Call for views: organisations' responses

The responses in this document are reproduced verbatim. Please note that not all respondents answered every section of the Call for Views, or all questions within each section. The original complete survey is provided in the Appendix.

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Abington Partners

1. a) What is good about UK science and mathematics education?
Mathematics education is on the whole good right up to the later stages of school although applied maths whilst rigorous lack real practical experiences. Physics is poor throughout lacking rigour at A level and being poorly assessed both in terms on knowledge but particularly in terms of practical science. Chemistry is somewhat better but relies far to much on teaching of factual knowledge and descriptive learning of complex analytical techniques. Biology lacks good experiences in practical work, is often not rigorous particularly in mathematics and the physical and chemical elements of the subject.

2. 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?
Significantly more emphasis on developing practical capabilities in students, Much more emphasis on creativity and discovery in science. Much more cross curricula experiences in the classroom.

3. c) What, if any, broader educational issues concern you? (These may or may not relate directly to science and mathematics education)
Students in science need communication skills which need to be a requirement in the curriculum.

4. d) How can a science and mathematics education system best meet the needs of employers and higher education?
Do all of the above. Involve employers in assessment. At present its a black box that only educationalists see inside.

5. Other comments
We need to have a curriculum that encourages large numbers of students to study stem subjects.

6. 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?
The far east is more fact oriented but at least they are more rigorous. We have experience of students from the Grand Ecoles in France and their capabilities are spectacular but they are at the top of the system.

7. b) What specific aspects of other countries’ high-performing education systems should we be learning from?
By all means look at other countries but also think innovatively about how we can do it better.

8. Other comments:
No Response

1. a) What needs to be done to make teaching a top career choice for trained scientists and mathematicians?
Ensure good science teachers can stay teaching children and not become school managers. i.e. higher salaries for staying as a science and maths teacher. Perhaps based on research activities and peer review.

1. 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?
Subject specialists at secondary level should have a degree level qualification in their specialism. Teachers must be tested for their ability to innovate in teaching and carrying our research.

2. 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?
Probably particularly in difficult subjects. We should also have teachers who are maths and science practitioners concurrently with their teaching role.

3. c) What is good about initial teacher training programmes in science and mathematics in the UK?
Not very much from what I have seen beyond crown control.

4. d) What changes to these programmes (eg philosophy, content, or emphases) are needed?
Much more emphasis on the teaching of the subject, Use of technology, and how to be innovative and carry out research.

5. e) How can the standard of science and mathematics initial teacher training programmes be of a consistently high quality across the UK?
Get them assessed by people form outside the education fraternity.

6. f) What types of courses (full and/or part-time) should be provided for training new science and mathematics teachers. Why?
It should be ongoing throughout a teacher career. Particularly in the effective use of technology and the development of better teaching methodologies.

7. g) In what sort(s) of institution(s) should science and mathematics teacher training take place? Why?
Imagine a collaborations between employers, a university and schools to deliver a training course aimed at getting wheat we need to transform mathematics and science education.

8. h) How much of this training should be spent gaining experience in the classroom?
A considerable amount.

9. i) How long should courses be for training (i) primary; and (ii) secondary science or mathematics teachers to become fully qualified?
Primary probably 1 year is adequate. At secondary it needs to be 10% of time for the career. You don't just become a good teacher for ever. it has to be developed over time.

10. Other comments:
One of the problems is highlighted by a comment from a Head of Science I spoke to today. "I only deal with children I don’t deal with anything technical". How will we ever move teaching into the 21st century with that kind of attitude!

1. a) What are the benefits of subject-specific CPD for science and mathematics teachers?
Mostly its rather antiquated. Courses aimed at how to be more creative and use technology more effectively have very poor uptake.

2. b) How should science and mathematics teachers best keep up with their subject and with new approaches to teaching, assessment and the curriculum?
There should be a requirement to attend training courses in appropriate areas on a regular basis. Also collaborative meeting to discuss best practice between schools should be set up.

3. c) At what times throughout their teaching careers and with what regularity should teachers undertake subject-specific CPD?
say at least once every 5 years but the courses need to me checked. This must not be a tick box exercise.

4. d) Should CPD be voluntary or mandatory? Why?
Mandatory because teachers are happy to lie in bubble of their own if its not.

5. e) Are there key obstacles preventing science and mathematics teachers from accessing subject-specific CPD? If so, how can these be overcome them?
Yes there is not enough time. We have really struggled to get time with teachers to provide CPD even though it is funded activity.

6. 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?
No. Its is different and actually we don't necessarily want all science and maths teachers to become leaders.

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

8. Other comments:
No Response

1. a) How and where should we be training laboratory technicians?
Partly in industry and university research laboratories so they can see best practice in the work place.

2. b) What CPD needs will laboratory technicians have and how will these best be accommodated?
Understanding of laboratory management outside the school environment as well as inside it. Awareness of how things are done outside education.

3. 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?
Yes. particularly if they have a role outside a school which uses science and mathematics skills. Supporting practical activities which tend to be support heavy.

4. 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?)
Most careers advice is very poor. Its a very diccicult area but start from understanding the local STEM businesses and what the offer. there is no local database of who these companies are.

5. Other comments:
No Response

1. 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?
This is really complex and depends what you mean. Certainly science and maths should have a say in the SMT in schools and there needs to be an emphasis on schools directing students into STEM subjects which doesn't exist at present.

2. b) What kinds of leadership skills should science and mathematics teachers be able to acquire?
Teaching in school is a lonely process. Finding ways to get teacher to collaborate more would be good.

3. c) How can school and college leaders encourage leadership among science and mathematics teachers?
Include them in the SMT.

4. d) How can leadership pathways for experienced teachers be introduced into careers?
Do we really want the best science and maths teachers to become leaders who don't teach science and maths?

5. e) What factors are most responsible for creating the ethos of different schools and colleges?
The head teacher.

6. 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?
this is very significant. The school ethos will influence whether the outcomes are judged on assessment or excitement for instance.

7. 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?
Governing bodies set an overall strategy but rarely in my personal experience get involved in subject specific aspects of the ethos.

8. Other comments:
No Response

1. 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?
Communication, innovative thinking, practical, working collaboratively etc.

2. b) How may the acquisition of such skills best be assessed?
They aren't at present!

3. c) How important is the impact of the transition between primary and secondary phases in terms of pupils' progression in (science and mathematics) education?
At primary schools many student experience cross curricular collaborative activities. This disappears at the transition. Retain it.

4. 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?
Less content, more understanding of applying maths and science to problems.

5. e) What characteristics of assessment best serve learning in its various forms in school science and in mathematics?
None that are used at present.

6. f) To what extent can/should science and mathematics be effectively assessed through other subjects?
It should be looked at from the perspective of what is needed in the world of work and then assessment should be across all subjects as appropriate.

