

Science and Mathematics Secondary Education for the 21st Century

Report of the Science and Learning Expert Group
Executive Summary

February 2010



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the 21st Century**

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Foreword

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The Rt. Hon. Lord Drayson
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Diana Johnson MP
Parliamentary Under-Secretary of State for Schools
Department for Children, Schools and Families

Dear Ministers

Here is our independent review, commissioned by Government on science and mathematics learning in schools and colleges. We believe that the timing of this review is important. Global development means that the competition and market for the products of science, engineering and technology are greater than ever before. It is a truism to state that the future of the UK depends critically on the education of future generations. Science, technology, engineering and mathematics (STEM) must be at the forefront of education in order for the UK to address some of the most important challenges facing society.

The UK does not have large stores of natural resources or a low-cost workforce. Our economy is highly dependent on our ability to add value, through scientific, engineering and technological innovation – and through advanced manufacturing skills. Our national infrastructure is ageing; our natural environment is ever more influenced by the impact of humans. We owe it to our children to prepare them for an exciting and uncertain future – and education is the most powerful tool to achieve this.

Education has had a high priority for successive governments – and we acknowledge the sustained focus on science and science education by the present government. Science education in schools has improved significantly in many respects during the last few years. We have consulted very widely in preparing this report. Many of our consultees agree that there is movement in the right direction. However, our consultation has also revealed a high degree of consensus about some key concerns. There remain important areas for improvement. We focus on these in this report and provide recommendations that we believe, if implemented effectively, will lead to substantial further improvements in education in STEM subjects.

Many of us have good cause to be grateful to a single inspiring teacher that we encountered during our school education. We must ensure that teaching is a

profession to which the brightest and best aspire. This can only be achieved if the teaching workforce is empowered to deliver the best education. Our overarching recommendation is that specialist teachers and their subjects need to come to the fore in the delivery of STEM education.

This requires teachers with a higher education qualification in their subject area, trained in how to teach their subject as well as in general educational skills. Experienced technicians should support teachers because practical education is an essential element of many aspects of STEM learning. Teachers and technicians should have the right and the duty to undertake first class continuous professional development throughout their careers. Subject-specific experts from relevant communities should support curriculum development and assessment. These experts should be given responsibility and accountability for the quality of their work. There should be a balance in the curriculum between subject content and context. In particular, mathematics education should be boosted – in its own right since numeracy is an exceptionally important life skill – and also as an integral element of the natural sciences, technology and engineering. At A level teachers should be empowered with the flexibility to teach some areas of the course in more depth than others, building on their own interests and aptitudes and to provide stretch and challenge for their pupils. Assessment should follow the curriculum, rather than define it. It should enable the proper testing of concept and content understanding by providing questions that enable extended responses. Even the most able teachers cannot deliver their best unless empowered by curricula and assessment that are both fit for purpose.

Science is popular amongst young people. However, it is not sufficient to assert the importance of STEM subjects at school and in colleges. It is essential that the life opportunities provided by an education in the STEM subjects are presented effectively. There needs to be an effective pull from the marketplace for young people with STEM skills; and, although society needs a STEM research workforce, it also needs young people with technical skills as part of an advanced workforce. It is vital that different pathways into STEM careers are clearly defined and laid out within schools and colleges.

There has been much focus on governance of education at a national level, through regulators such as Ofsted. However, local governance and support of expert STEM teachers is also essential. There is a sophisticated set of levers that needs to be in place to ensure the rich diversity of activities within a school or college that are needed to sustain a first class education. Responsibility and accountability for effective delivery of these diverse activities need to be provided to teachers and their local governing bodies. As one of our respondents said: "You recognise the ethos of a first class school when you go through the front door".

We would like to end by thanking all of those who have given their time and wisdom during our consultation and those who have read successive drafts of this report. We would especially like to thank our hard working secretariat, Matthew White, Rory Gallagher, Alex Morris and Heeran Buhecha. We recognise that it will take time and hard work to implement all of the recommendations in this report – but we believe that the effort is essential and will reap important dividends.



