers be introduced into careers?

- *Such teachers could receive training to enable them to train other, less experienced teachers, perhaps through the Teaching Schools network which is currently being set up.*

e) What factors are most responsible for creating the ethos of different schools and colleges?

- *An institutional ethos that focuses on education as a means to make sense of the world, rather than as a means to obtain qualifications.*

- *Teachers' enthusiasm for their subject.*

f) What impact do leadership and ethos have on the quality and range of science and mathematics education offered within schools and colleges? What evidence exists for this impact?

- *Rates of progression to A level provide useful evidence of the quality of science and mathematics teaching at GCSE level. Rates of progression to higher education STEM subjects provide important evidence for the quality of science and mathematics teaching at A level. This evidence is at least as valuable as that provided by examination grades.*

g) What is the role of governing bodies in shaping the ethos of schools and colleges and how, if at all, does this impact on their provision of science and mathematics?

- *This depends on the skills and experience of members of governing bodies. Governors with scientific or mathematical backgrounds can play an important role.*

Other comments:

Skills, Curriculum and Assessment

Acquiring the right scientific and mathematical skills and knowledge is a key component of an 'ideal' 5-19 education process. Teachers teach to a relevant curriculum and enable learners to acquire useful knowledge and understanding, which is then assessed at a critical point in time to certify what a young person knows and can do in these areas.

a) What skills are particularly important to young people's progress in (i) science and (ii) mathematics, and when should they begin to acquire them?

- *The ability to solve problems is the most important and most highly valued mathematical skill. Problem solving skills should be explicitly taught from the start of mathematics education. The range of techniques addressed should include the use of simple mathematics to solve problems in complicated contexts. As part of the problem solving programme, a clear emphasis on the use of reasoning should be evident.*

b) How may the acquisition of such skills best be assessed?

- *Mathematical problem solving is hard to assess because it cannot readily be demonstrated by learners within the fixed amount of time usually allocated to public examinations. By its nature, the problem solving process may take considerable time. However, since this is the most valued mathematical skill, the difficulty of assessing it should not mean it is not part of public assessment. On the contrary, there are very strong arguments for changing the style of these assessments so that they can include assessment of problem solving. Assessment of reasoning fits more readily into conventional assessment; note, however, that the assessment of proof in A level Mathematics has caused awarding organisations immense difficulty.*

c) How important is the impact of the transition between primary and secondary phases in terms of pupils' progression in (science and mathematics) education?

- *Year 7 is a crucial year; a high proportion of pupils begins secondary school enthusiastic about mathematics, but can quickly be turned off it. A key factor seems to be that many secondary schools use year 7 as a 'levelling up' year, which can be very demotivating for many students.*

d) How should a curriculum be structured so that:

i. science and mathematics are adequately incorporated as subjects which have both conceptual and applied contexts e.g. practical work in science;

ii. teachers are able to use what they judge to be the most effective pedagogical methods and approaches to learning?

iii. diverse types of student acquire the specific knowledge, understanding and skills they will need for their adult lives:

iv. there is flexibility to include new topics or react to new discoveries or advances in science that can enthuse and excite?

- *i This is recognised in the twin pilot GCSEs in mathematics and also in the structure of A Level Mathematics, which has a balance of Pure and Applied units. However, review of both GCSE and A Level is essential to ensure that they best meet the needs of students and reflect future national needs. Such review should take account of current best practice in the UK and beyond.*

- *ii The curriculum should define what it is that pupils should learn, not how they should learn it.*

- *iii There is a balance to be struck between personalising the curriculum and having so many options that it is confusing for students and other end users and impossible for most schools and colleges to provide. Mathematics is a fantastically flexible tool, provided students are taught how to apply it in different contexts, rather than focusing on answering standard examination questions.*

- *iv It is very difficult for timed formal examinations to respond to new ideas. However, qualifications such as the Extended Project Qualification, or suitable coursework, provide the room for such flexibility. Although there has been a move away from coursework in mathematics assessment in the UK, it should be noted that some form of teacher assessment forms a part of school leaving assessment in many other countries.*

e) What characteristics of assessment best serve learning in its various forms in school science and in mathematics?

- *The most effective assessment is assessment that validly assesses the intended curriculum. This will often require assessment instruments that are different from the most conventional types (timed, written tests, multiple choice tests). In mathematics, it is vitally important that mark schemes should be used that permit examiners to mark responses more holistically than the conventional 'M1A1' approach. Sometimes, "level of response" mark schemes will be appropriate. The use of adaptive comparative judgements enabled by modern technology enables the holistic assessment of projects; see http://www.cambridgeassessment.org.uk/ca/digitalAssets/113610_Richard_Kimbell_Paper.pdf and http://www.slideshare.net/mattwingfield/comparative-pairs-assessment-and-eportfolios*

f) To what extent can/should science and mathematics be effectively assessed through other subjects?