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

With the move to education be required up to 18 it should happen at that age. Before tat there should be assessment aimed at checking a schools performance (not necessarily the whole cohort).

8. h) What evidence of learning is needed for assessment to operate effectively?
Not sure what this question means!

9. Other comments:
No Response

1. a) Where will/should science/mathematics primary and secondary school learning take place, both within and outside school?
Learning should move from the rigorous class room model. Look at models of learning which are more project based with activities being carried out in the schools, homes and through visits to relevant environments for particular teaching activities.

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

3. c) What kinds of specialised facilities, linked to key areas of learning in science and mathematics, should be available in the future?
Students should experience using the kinds of equipment and environments which they will encounter in the world of work. What research laboratory uses bunsen burners to heat experimental set ups? What research laboratory carried out measurement by hand? This needs to be transformed through investment.

4. 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?
Again look at the whole as cross curricular. We have worked as much with the English department on science projects as the science department.

5. e) What other resources and systems should be used to support science and mathematics?
Lots of technology and equipment.

6. f) What other more general changes to school infrastructure would support excellent science and mathematics teaching and learning? How can we measure this?
Look at the building as a scientific experiment for instance. See the work done at the Kings School in Peterborough for an example.

7. g) What evidence is there of the effect on their learning of science and mathematics of separating cohorts by (i) age and (ii) gender (eg should there be single sex classes or schools)?
Not sure. Certainly some single sex schools get a lot of girls doing physics.

8. Other comments:
No Response

1. 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?
Ofsted should have representatives (appropriately trained) from industry, government, HE etc.

2. b) How should qualifications in science and mathematics be regulated?
There should be an involvement in the process from employers as well as education.

3. c) How can we ensure that all students can access the science and mathematics courses they wish to?
Collaboration between schools which requires incentives to do so.

4. d) What are (i) the advantages and (ii) the disadvantages of performance targets and do any apply particularly to science or mathematics education?
Beware the targets will deliver what they measure. Not what you want.

5. e) How should measures of performance best be reported to different audiences? What other measures of performance may be required?
We should measure engagement with employers and HE.

6. Other comments:
No Response

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2. Organisation (if applicable)
Abington Partners

ASE

A response to the Royal Society 'Vision for science and mathematics education 5-19' Call for Views.
The **Association for Science Education (ASE)** is the largest subject association in the UK. Members include teachers, technicians and others involved in science education. The Association plays a significant role in promoting excellence in teaching and learning of science in schools and colleges. Working closely with the science professional bodies, industry and business, ASE provides a UK-wide network bringing together individuals and organisations to share ideas and tackle challenges in science teaching, develop resources and foster high quality Continuing Professional Development. The Association for Science Education can trace its origins back to 1900. Incorporated by Royal Charter in October 2004, the ASE operates as a Registered Charity.

The Association welcomes the opportunity to respond to this Call for Views which is informed by ASE's national primary science, 11-19, Laboratory Technicians, and Safeguards committees plus ASE's special interest group of the National Advisers and Inspectors Group for Science (NAIGS). Together these groups bring expertise and a range of viewpoints, including those of classroom practitioners in schools and colleges, initial teacher education, education research, and professional development.

This response is not designed to present a particular view from the Association but rather to give an opportunity for the expertise within our national groups to voice their considered views following group discussion; with a particular focus on the areas of Teachers and the wider workforce, and Leadership and ethos. Given the time limitations for producing a response, we have chosen not to focus on the other areas requested, but can draw on recent policy statements for contributions on the area of Skills, curriculum and assessment, should this be of interest.

Teachers and the wider workforce

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

To make teaching science an attractive career, good working conditions are required. These include good support for practical work (including fieldwork) including adequate equipment, laboratory facilities and good laboratory technician support.

Treat teachers and the wider workforce as professionals. Provide attractive, comparative remuneration to other professions and clear career progression routes.

Provide an entitlement to subject specific professional development for all teachers as part of a personalised CPD programme over the first three years in teaching.

Build links with science industry and universities to allow employees and students to have 'sabbaticals' in schools. Provide sabbaticals for teachers to allow them either time to carry out voluntary work/further study/interest (e.g. Canadian model of 4 years at 80% salary, 1 year sabbatical at the same rate).

There would need to be a relaxation of the National Curriculum so there was greater freedom to develop in-depth approaches to aspects of study. That would enable teachers to encourage greater understanding in their students, with flexibility to develop students' own ideas as a element.

More history of science plus more science career scenarios as a part of the standard curriculum - not just what effective science teachers provide because they intuitively know this works. More settings of science in social and environmental ethical situations so that the positive aspects of science applications becomes self-evident and engages the moral and emotional sensibilities of more young people who see the possibilities of a real career interest area through sustaining science learning.

Ofsted inspections need to be perceived as less gladiatorial and combative.

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

The main benefits are in maintaining enthusiasm for one's subject, keeping up to date on the often fast-paced scientific and technological developments in a variety of contexts, and providing support for teachers in making science engaging for all students including those considering a career using their science.

Though there are some aspects of subject specific CPD that are important such as management of practical work and specific training for Heads of Science, much of CPD needs to focus more broadly on teaching and learning across the subjects – with time allocated for reflection and identifying new goals, to explore and share ideas, strategies and innovative approaches.

General benefits of CPD are feeling valued as a professional, feeling empowered to choose targeted support and feeling supported and able to take risks in trying new approaches and reflecting on their impacts.

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

Look at and learn from models from other professions and give time for keeping up with the subject. This should be a valued part of the job and schools need find the time to introduce it. Look for models of school years that build in more time - about 5 days annually would be required.

One size does not fit all. A variety of approaches are needed including face to face training, regular events with other teachers from different local or regional schools to share good practice (cluster meetings, teacher learning communities, Teachmeets) , online training/webinars and video conferencing, online resources/newsletters/email alerts.

Mentoring and coaching on the job are important, as well as online mentoring. Provide opportunities for teachers to observe effective teachers critically and reflectively, to then apply what they see and account for what works. Science teaching coaches in the department who are dedicated to raising teaching and learning levels can have positive impacts.

Opportunities to interact with scientists and HEI with relevant expertise are also important.

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

There should be an entitlement for all teachers to undertake subject specific CPD throughout their careers to renew their skills and update their knowledge of science ideas and further refine their science pedagogical content knowledge.

At least one of the six annual training days should be subject specific and linked to a personal action plan (reflection and impact on practice), endorsed by senior leadership. Professional development should be personalised and teachers able to choose the type of CPD to meet their requirements, taking into account when and how it will be provided.

Different models could be explored, including the current FE model, which has a bank of hours that can be cashed in over three years for CPD with a menu of subject specific choices within this.

Sabbatical periods, for example one term every five years, for effective teachers are also considered to be valuable.

In addition, regular discussions, presentations, seminars, or workshops on the pedagogy relating to learning specific science concepts and procedures should take place in every science department.