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Executive summary

Background and Introduction

The Science and Learning Expert Group is one of five Expert Groups set up by Government during 2009 to take forward the UK's Science and Society strategy.

We were asked to consider pre-19 science and mathematics learning in schools and colleges, to note where this is currently working well and to recommend how it could be improved. Our Terms of Reference are attached at Annex A). We were asked specifically to consider how to stretch and challenge the most able pupils and ensure that all those with the aptitudes to study the STEM subjects (sciences, technology, engineering and mathematics) at university are given the best opportunities to succeed. It is important that we make a brief taxonomic note at this point – the majority of education in schools and colleges for young people interested in STEM subjects is provided by science and mathematics teachers – and because of this we tend to refer to science and mathematics education throughout the report. In doing so, we do not neglect the importance of technology and engineering as subjects, which many young people will pursue at a higher level in HEIs and employment – and which are subjects, that, together with science and mathematics, are key to the future prosperity of the UK.

We have consulted extensively in undertaking this work. A written online consultation produced a wide range of thoughtful and constructive responses from teachers, lecturers, scientists, engineers, mathematicians, employers and others. We have also visited schools and colleges, and had a series of one-to-one meetings with key stakeholders. In November 2009 we held four workshops to 'road test' our emerging recommendations. The areas on which this report focuses represent those which came up most consistently and most strongly in this consultation. Summary reports of our consultations are provided in the annexes to this report.

Science and mathematics education has been much debated. We are not the first to look at this issue and a list of recommendations from previous reports is attached at Annex E; many of these retain contemporary relevance. We have read and taken note of these previous reports in the context of developments implemented by successive governments to address problems in science and mathematics education.

After a period in which the popularity of and attainment in these subjects declined in schools and colleges during the 1990s and into the early part of the new century, much has been achieved in recent years in reversing this decline and promoting higher take up and achievement in science and mathematics education. There has been a sustained effort by the science and education communities, the Government and many individuals who have contributed their resources, expertise, drive and commitment. The numbers of young people taking science

and mathematics in school and college is once again rising and this country fares comparatively well in international studies of science and mathematics education such as the PISA and TIMMS research.

However, in spite of much good work, there are still significant problems in education in science and mathematics in schools and colleges. In particular, we have identified five important areas where there is significant scope for improvement, building on what has been achieved to date. These areas are:

- the science and mathematics education workforce in schools and colleges;
- curriculum, qualifications and assessment;
- coherent STEM programmes, pathways and enrichment;
- pull mechanisms; and
- school and college ethos.

We consider each of these priorities in turn and make recommendations to support excellent science and mathematics education in schools and colleges, and progression into higher levels of study and employment in STEM subjects and careers.

There are two overarching themes in our recommendations. The first is that the importance of the subjects themselves, ie science and mathematics, needs to be brought to the fore. There is a need to empower science and mathematics teachers as subject specialists within schools and colleges, and to engage them and other subject experts from higher education institutions (HEIs), professional bodies and employers in all aspects of delivery of education, including the design of the curriculum, assessment and progression. We make recommendations that will empower teachers and provide much stronger professional engagement by subject experts from the relevant communities in science and mathematics education within schools and colleges.

Our second overarching theme is that there needs to be much stronger local governance of the educational process within schools and colleges. This requires substantial strengthening of the capacity of the governing bodies of schools and colleges in terms of their role, composition and training. We recommend the development of a framework for support, challenge and accountability for science and mathematics education that can be applied locally within schools and colleges, working closely with the national regulators and agencies such as the Office for Standards in Education, Children's Services and Skills (Ofsted), the Office of Qualifications and Examinations Regulation (Ofqual), the Qualifications and Curriculum Development Agency (QCDA) and the Training and Development Agency (TDA).

An excellent education depends on excellent teaching, a strong curriculum, and assessment that is fit for purpose. It is therefore not surprising that our first three areas of recommendations cover each of these areas. In addition, pupils in schools

and colleges have to choose which subject areas to pursue. Their choices are influenced by the quality of the education they receive, their individual aptitudes and their understanding and perceptions of potential career opportunities. Our fourth area of recommendations therefore relates to enhancement of the 'pull mechanisms' for the STEM subjects. The best education is provided in schools and colleges that have an outstanding ethos, manifested by strong leadership and governance at both an organisational and subject level. For this reason, our fifth and final area of recommendations aims to provide the levers that will enhance the leadership, ethos and governance of STEM education.