- *There is an argument for assessing some mathematics through other subjects, especially at age 18, in order to ensure that students get the message that mathematical skills are essential for further progress in many areas of work and study and that the mathematics is assessed in contexts which are reasonably familiar to students. However, it is essential that such assessments are mathematically accurate. Anything else is misleading at best and may be damaging to student understanding. In the short term, when examiners of other subjects are not mathematically confident, it may be desirable to have mathematicians check specifications, draft assessments and mark schemes.*
- *Some subjects rely heavily on mathematics and statistics, especially as students progress through A Level onto further study. Students should be required to continue with mathematics post 16 to ensure that they are adequately prepared for further study.*

g) At what age(s)/stage(s) should public examinations and testing be conducted during students' school careers?

- *The number of stages at which public examinations are used should be as small as possible. It is highly doubtful whether it makes good sense to assess our young people in each of Y11, Y12 and Y13. Tests for pupils at the ends of key stages should be low stakes internal assessments, not the kind of high stakes tests that were used following the first introduction of the National Curriculum.*

h) What evidence of learning is needed for assessment to operate effectively?

- *Theoretically, any kind of evidence, including ephemeral evidence may contribute to effective assessment. However, for examinations leading to qualifications, evidence which is not gathered under controlled conditions needs to be verified in some way. For example, the Extended Project Qualification incorporates a planning log, reflection by the student and a presentation; these all help to ensure that the work is genuinely that of the student, as well as providing evidence to enable the assessment of skills acquired.*

Other comments:

Infrastructure

Infrastructure refers to the nature of the learning environment in which formal teaching and learning take place. For the purposes of this exercise, picture an 'ideal' learning environment of the future (in one or two generations' time, for example) which has all the resources and support systems in place to enable the best possible teaching and learning in science and mathematics.

a) Where will/should science/mathematics primary and secondary school learning take place, both within and outside school?

b) Will science and mathematics education benefit from having more, or less, diverse types of 5–19 educational institutions (e.g. primary, secondary, middle, all-through schools)? Why?

c) What kinds of specialised facilities, linked to key areas of learning in science and mathematics, should be available in the future?

d) How might teaching and learning in science and mathematics be supported by and support learning in other subjects, for example through using other facilities?

- *Mathematical and statistical modelling allows insight to be gained in a variety of situations. This allows better understanding of other subjects as well as enabling students to see the power of mathematics. MEI's Integrating Mathematical Problem Solving project is currently working to develop suitable teaching resources which are being trialled in schools. This will inform future curriculum development.*

e) What other resources and systems should be used to support science and mathematics?

- *The work of the Further Mathematics Support Programme has shown that it is possible to widen access to high quality tuition and expand opportunities through:*
    - *Specialised online resources and support for both teachers and students which can widen access to high quality tuition and expand opportunities.*
    - *Developing links between schools, colleges and universities*

f) What other more general changes to school infrastructure would support excellent science and mathematics teaching and learning? How can we measure this?

- *Sharing specialist expert teachers between institutions, both physically and through the use of technology.*

g) What evidence is there of the effect on their learning of science and mathematics of separating cohorts by (i) age and (ii) gender (e.g. should there be single sex classes or schools)?

Other comments:

Accountability

Those who are responsible for science and mathematics education within schools and colleges should be accountable for their performance.

a) How should science and mathematics in a 5–19 education system best be made accountable to (i) students; (ii) parents/guardians/carers; (iii) higher education; (iv) employers; (v) taxpayers; and (vi) ministers?

- *All the identified groups of stakeholders want students to learn something that will be useful to them in their future lives and studies. Exam grades can be an indicator of such learning but should not be regarded as an end in themselves. Student progression should be used as an indicator. It would be helpful to study accountability systems which work well in countries that value teacher assessment as part of students' overall assessment.*

b) How should qualifications in science and mathematics be regulated?

- *Qualifications should be better regulated than they have been to date. There has been a collective failure to require awarding organisations to deliver valid mathematics assessment. The interests of awarding organisations have been dominant; these have been served by allowing awarding organisations to continue to produce conventional examinations, with traditional approaches to marking. A significant shift is needed to ensure that examinations assess what the mathematics education community and users of mathematics qualifications value. Such examinations would place much greater emphasis on the central skills of reasoning and problem solving. An effective system of regulation would require that awarding organisations actually deliver assessments with greater emphasis on these features. To do this would require the regulator to acknowledge that different subjects may require different kinds of assessment.*

c) How can we ensure that all students can access the science and mathematics courses they wish to?

- *It can be difficult for small sixth forms to provide more than a small range of courses. The successful experience of the Further Mathematics Support Programme in combining external tuition with school based provision shows a possible model for enabling access to courses for all students.*

d) What are (i) the advantages and (ii) the disadvantages of performance targets and do any apply particularly to science or mathematics education?

- *The importance of A* to C in GCSE Mathematics has skewed provision for learners. Those who are working at a level below grade C are sometimes targeted for intervention and multiple entry. However, the aim of education is not to maximise the number of grade Cs; it is to support every student to achieve his or her potential and to acquire the greatest level of understanding they can.*

e) How should measures of performance best be reported to different audiences? What other measures of performance may be required?

Other comments:

Permissions

a) Are you content for us to publish extracts of or the whole of your submission? *Yes*

b) Would you like to be kept in touch with the project? If 'yes' please provide a contact email address. *Yes* email address: stella.dudzic@mei.org.uk