Should CPD be voluntary or mandatory? Why? d) What, if any, impact would the imposition of any formal requirement to undertake subject specific CPD have on teacher retention?

Professional development should be mandatory with an understanding that it impacts performance management and career progression and in line with the requirements of most other professional bodies have this as a requirement that their members are kept up to date with developments in their profession. This sends a clear message that updated subject knowledge and subject pedagogy is important and is valued by senior leaders and Governors.

However there should support in place to enable this CPD to take place. With a personalised programme of CPD, teachers will feel valued, empowered and informed, and will value professional development opportunities; thus it will have a positive impact on teacher satisfaction and retention.

However, a realistic view of CPD is also required, to understand and counter the notion of some teachers that impositions of formal requirements engender an elaborate and skilled process of getting through the required training with the least possible effort and variation away from the normal practice.

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

There is a perception still in this country and elsewhere that teachers are a working group, not a profession, despite fulfilling the criteria of having esoteric knowledge required teaching to develop effective learning in young people. The perception that the science curriculum in schools and colleges is unchanging and that there is little room for innovation; and hence the need for CPD, both in primary and secondary science education, persists.

Competition with whole school priorities for professional development is a major obstacle. Budgets and time, to take time out of the classroom to carry out CPD and then cascade to colleagues back in schools, are in increasingly short supply and present major obstacles to CPD uptake. Teachers' morale, workloads and perceptions on the benefits of CPD can also be seen as obstacles by some of the profession.

A strategic approach, focusing on a personalised model of CPD is required and might include: ring fenced funding for professional development activities with all teachers have their own professional development allowance, a review of school holidays, the school working day, with the objective that CPD is built into the status quo to the status and not perceived as an unreasonable add-on. CPD should have a more local, classroom based focus for delivery.

CPD for teachers 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?

There is a strong case for linking broader, whole school strategies into the CPD offered in subjects, and this is important for securing the impact of science CPD. Increasingly under the new Ofsted Inspection Framework, subjects are expected to have clearly identified opportunities in lessons for assessment and aspects such as literacy. Recent school inspections under the new Framework have identified these as development areas for subject teachers. In primary schools, opportunities for leadership are more limited than in larger secondary schools and leadership in primary schools is usually linked to more generic concerns than subject specific concerns.

There should be a balance between whole-school professional development and subject-specific professional development entitlement. Both are needed and both are valuable to the whole school and the individual.

CPD for teachers g) Should CPD be accredited (eg through the awarding of Masters-level credits)?   To what extent should subject specific CPD be used to develop, and recognise, teaching expertise, through Chartered Teacher status or other forms of accreditation?

Teachers should be given the opportunity for accreditation for professional development activities undertaken. For Masters-level accreditation, subject-specific CPD should be a mandatory component.

Teaching expertise is critical; subject expertise may not translate into teaching expertise. Chartered Teacher status (particularly the current CSciTeach) needs to be given more credibility with recognition through the National College of School Leaders. Secondary teachers appear not to apply for Chartered Status because school leadership does not value it. It is a useful milestone to have, but currently does little to sway the majority of interview panels.

Leadership and ethos

Leadership and ethos 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 impact of effective leadership on the quality of education, student experience and performance of departments is huge.

‘A leader is one who influences a specific group of people to move in an inspired direction’ J. Robert Clinton defines leadership as lifting a person’s vision to higher sights, raising a person’s performance to new and higher standards, building of personality and character beyond normal limitations and expectations. Peter F. Drucker’s visionary teachers understand the transformative project they are undertaking when setting out to develop a novice class into an expert group of individuals within the subject setting.

In his review of the literature Hattie (Hattie; Visible Learning 2009) identifies two main types of school leaders, he implies but doesn’t specify that he is referring largely to school Headteachers and Principals, however many of the criteria could also refer to Subject leaders in science and maths. Hattie’s distinctions are Instructional Leaders and Transformative Leaders. Instructional leaders have ‘their major focus on creating a learning climate free of disruption, a system of clear teaching objectives and high teacher expectations for teachers and students’. He describes transformational leaders as those leaders who ‘engage with their teaching staff in ways that inspire them to new levels of energy, commitment and moral purpose such that they work collaboratively to overcome challenges and reach ambitious goals’.

Hattie’s review of the evidence would suggest that Instructional leadership is more effective, especially in primary education. He continues to list dimensions of leadership that have the greatest effect on student outcomes; ‘promoting and participating in teacher learning and development; planning, coordinating and evaluating teaching and the curriculum (direct involvement in the support and evaluation of teaching through regular classroom visits and provision of formative and summative feedback to teacher); strategic resources (aligning resource selection and allocation to priority teaching goals); establishing goals and expectations and ensuring an orderly and supportive environment such as protecting time for teaching and learning by reducing external pressures and interruptions, and establishing an orderly and supportive environment both inside and outside classrooms’. Much of this could be assigned to Subject Leadership.

Throughout his review of the literature on school leadership, Hattie finds that the most important factor for school leaders is to concentrate on Learning and Teaching and it is through this that they achieve their greatest effect. If one sets a vision about significantly changing/improving the Learning and Teaching within science departments of a school or college and see this through with the entire department involved, it will always move the department on. This does not necessarily imply that results will automatically improve, but as long as good tracking, monitoring and intervention strategies are in place, engagement should improve, quality and consistency of teaching should improve and standards at least be maintained.

Primary Science Quality Mark is a high quality means of evidence of the impact of leadership on the quality of the science learning and engagement that takes place in primary schools.

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

Leadership is about having a vision and management is about how to achieve the vision. Both leadership and management skills are essential for school leadership. Leadership qualities, whilst harder to teach than management skills, can be improved; leadership skills like interpersonal skills, emotional intelligence, communication, moral purpose, resilience, vision, beliefs will all improve with self–reflection, a good system of coaching and mentoring and then a good support network to help people access the CPD or experience they need to develop as a leader.

Management skills include the day to day running of the department, time management, lesson observation, performance management, QA, scheme of work design, health and safety rules, procurement of a wide range of equipment, and importantly, data analysis, controlling variables and having a critical view of the validity of data sets. In the current climate of targets and tracking and monitoring performance of students and staff, this is a very valuable skill set.

The areas where subject specific development is needed are concerned with management of health and safety, and management of associate staff.

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

All schools should be looking to grow all their leaders regardless of subject by developing leadership programmes or accessing programmes external to the school, developing mentoring programmes for new leaders, providing opportunities for networking between subject leaders within a local area, auditing leadership skills and supporting performance management linked to professional development.

In his section on leadership Hattie (Visible Learning 2009) describes how whole school leadership can engender job satisfaction among teachers. The best way that school and college leaders encourage leadership in others is to demonstrate good leadership themselves. Schools that focus on teaching and learning, cut down bureaucracy, celebrate success and achievement in both students and teachers (for instance, in achieving CSciTeach and entry into National Teacher of the Year Awards) will create environments where colleagues wish to excel.