Throughout our work we have stuck to our brief, which is to look at education in science and mathematics in schools and colleges to support young people who have an interest and aptitude for the STEM subjects. However, it is impossible and inappropriate to isolate science and mathematics education from other aspects of school and college education. We believe that many of our recommendations, if adopted effectively, have broad relevance to school and college education.

In this executive summary we provide the briefest introduction to each of the five areas of our recommendations, and set out our specific recommendations. However, these recommendations make the most sense if read in the context of the detailed arguments and evidence that we set out in the body of the report.

Priority 1: The STEM workforce

In order to increase the quantity and quality of specialist teachers we will need to continue to recruit more STEM graduates into teaching, provide excellent training for them and retain excellent teachers within the profession by ensuring that their careers are rewarding in every respect. There are important sources of teachers and technicians in science and mathematics from other areas of employment. There are key opportunities in the context of the current economic environment to increase the recruitment of first class people. This has been an active area of policy for some time, and significant progress has been made in developing new ways of attracting and retaining effective teachers. Technical support staff similarly play a crucial role in delivering science with its strong practical element and we must ensure continuing expansion and development of this part of the workforce.

Teachers and technical staff must also be provided with the necessary development throughout their teaching career to enable them to teach most effectively. Continuous professional development (CPD) is central to effective career development for all teachers. Subject-specific CPD is especially important for STEM teachers who need to keep up with the latest developments in their fast-moving subject areas. Both teachers and technical staff need continuing support and updating to develop excellent practical classes and demonstrations for their pupils. New initiatives such as the License to Practice and the Masters in Teaching and Learning provide a basis for career progression rooted in excellent continuous

professional development. It is essential that the highest quality CPD is valued consistently by all schools and colleges and that science and mathematics teachers and classroom support staff should be rewarded for updating their subject and teaching skills throughout their careers.

Recommendation 1: Maintain and extend programmes for recruitment of science and mathematics specialists to teaching, building on, in particular, non-standard routes such as Transition to Teaching and Teach First and take full advantage of the current 'spike' in applicants. While this situation persists, resources should be made available to TDA to ensure that no well-qualified applicant is turned away from science and mathematics teacher training.

Recommendation 2: Technicians should be recognised as essential contributors to the practical teaching of STEM subjects. Metrics should be collected on the extent of technical support within schools and further education (FE) colleges.

Recommendation 3: Schools, colleges and local authorities should make greater use of current recruitment and retention pay flexibilities to reward and retain effective science and mathematics teachers. This should be part of the accountability framework as set out in Recommendation 21.

Recommendation 4: TDA should investigate further the consistency between initial teacher training (ITT) providers in the balance between subject-specific and general pedagogical training to ensure that subject-specific pedagogical training receives a high priority.

Recommendation 5: Schools and FE colleges should collaborate in local clusters to deliver science and mathematics teaching, working wherever possible with HEIs and employers. The collaborative aspects of advanced skills teachers (AST), Specialist Schools and High Performing Schools programmes should be reinforced. Schools and FE senior executive staff should be accountable for establishing appropriate collaborative arrangements and be supported and challenged to achieve this by school and FE governing bodies and Ofsted (see Recommendation 21).