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

Leadership can be encouraged through work-shadowing of colleagues on the leadership team and/or providing opportunities for experienced teachers to lead on a project across the school. Temporary secondments to the senior leadership team have been used successfully in many schools.

Well established whole school coaching and mentoring programmes are important in all schools, followed by a personalised plan for aspiring leaders with an appropriate time period, to be extended or adjusted to do the job effectively.

Whilst the focus is on leadership pathways here, professional development and performance management should be used from NQT/GTP upwards to develop individualised career pathways for teachers. These should be linked to the core standards and professional standards for teachers at different levels.

Career pathways exist, especially if the Master Teacher status is accepted. Teaching and Learning points, with pay scale points for experienced teachers working in leadership positions, are seen as valuable incentives for professional development and should be retained with budget restructures.

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

The ethos is largely due to a shared vision amongst all the staff about the values of the school and how it is communicated to the students and the community. It is the role of the Head and the senior leadership team to set out the vision and to model and encourage all staff to be part of that vision.

Underpinning the vision, a range of factors is important including creating a culture and climate for learning with high expectations from everyone in an atmosphere of enrichment, equality and inclusion. Additionally inspiration and innovation, hope and passion, diligence and perseverance, openness and calculated risk taking would be some of the factors characterising the ethos of successful schools.

Leadership and ethos 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?

The vision and ethos of a department and school, articulated by the leadership, have a huge effect on the quality and performance of the science department. Subject leaders demonstrating persistence, enthusiasm and tight organisation can be the greatest agents of change in improving the quality and range of science and maths education within schools. There is observational evidence that for instance the courses, extra-curricular activities and enrichment offered by a department demonstrate the impact on ethos and individuals' leadership, and not necessarily those in positions of responsibilities.

The ethos of the school has a significant impact on the quality and range of provision. Leadership that equally values every individual learner, meeting the needs of all abilities and interests, through providing a rich, successful and enjoyable learning experience will generate success attainment and achievement success across the board, with healthy numbers of students studying sciences or mathematics to higher levels and in work related contexts. Evidence of success is also seen through teacher retention and positive staff voice.

Leadership and ethos 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?

Governing bodies support the head and senior leadership team to develop the vision and ethos of the school. As executive leaders of the school, governing bodies take responsibility for what the school is, does and achieves; holding the school to account for the attainment and progress of their students. High attainment will only be achieved if the curriculum pathways on offer, together with effective teaching and learning provision, meet student needs. Governing bodies should be aware of this and through their monitoring role, ask the right questions to support science and maths departments to provide this.

The ethos of the school rarely affects one subject in isolation. The only time this may happen is in specialist schools, which is becoming less of a focus for many as specialist schools' funding has been removed, even though the designation is not.

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?

Effective science teaching learning is underpinned by substantial, high quality practical work. This in turn depends heavily upon the support of a sufficient number of properly trained and skilled technicians. Therefore it is vital that school and college leadership and management understand and value the contribution that technicians make to the work of an effective science department.

We note that those working as technicians in schools and colleges come from a very wide variety of backgrounds including:

- those who have been formally trained as technicians (eg through a City & Guilds or TechCen route);
- those who have a scientific background, possibly in a relatively narrow area but no training in technicians' skills (eg, graduate scientists); and
- those who have little by way of scientific background.

Therefore, we believe that training for technicians is an entitlement for all should be provided in a manner which meets individuals' needs, considering their specific roles and responsibilities, prior experience and training, requirements of legislation (eg, health & safety) and provides an appropriate induction into any new roles and situations. Additionally, CPD for technicians is required to maintain and develops skills, knowledge and understanding in line with current best practice. CPD must be accessible, affordable and inclusive of all technicians, and support professionalism and progression, demonstrating clearly to technicians, line managers and employers what has been addressed and achieved through each particular episode of training. Importantly, CPD must be of demonstrable high quality and has impact on practice.

It is important to distinguish between:

- baseline training, which fills in skill gaps for the day to day work of technicians and includes induction into the procedures and practices of an individual department; and

- higher-level professional development, which provides added value to the science department in enhancing the quality of teaching and/or management and leadership. Such training for experienced, senior technicians may include aspects of leadership and management, working in the classroom, working as a practical demonstrator and providing advice to trainee teachers, NQTs and non- specialist teachers. A recent National Technicians' Survey (ASE) expands on the activities required by some technicians.

In order that technicians' varying, individual needs are met, we believe that each technician should, before and/or after appointment, be required to complete a self -assessment of their scientific/technical skills and knowledge and match these to the requirements of their job in a particular establishment. This will determine the immediate induction and training needs and help to determine the nature and extent of their on-going, longer term professional development and enhance their career prospects. (A resource that is already available to assist in this self-assessment process is available to members from CLEAPSS (Guide DL234, *Induction and Training of Science Technicians*.))

The Royal Society might find it of value to study the system in Scotland and to contrast it with that in England and Wales.

The new Register, supported by the Science Council and ASE, RSciTech, has a requirement for continuing professional development. Failing to provide such training denies technicians the opportunity to achieve and retain their registered status.

Association of Mathematics Education Teachers (AMET)

1. 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?
At present primary PGCE students only require grade C at GCSE in Maths and Science subjects. However many of these students (with grade C) are not confident with maths and science subject knowledge. In an ideal world they should have grades higher than C although this might have an effect on recruitment. Perhaps they should be given more support with subject knowledge in the manner of SKE courses for Secondary PGCE students. For secondary PGCE, students are recruited who have a related degree of a lower second degree or higher. If this were revised to upper second as a minimum this would affect recruitment and we would lose out on some potentially good teachers. Some students enter Secondary PGCE in maths or science through a SKE in their subject. At present there is no requirement that their A level in the subject should be above a particular grade. However it may be a reasonable suggestion that the candidate has grade C or above in an A level in their subject if they are to go on to a SKE course (or an equivalent level 3 mathematics qualification from a less traditional source such as HND engineering). When we ask those involved in training and educating mathematics teachers we invariably find that their experience is that students with upper second class and lower second class degrees

are each as likely to become excellent teachers. Students who come into teacher training with first class degrees are no more likely to become better teachers than those with second class degrees. In fact some may struggle to understand where their pupils may experience difficulties, then again, they may be very good teachers. The point is that we find no correlation between degree classification and their final grade when completing their teaching qualification.

2. 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?
No Response

3. c) What is good about initial teacher training programmes in science and mathematics in the UK?
There is a lot of good practice in ITT for science and mathematics. The support that the course tutors give is very good. Most school tutors are supportive and helpful. There are some schools where the classroom practice in maths and science lessons leaves a lot to be desired and the ITT students do not get to see the good practice they learn about on their ITT courses. Other good aspects of Maths and Science ITT are the support for developing subject knowledge and also pedagogical content knowledge and connecting this to classroom experience. These three aspects were identified as crucial by Ofsted and praised in the 2009 – 2010 review of teacher education as a crucial factor in securing the high quality of students trained in HEI settings.

4. d) What changes to these programmes (eg philosophy, content, or emphases) are needed?
What would really improve school experience for the ITT students would be if the school had a good CPD programme so that teachers and ITT students could learn and develop together. Coherent policies that support the ongoing development of teachers in employment together with the training of new entrants to the profession are an inherent part of provision in all the high performing countries that the current government is keen to emulate. In addition to this, teachers in employment in these regimes have an entitlement to professional development and an expectation that they will engage with it that we do not have in England.

5. e) How can the standard of science and mathematics initial teacher training programmes be of a consistently high quality across the UK?
Most of these courses are of a high quality, particularly those based in HEIs (see 2009 -2010 Ofsted report). It has to be understood that recruitment to these courses is not as easy for mathematics as for other subjects such as English and the Humanities owing to the overall shortage of mathematics and science graduates and the other opportunities for employment open to such candidates. Maths and Science ITT courses recruit some students who are not of such a high calibre as those for some other subjects such as English. This inevitably has effects on the outcomes at the end of the course.

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

The courses need to link practical classroom experience with theoretical understanding both of ways of teaching specific subjects and of the ways in which children learn at different developmental stages. Courses also need to allow space for students to reflect on their own professional learning and to develop as reflective practitioners. The PGCE or BA based in an HEI is best placed to deliver this.

7. g) In what sort(s) of institution(s) should science and mathematics teacher training take place? Why?
HEIs are the best places for ITT of maths and science to take place because the tutors combine their own classroom teaching experience with up to date knowledge of educational research and development. They are in a position to offer the students understanding of the broader picture of education and schooling than schools can on their own. The universities are also good at ensuring quality control of the ITT process.

8. h) How much of this training should be spent gaining experience in the classroom?
At present two thirds of the course is spent in the classroom and this is more than adequate to gain the necessary practical experience. Time is also needed to develop understanding of the necessary knowledge of subject, ways of teaching it and of the ways in which children learn it. The criteria, as presented in Annexe E, does not make it clear whether prospective teachers will experience anything more than training in two schools. Teachers should be prepared to teach so that they can work effectively in any school, and they need the wider context which is provided by Higher Education Institutions. As key findings in the Ofsted annual Report for 2009-10 states: There was more outstanding initial teacher education delivered by higher education-led partnerships than by school-centred initial teacher training partnerships and employment-based routes. It is surely important that prospective teachers, have the opportunity to develop a wider set of skills than will be provided by experience in just one or two schools during their initial education and training.

9. i) How long should courses be for training (i) primary; and (ii) secondary science or mathematics teachers to become fully qualified?
The year long courses for PGCE could be usefully lengthened to two years to ensure a more secure set of knowledge and skills for teaching. This would match more closely with programmes in the high performing jurisdictions across the world. Question about amalgamating the criteria between different routes into teaching – IMA commented The different schemes (GTP, SCITT, Teach First, BA, PGCE) are very different. There is a danger that bringing them all under one set of criteria will result in a lowering of overall standards.

10. Other comments:
These comments are the joint submission of the Association of Mathematics education Teachers (AMET). Chair is Dr Jenni Back

1. Name
Sue Forsythe
2. Organisation (if applicable)
on behalf of Association of Mathematics Education Teachers (AMET)

British Mycological Society

The British Mycological Society (BMS) believes that science teaching should include an appreciation of the importance of different prokaryotic and eukaryotic kingdoms. With the interest in more integrated science at school and University, including diversity and systems biology, mathematics skills and biology-mathematics skills are also critical. We believe that the teaching of biology should include basic knowledge and practical classes to enhance recognition of the importance and economic significance of fungi in a very wider range of applications in the environment, food and industry sectors. Fungi also have key impacts in the contexts of food security and climate change.

Key points that should be used as part of the curriculum include:

- Kingdom Fungi is huge with considerably in excess of 1.5 million species
- The terrestrial ecosystems of planet Earth would not work without fungi. Almost all plants rely directly on fungi to obtain nutrition. Many animals rely directly on fungi, and almost all indirectly on fungi
- Decomposition processes and nutrient cycling all rely on fungi
- Products obtained from Kingdom Fungi include antibiotics (e.g. penicillin), cholesterol-lowering drugs (e.g. squalistatins) and crop protection chemicals (e.g. strobilurins)
- Many industrial enzymes are harnessed from fungal fermentations, such as enzymes for softening of jeans and textiles
- Mushrooms are the most successful biotechnological and economically valuable protected crop in the UK and in Europe
- Most man-made materials can be colonised by fungi, causing economically significant biodeterioration (e.g. computer circuit boards, paints and plastics)
- Food spoilage by fungi pre- and post-harvest is a significant problem world-wide
- As well as being important in their own right, fungi can be used in examples alongside plants and animals to illustrate basic biological processes

It is possible to develop simple activities and practical classes to convey these important messages. The BMS has already designed some material to support such activities in schools. We believe that the exam boards must liaise with expert mycologists on future curriculum development and in getting the facts correct within school material and associated text books.

British Science Association

The British Science Association is a registered charity that provides opportunities for people of all ages to learn about, discuss and challenge the sciences and their implications.
Our primary aims are to:

- promote open and informed discussion about science and its place in society
- affirm science as a prime cultural force by engaging and inspiring adults and young people directly with science and technology, and their implications

Established in 1831, the British Science Association organises major initiatives across the UK, including the annual British Science Festival, National Science and Engineering Week, programmes of regional and local events, and an extensive programme for young people in schools and colleges.

The British Science Association is established under Royal Charter and governed by a Council which forms the Board of Trustees. It is registered with the Charity Commission (number 212479) and with the Office of the Scottish Charity Regulator (number SCO39236). Given our remit is far broader than the formal curriculum we have only responded to specific questions as part of the call for views.

1) Science and mathematics education in the UK

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

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

When considering Science education in the UK, we particularly believe that practical work needs to be an essential part of any young person's science education, with the benefits being well documented and were summarised in the **SCORE** (2008) report[1] which stated "practical work promotes the engagement and interest of pupils as well as developing a range of skills, science knowledge and conceptual understanding".

The OECD-wide **PISA** studies provide compelling evidence of the value of practically-based activities[2]. They show that involvement by students in enrichment activities such as science fairs, competitions and visits is one of only three 'educational resource factors' correlated with increased performance in science after allowing for socio-economic background. Our own small scale research with admissions tutors in HE has suggested that students often arrive at the start of their course without the skills set to persevere and problem solve in longer term project-based work. This could directly relate to the lack of opportunities for such practically-based project work that students undertake in schools/colleges and this reinforces our belief in the value of the CREST Awards.