Recommendation 6: Reinforce the link between updating subject specialist skills and career development and progression for science and mathematics teachers, including:

- **more emphasis on updating subject specialist skills in TDA's Professional Standards for Teachers and the criteria for moving to advanced teacher scales;**
- **clear specifications for subject-specific teaching skills and subject knowledge should be integral to the Masters in Teaching and Learning, and the License to Practice and linked to entitlement to subject-specific CPD; accompanied by more effective**

communication to teachers of the CPD opportunities available to them;

- **more effective use of the 5 statutory school training days to improve subject teaching; and**
- **extended in-service schemes such as the second science specialism and conversion to mathematics programmes.**

Recommendation 7: Embed CPD into a clear governance framework at school level through:

- **more effective links between performance management and CPD expectations in schools; and**
- **head teachers reporting annually to the governors of their school on how staff skills are kept up to date and the use of the school's financial resources to support CPD.**
- **TDA and DCSF should establish and maintain robust quality assurance arrangements for CPD providers to support schools in choosing high quality CPD provision.**

Recommendation 8: DCSF should continue to support and fund a national network of Science Learning Centres and the National Centre for Excellence in the Teaching of Mathematics, in order to secure continuing subject leadership, building on the legacy of the National Strategies.

Priority 2: The curriculum, qualifications and assessment

The content and assessment of science and mathematics at GCSE and A level is a prime concern to many within the science and teaching communities – especially in relation to the adequacy of the mathematical content of science education, the increased scope for in-depth study within the subject, the need for accurate use of English language in science and the potential harmful impact of modular assessment on teaching and learning. We make several important proposals to address these. This is an area in which significant changes have been made very recently or are currently planned – both in relation to the design of science and mathematics qualifications and to the roles and responsibilities of the organisations which oversee the qualifications framework, so our recommendations are set in the context of the need to evaluate how far these changes have addressed the issues we identify, as well as the need for further action.

Our consultation revealed widespread concern within the science and teaching communities about the qualifications system. We believe this provides compelling evidence of a significant gap in perceptions and engagement between the specialist organisations which design and deliver qualifications, and the science and teaching communities which provide education. The teaching community

depends on the availability of courses and assessment that empower teachers and maximise young people's potential for science and mathematics learning. In particular, there is a strong perception that assessment has become the 'tail that wags the dog' of the education system and that the assessment process has been inadequate in the testing of students depth of subject knowledge and understanding of key concepts.

We believe that it is crucial to ensure that the education, mathematics and science communities have much greater ownership of and engagement with the development of qualifications and assessment. We believe that this requires a culture change underpinning regular, structured engagement with these stakeholders by QCDA, Ofqual and others to develop high quality science and mathematics qualifications, which have widespread buy-in from across the range of sectors.

Recommendation 9: Ensure that the Higher Education sector and other stakeholders are engaged in the design and development of qualifications and assessment in ways that will enable them to accept accountability for and ownership of the quality of the system. In particular:

- **standing STEM expert groups should be established in each major subject to advise on the development over time of 5-19 curricula and GCSE and A level criteria in these subjects. This should be part of a process within QCDA that puts partnership and shared ownership with stakeholders at the core of its culture. QCDA must ensure that it draws transparently on the best professional, academic and employer expertise in order to develop the National Curriculum, the qualifications criteria signed-off by Ofqual, and to advise ministers; and also ensure that stakeholders are clear about how they can influence the final products;**
- **awarding bodies should engage independent subject experts from HE and business to advise on the development of specifications and examinations in these subjects; and**
- **Ofqual should include in its annual report to Parliament how it engages with the STEM community to ensure confidence in science and mathematics qualifications**

Recommendation 10: Strengthening the mathematics content of STEM pathways:

- **the mathematics content should be boosted substantially within 14-19 science education, and particularly for Chemistry and Physics A levels, drawing on input from the wider science and mathematics community on the level and types of mathematics needed for progress in STEM beyond school/college;**
- **the developments in content and criteria for the new generations of GCSEs and A levels which have yet to be examined should**

be evaluated at the earliest opportunity using the mechanisms outlined in Recommendation 9; and

- if the pilot of the GCSE Mathematics pair is successful it should be available to all students. The mathematics community supports replacing the single GCSE option with the linked pair so that all students follow both specifications at KS4, even if some do not take both examinations. We can see the attraction of this and recommend that this option should be considered in the light of the pilot outcomes.