Raising awareness of the breadth of careers that may result from science and maths routes remains a challenge in schools, though there have been recent developments (such as Future Morph) which strive to effectively communicate STEM opportunities. As stated in the **Aspires** report[3] "Currently careers in and from science are not commonly perceived as 'for all', which discourages many children from developing science aspirations" which is something we endorse as an important consideration for science and maths education systems.

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[1] Science Community Representing Education (2008) *Practical Work in Science: A Report and Proposal for a Strategic Framework*, Royal Society, London

[2] PISA 2006: Science Competencies for Tomorrow's World, Vol. 1, pp258-264 and Executive Summary pp43-44

[3] Aspires Project (2011) *The Case for Early Education about STEM Careers,* King's College London, London

High quality enhancement and enrichment is very important to improve engagement with role models and scientists helping to remove stereotypes and playing a key part in enthusing young people. Learning does not just take place in lesson time and young people can benefit from having a wide range of learning experiences in different environments outside of the classroom and through field trips. These principles are firmly supported through the CREST Awards scheme.

STEM Clubs are an excellent location for student-led project work in STEM subjects. Unfortunately, the Government will cease funding their support network for Clubs (led by STEMNET, in partnership with the Association and the National Network of Science Learning Centres) so the number of opportunities for open-ended project work and experimentation may decline in the next few years.

3) Continuing Professional Development (CPD) for teachers

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

CPD (both within an establishment and through external support providers) is an essential part of a teacher's development. Our recent personal experiences through running teacher events for STEM clubs and through the CREST Expansion Project illustrate the difficulties teachers have in attending such events, given the pressures and priorities within schools, even when they feel the content of the course will be beneficial to their teaching practice. Though new technologies can provide support through alternative means this cannot be a replacement for face-to-face experiences.

There is a wide range of organisations that are well-placed to help teachers professionally develop, ranging from national bodies like the British Science Association, the Association for Science Education, the various professional bodies and STEMNET through to small local organisations that work with a small number of schools more intensively. These organisations are facing considerable turbulence at the moment as a result of reductions or disruptions in their funding streams. While this may be an inevitable consequence of the Government's current spending priorities, we need to ensure we don't inadvertently lose a swathe of experienced activity providers who can help to safeguard the future health of the UK's R&D base.

The value of informal professional development in subject knowledge though exposure to new developments in science and technology must also not be forgotten. Over the years, the British Science Festival has also provided excellent opportunities for teachers (as part of the wider public) to find out about new developments and to discuss topical science. School groups greatly benefit from attending the British Science Festival, but it does prove difficult to enable teachers to view this as subject professional development.

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?

We believe that it is essential for young people to experience hands-on science investigation and enquiry from a primary school age, enabling their personal growth and skills development to benefit from the inclusion of such experiences, whilst potentially igniting an interest in science at this developmental stage. This is reinforced through the various programmes we run through the British Science Association where CREST Star Investigators provides opportunities for such experiences for primary aged pupils.

The value of developing skills through project based learning was evident in our **CREST Awards scheme** external evaluation carried out by Liverpool University[4]. The findings from the impact study showed that:

- CREST has a strong positive impact on its primary target audience
- Students gained knowledge and developed transferable skills
- Students' attitudes towards STEM and aspirations for STEM careers were improved
- A large number of teachers commented that CREST enthuses and motivates students and many commented on the skills and confidence that students develop
- Many teachers felt that the scheme helped inform their teaching and gives students a broader experience of STEM than school alone can offer
- Teachers felt that CREST raised the profile of STEM in the school
- Mentors highlighted the impact on students' decision-making at Gold level, and described the impact on young people's subject choices at university.
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Additionally, the British Science Festival (organised by the British Science Association) provides inspirational hands-on practical experiences for young people outside the classroom, reinforcing our organisation's dedication to these principles.

The Association also manages the National Science and Engineering Competition which strives to develop young scientists' and engineers' communication and ambassadorship skills as well as highlighting young people's research achievements to a wider audience. The Competition finals are hosted at The Big Bang (UK Young Scientists' and Engineers' Fair), of which the Association is a founding partner. The Fair showcases the broad range of STEM careers available to students with the aim of stimulating their interest in STEM subjects.

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

As an organisation focusing primarily on informal learning opportunities we are not best placed to comment on formal assessment in detail. However, we do recognise the difficulties in employing fair models that uniformly assess practical work as part of exams. A variety of techniques have been used by examining bodies (e.g. ISAs, IAA tasks) but anecdotal comments from teachers suggest that some may look for the easiest way for students to safely score the best marks (rather than choosing the assessment approach that may provide the best opportunities for students to develop a broad range of practical skills) given the emphasis on league tables and results. We are very interested in the development of new qualifications recognising the importance and value of longer term project work (which

[4] Grant, L. (2006) *CREST Awards Evaluation Impact Study*, University of Liverpool

is often practically based) such as the Extended Project Qualification, which echoes the ethos of CREST and the principles of the British Science Association.

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?
Wherever the learning takes place, the focus needs to be on providing space for creativity and the development of broader skills. Practical activities and field trips offer particular opportunities for young people to develop creativity. Creative activities, according to the report of the National Advisory Commission for Creative and Cultural Education (the **Robinson** report[5]), have four characteristics, namely: being imaginative and purposeful, and developing something original and of value in relation to the purposeful objective. That implies the need for contexts that offer opportunities for exploration, for taking risks and making mistakes, provide exciting or unusual stimuli, sharing and reflecting openly on ideas, respecting difference and offering choice and control to students.

We strongly believe that young people should experience science and technology by engaging in exploratory and open-ended scientific and technological activities themselves. Project work allows students to gain experience of some of the technical skills associated with doing science as well as benefiting from team working and problem solving. Alternative technologies and the internet provide faster access to information in new formats and this is increasing part of our everyday lives. However, it is important to ensure these new opportunities are constructively applied to reinforce the underlying principles of science and mathematics, rather than the potential to lead to misrepresentation or misinterpretation.

Careers Research & Advisory Centre (CRAC)

The attached information is provided by CRAC (the Careers Research & Advisory Centre Ltd). It has been prepared by Dr Robin Mellors-Bourne[6], CRAC's Director for Research & Intelligence, and was submitted on 14 March 2012.

About CRAC
The Careers Research & Advisory Centre (CRAC) was established in 1964 and provides expertise and innovation for all those who support career development and career-related learning of people at all ages. In addition to a long heritage of development work (devising career-related activities and training interventions, many of which were pioneering in their time), CRAC now undertakes career- and education-related research on a contract basis for

[5] http://sirkenrobinson.com/skr/pdf/allourfutures.pdf
[6] Contact robin.mellors-bourne@crac.org.uk

Government departments and agencies, public sector bodies, professional associations and employers. This has included major evidence-gathering work for the Department for Business, Innovation & Skills on STEM graduate careers (‘*STEM graduates in non-STEM jobs’,* 2011).

Section 3. CPD for teachers

Other comments

It is our belief that Continuing Professional Development for science and mathematics teachers should not be restricted to ‘subject-specific’ development. There is a growing and important need for subject teachers to be able to provide effective information and advice to support students’ subject and progression choices and to support their development of careers awareness. This results from two significant policy developments:

- The (well-established) ‘STEM agenda’ which aims to increase the number of students that study science and mathematics post-16 and post-18, which will ultimately benefit the UK economy as well those individuals and society. Within this there is an aim to foster greater STEM careers awareness amongst students. This will enable them to see potential career ‘applicability’ of their studies, which is now recognised as the strongest motivator in choices to study physics and mathematics post-16[7]. It also provides ‘real-life’ contextualisation of their subject learning which improves engagement.
- The current shift of responsibility for provision of progression- and career-related support and information (back) into schools rather than reliance on external support.

Although the Government is imminently launching the ‘National Careers Service’ for England, this appears to be largely adult-focused. At the same time it is returning the responsibility for careers support at 14-16 to schools. Without ring-fenced funding for that provision in schools, it is widely understood that face-to-face guidance, purchased from (external) independent and impartial careers professionals, is likely to be restricted only to vulnerable and disadvantaged students, while the majority will be reliant on online information and within-school support from subject teachers and tutors. This is potentially in some tension with a more generalised policy direction towards empowering student (and/or parent) choice, and providing sufficient information to make an informed choice.

With specialised advice and guidance available to fewer students, subject teachers in schools/colleges are being expected to play a greater role in supporting the progression decisions of students and in developing their careers awareness. However, how are those teachers expected to gain greater careers awareness themselves, or up-to-date knowledge of pathways and progression routes? There is currently a danger that teachers know rather little other than their own (often ‘traditional’) progression pathway and lack knowledge of genuine alternatives. For example, their knowledge of the role of vocational qualifications in progression to STEM careers at different qualification levels is probably very limited (and recent reports suggest that this is an area in which parents are also poorly informed).

For clarity, the expectation is not that subject teachers will become careers advisers. Rather this is about them being able to provide, alongside their subject teaching, better information

[7] Mujtaba, T. et al. (2011) Physics participation in England, ESERA Conference

about the potential (career) usefulness and benefits of studying such subjects, and well-informed advice when questioned about progression routes.

A recent evaluation of the STEM Cohesion Programme[8] reported that around half of STEM subject teachers claimed to be confident about progression routes into HE and careers related to STEM. However, only 15% had engaged to a significant extent in any professional development in relation to this, and 2/3 had had no engagement at all. This reflects our observation that few teachers participated in courses offering such CPD within the STEM Cohesion Programme. Although we do not believe there is research evidence, CRAC and others anticipate that this lack of engagement by STEM subject teachers (in this form of CPD) results from:

- weak support for this activity from school leadership (if opportunities for CPD are limited, they almost certainly will prioritise subject-specific CPD);
- few teachers being motivated to undertake it, as they may not understand why they should take on this additional role and/or be quite fearful due to their lack of knowledge of careers outside education (and especially STEM careers);
- the ‘rarely cover’ policy which reduces the cover available for absence during external CPD.

In summary, we believe there is a need for science and mathematics teachers to develop their knowledge about STEM careers and progression routes, in order to fulfill the increasing role that they will need to play in supporting their students. This is reflected in our response to Section 4 (d), where we state that support for STEM careers needs to be much wider and more integrated than purely by a ‘wider workforce’.

Returning to this question, we believe CPD is likely to be one avenue through which subject teachers could improve their knowledge and capability in relation to their wider role, and that consideration of CPD should not be restricted to subject-specific learning.

Section 4. The wider workforce
(d) Who should be responsible for providing advice on careers in or related to STEM?
In the argument presented in relation to Section 3 on CPD, we believe we make a compelling case for greater knowledge of careers and progression routes amongst subject teachers, in order to improve their support for students. We believe the subject teacher should play a role in providing access to information, and some limited advice themselves on careers. This is partly a pragmatic response to current policy through which the majority of students of school age are not expected to have any direct engagement with a careers adviser (either for advice or guidance).

From that argument, it will be clear that we do not see the responsibility for providing advice on careers as something exclusively for “the wider workforce”. To do so is to display an outdated concept of the way careers support for young people is being provided.
Rather there is increasing agreement that students’ development of awareness about careers should not only come through formalised sessions with designated careers

[8] NFER (2011) The STEM Cohesion Programme: final report, Department for Education

professionals, but should also be facilitated by subject teachers. We believe subject teachers should provide some element of progression support and also contextualise their subject teaching through some reference to the application of the subject in the 'real world'. This could include some reference to its utility in terms of jobs and careers.

We therefore see responsibility for provision of advice on subject choice, progression pathways and possible careers as a shared responsibility for those 'careers professionals' and other staff whose primary role is to provide advice and also subject teachers. It is likely that the distinction between these groups of people is likely to decline progressively.
We refer to the input provided in Section 3 for the full rationale for our view, but we would reiterate that practical implementation of current educational policy assumes a 'shared' responsibility not responsibility solely on the part of designated careers advisers.

There may well be value in a network of careers advisers who have specialist knowledge of STEM careers, but this should be seen in the context that few students will actually have any direct access at all to such people, at least in the state-maintained sector. Currently the majority of students do not receive one-to-one advice or guidance from a professional careers adviser up to age 16 (and after which it is not currently statutory). This situation will only decline further with the careers arrangements now coming into force.

Therefore although such a network could possibly be useful in an advisory capacity to assist subject teachers and school staff who do support choices and progression, and careers professionals in general, we think it is simply unrealistic to expect that many students will have any direct access to such specialists. We would therefore respectfully suggest that this is not a key policy issue at this time.

City & Guilds

City & Guilds is the UK's leading vocational awarding organisation for work-based qualifications, committed to offering high quality qualifications across a wide range of industrial sectors, through 8500 colleges and training providers worldwide.
City & Guilds Group also includes the Institute of Leadership & Management, the UK's largest leadership and management body, combining industry-leading qualifications and specialist member services.

Two million people every year start City & Guilds and ILM qualifications, which span levels from basic skills to the highest standards of professional achievement at Level 7, and are designed to help people and businesses achieve growth, prosperity and success.

Main recommendations

- We need alternative qualifications to the GCSE Maths, it was never designed as a measure everyone should achieve.
- Maths is best taught when students can relate it to real life situations.
- A cultural change is needed so that poor Maths is not seen as acceptable for anyone.
- We need more and better qualified Maths teachers, critically in the primary sector.

General Comments

City & Guilds has an unrivalled experience and understanding of vocational learning across all sectors of industry. Employers tell City & Guilds that GCSE English/Mathematics/ICT qualifications do not provide the answer they need. One particular type of qualification cannot be expected to meet the needs of all learners, particularly when they are in or seeking to enter the workplace.