Recommendation 11: The style of examinations should be rebalanced towards assessment of students' in-depth problem solving and deeper understanding of subject concepts; and there should be greater emphasis on the accurate use of the English language in answers to examination questions. As a first step, QCDA should evaluate the impact of the new criteria in GCSE and A level science, once the new specifications based on them have been examined for the first time, specifically in relation to the assessment of mathematics, students' in-depth problem-solving, and understanding of subject concepts. This should be undertaken according to the principles set out in Recommendation 9.

Recommendation 12: The developing regulatory framework currently being developed by Ofqual for awarding bodies should be strengthened as follows:

- in approving A level and GCSE specifications, Ofqual should ensure that the awarding body has matched the specifications to meet fully the relevant subject criteria, and that sufficient examining expertise and resources are available to the awarding body to deliver their specifications;
- the GCSE and A level awarding bodies should be regulated to prevent competition between them resulting in a lowering of examination standards;
- ensure that the governance mechanisms of the organisations that set curricula and qualifications criteria and that deliver the examinations provide the necessary executive challenge and public accountability for the quality of their work;
- the practice of awarding bodies endorsing textbooks should be stopped; and
- awarding bodies should ensure that they recruit and ensure training for a sufficient supply of examiners to improve the quality of examination question-writing across the full range of science and mathematics specifications. This will be particularly important if the call for more mathematical content in questions is to be

implemented effectively, and if we are to have better 'How Science Works' questions.

Recommendation 13: There should be a major effort to reduce the modular burden of summative assessment at A level. This should include:

- **restricting modular examination sittings to a single period during the Summer term to avoid disruption to teaching and learning at other times of the year and discourage unnecessary re-sits;**
- **making guidance, exemplar material and support available to any school which wishes to teach some or all of its A levels in linear fashion – ie with all the necessary examinations taken at the end of a continuous two year course; and**
- **the examinations at the end of the A level course should include synoptic questions aimed at ensuring that students retain an understanding of subject content and concepts across the breadth of the subject matter covered during the two year course of study.**

Recommendation 14: Scope for in-depth and exploratory learning in science and mathematics should be increased through:

- **greater flexibility to explore some elements of the course in greater depth. This will require modification of the examination system to allow a greater degree of choice in answering questions; and**
- **encouragement and guidance to schools and colleges on using the A level Extended Project to support science education programmes by providing opportunities for exploring the ways of working used by professional scientists, including working collaboratively. Completed projects should be available as a portfolio of work to support HE admissions.**

Priority 3: Coherent STEM programmes, pathways and enrichment

All young people should have access to coherent pathways in science and mathematics education so that they can achieve appropriate qualifications and gain the necessary experiences (both in the classroom and through external enrichment activities) to progress to different areas of STEM in further or higher education or employment, according to their aptitude and attainment. A variety of routes, including GCSEs, A levels, vocational qualifications, and the new Science and Engineering Diplomas provide opportunities for young people to match their choices to their preferred learning styles, aptitudes and destinations in employment and HE. It is essential that these options are differentiated clearly and

communicated unambiguously. This will ensure that young people can make their choices based on the best information.

Success in STEM at higher levels requires more than specialist subject knowledge. Students must acquire more generic skills and experiences, such as the ability to use language effectively and to work on long projects, often in teams. These requirements are not always evident to young people when they are choosing their A levels, and the structure of A level programmes does not automatically mean that they will acquire this wider learning as a natural part of their programme. In particular, HE needs to do more to explain the breadth of skills and attributes it looks for in potential STEM recruits.

In this context, practical and project work, and the opportunities for enrichment of STEM education outside the classroom, are important as ways of engaging young people in science and mathematics, and delivering the experiences and skills that are needed to underpin later study and employment.

Recommendation 15: The science community and higher education institutions should provide clear information and advice to young people about the range of learning and achievement they value beyond specific science and mathematics specialisms as preparation for progress into STEM HE courses.

Recommendation 16: The niche for the Advanced Science Diploma needs to be defined clearly as an educational route for those planning to enter applied science careers. The new Advanced Science Diploma should be developed as a differentiated, rigorous and challenging pathway for applied science learning.

Recommendation 17: There should be more support, guidance and CPD for science teachers on delivering effective practical learning to enable students to participate in practical science and to provide practical demonstrations at all levels (see also Recommendation 6). Support from scientifically-qualified and experienced technicians should be available to specialist science teachers. This should be part of the accountability framework as set out in Recommendation 21.

Recommendation 18: All students following science and mathematics subjects in schools and colleges should be entitled to good quality enrichment:

- responsibility for access to this should be locally devolved and should be an aspect of school and college performance for which school leadership should be held accountable (see Recommendation 21); and
- the development of consistently high-quality enrichment for all science and mathematics learners should be promoted, especially through the development and dissemination of good practice.

Priority 4: Pull mechanisms

It is necessary but not sufficient to provide first class education in science and mathematics: it is also essential in addition to explain to young people what opportunities in life and employment are enabled, enhanced and enriched by such education. This is not a matter for schools and colleges alone; it requires the input of Higher Education Institutions (HEIs) and employers. The incentives and communication which come to young people – especially from HE, employers and careers advice – are essential in order to give young people an insight into the benefits and options open to them from careers in STEM subjects. We have considered the information, advice and guidance that young people receive currently at schools and college, and also the input that universities and employers make to pre-19 education. Some of the schemes already in place in this area are truly inspirational; however, too much of this activity is done on an *ad hoc* basis and we have considered how it can work more systematically and effectively.

Recommendation 19: All young people should receive planned systematic information, advice and guidance on STEM careers from KS2. This should be integrated into science lessons and enrichment, rather than being an 'add-on', complementing the support provided by external services and specialist careers teachers:

- **teachers, including subject specialists and other staff who provide information, advice and guidance on science progression, should receive regular, up to date training and resources on how to provide this information and specifically on what jobs and further courses exist in STEM and related subjects; and**
- **regional networks amongst schools and FE colleges should ensure that, within a locality, as many students as possible have access to high quality information, advice and guidance.**

Recommendation 20: Continue to develop HE's links with schools and colleges, through:

- **the follow up to the National Council for Educational Excellence (NCEE) recommendations and making progress with, and building on, the Goodfellow/Coyne recommendations;**
- **improving the opportunity for short-term placements and exchanges of skilled personnel in schools, FE, HE and the workplace; and**
- **developing guidance on appointing governors who have specific knowledge and experience of working with or in industry or HE in order to facilitate links between schools and these sectors.**

Priority 5: School and college ethos

In order to create a culture amongst schools and colleges that fosters a commitment to excellence in science and mathematics, accountability mechanisms and incentives are crucial. We have considered how the leadership and governance of schools and colleges can encourage and enable excellence in STEM education. Strong leadership at an institutional and subject level, held to account by supportive and challenging governance, is the best way to ensure the delivery of excellent science and mathematics education. We make recommendations to strengthen the governing bodies of schools and colleges and to improve the accountability of schools and colleges to their governing bodies for the delivery of excellent education. Strong local governance is important to support the development of local and national networks that can share good practice, support and advice to schools and colleges on the delivery of high quality science and mathematics education.

Recommendation 21: The governance mechanisms for STEM education should be transformed by:

- **strengthening the capacity of school and FE college governing bodies to provide rigorous governance combining support and challenge to the executive team, including rigorous training and wider recruitment of governors with experience of accountability systems in other environments including the commercial sector; and**
- **Ofsted, working with Government and other stakeholders, should develop a Statement of Recommended Practice (SORP) for schools as a robust framework for identifying and measuring progress against key measures of performance that should drive and challenge the executive to provide a first class education. For science specialist schools the new School Improvement Partners should be individuals with matched specialist expertise in STEM, and should work with governing bodies to support their specialist mission; schools and colleges should produce a public annual report setting out their performance in relation to these measures.**

Recommendation 22: Strengthen the capacity for well-planned, coherent science and mathematics education within schools and colleges by supporting the development of local clusters for sharing advice and support on curriculum planning and subject leadership. As part of the promotion of local clusters, reinforce the impact of specialist science and engineering colleges and schools to deliver outstanding science and engineering education; to support local curriculum leadership and collaboration; and to share expertise in the planning and delivery of STEM education in schools.

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