We need to build on our long history and expertise in these areas, and in meeting the needs of employers. We also need to learn from the experiences – good and bad – of basic, key and functional skills, and of essential skills in Northern Ireland and Wales: for instance, we have unrivalled expertise in testing functional skills onscreen, and can use the systems, technology and assessment skills in new and creative ways.

Maths has many different purposes and therefore the level of understanding and the ability to apply concepts will vary considerably. We are focusing here primarily on the general requirements for employment rather than on any specialism which would probably continue to be met by A level and degree courses. While the numbers studying A level Maths have more than doubled in recent years to 77,000 (with 11,600 doing Further Maths), Alison Wolf pointed out in her recent (March 2011) report that less than half the cohort who were 15 in 2005/6 achieved a GCSE A*-C in both English and Maths by the time they are 18. A point worth noting here is that GCSE Maths was not intended or designed to be a standard all should reach. The fact that it is now viewed as one (at least by Minsters). Wolf is also dismissive of Key Skills ('valueless') and is highly sceptical about the likelihood of Functional Skills being the solution.

Professor Wolf's detailed survey of Maths provision for 14-19 year olds has effectively drawn attention to what is still a parlous state of affairs, even if there are some small signs of improvements in some areas. Much of her attention is focused on the large numbers who are not achieving GCSE A*-C. She insists that we should not allow those who will now have to remain in full-time education or training until they are 18 to drop Maths if they have not achieved a good GCSE and, although she deliberately avoids suggesting that there should be compulsory re-sits until the standard has been achieved, she appears only to endorse free-standing Maths as a worthy alternative. She acknowledges that for some who have demonstrated no interest or real accomplishment a compulsory diet of 'more of the same' will probably not achieve anything but fails to come up with a convincing alternative.

This raises the question as to what then a suitable qualification would be. If we want to have a qualification which sets the benchmark attainment or national standard for Maths at the age of 16. The Maths Task Force report of 2011, as one example, recommended two GCSEs. This approach is currently being piloted. City & Guilds is working with a number of stakeholders in this field and we would be happy to discuss this separately with the Royal Society. The approach we are suggesting 'Future skills' (working title) will consist of three strands:

- A 'core' skills test covers essential 'basics' that all learners need to master.

- Skills development modules based on the numeracy core curricula, this might be data handling, measure/shape
- Application profile, modelled on the idea of an artist's portfolio (that could be shown to a prospective employer), rather than a 'portfolio' in the NVQ sense.

This would contain a range of examples where the learner has applied number skills in real work/life situations. It would need to include examples covering a range of skills (eg addressing each of the technical skills modules the learner has completed) but with focus on process skills and 'bringing together' rather than box ticking.

There is widespread concern that the level of understanding and ability of the majority of people in this country to apply mathematical and numerical concepts is woefully inadequate to cope with future challenges and requirements in virtually all occupations. And yet, the national provision in place seems ill-fitted to meet our needs.

There are further doubts that the mathematical content of other programmes is adequate for subjects where one might expect a need to demonstrate an understanding of mathematical principles or an ability to use Maths in a practical sense. As qualifications moved over first to the NQF (National Qualifications Framework) and then to the new QCF (Qualifications and Credit Framework) so the mathematical content appears to have diminished. This was a direct consequence of the imposition of centrally set criteria and formats for qualifications, the NVQ model of competency based assessment did not lend itself to core knowledge development, and the issue was exacerbated by the introduction of the Qualifications and Credit Framework where units have to fit a rigid template. To give one example: the pre-NQF City & Guilds Plumbing certificate required a high level of practical technical expertise, it also tested knowledge of physics, electronics, Maths, technical drawing and technology. You would be hard put to find much of this in the current qualifications. So there is a case for root-and-branch reform to ensure that key elements like algebra, trigonometry and geometry are restored within vocational provision.

Two factors blight prospects for embedding Maths once again in school curricula, and in programmes for 16-19 year olds and adults. The first is the paucity of Maths teachers. Figures from DfE suggest that the tide has turned in that there are now 2800 new Maths teachers entering the profession – double the number 10 years ago. But the pool of Maths graduates is still too small to provide an adequate pipeline. This is further held back by restrictions on HE admissions; we suggest all caps on STEM undergraduate admissions are removed from HEIs. In addition, more can be done to make Maths teaching more attractive by providing a premium on salaries which could be further engineered to encourage recruitment in particular geographical areas.

The second factor is the cultural bias against Maths that still holds sway in many households, so that many young people view the subject as difficult and arid - with the consequence that motivation is subverted and the subject is dropped at the first opportunity. We welcome the recent launch of National Numeracy, it is essential that cultural perceptions change so that 'being no good at Maths' is not viewed as socially acceptable. Everyone should have good numeracy skills and this needs to be the absolute focus. A number need good Maths skills for future STEM jobs but everyone needs the opportunity to find out if they like Maths and that means we need to teach Maths better / in context.

We also need to have much better labour market information given to young people and their parents at the appropriate time (which may be when the children are transitioning from primary to secondary), so that there is a much better understanding of the Maths content of a wide range of occupations. Moreover, we need to give more practical and tangible examples of just how significant Maths is in everything from building search engines like Google to computer games, from cooking to agriculture, as well as virtually any sort of management analysis.

We recently commissioned some research to establish the views of young people on all aspects of education. (The results of this have not yet been published, we would be happy to provide the Royal Society with a copy when they are.)

Data collection was via an online survey of 3000 young people in February 2012. Respondents comprised 1000 individuals from each of three age groups 7-11, 14-16 and 16-18. Respondents in each age group represented a 50:50 male: female split and were nationally representative in terms of nation and region across the UK.

A selection of the findings below in relation to Maths and Maths teaching gives some clear indicators to the enquiry:

- Among 7-11 year olds Maths is as equally liked as disliked. This age group already appreciate that they need Maths but the fact that it is thought of as 'boring' and not 'fun' splits opinion, leaving almost as many voting it their favourite subject as voting it their least favourite.
- Across all age groups, Maths is strongly liked and disliked equally with 27% of boys voting it their favourite subject and 32% of girls voting it their least favourite. Overall Maths is slightly more liked than disliked with 21% voting it their favourite and 24% voting it their least.
- Unprompted, the survey respondents indicated that they thought of Maths as a useful subject but it is boring and should be taught differently to reflect the use of Maths in the 'real world', specifically business and finance. Much of the apathy with Maths comes from the fact that young people do not see the relevance in what they learn and do not find the method of teaching accessible. Young people would like to *'Have more activities and interactive lessons about things that we will actually need to learn for our lives ahead.'*
- Many survey respondents felt Maths needs to be taught more practically; *'we need to learn more practical uses'.*

There is a significant desire to learn Maths that would either be used in everyday life, or in business;

'Show me how I can use Maths in business, to do accounts or banking.',

‘More based on life skills, I am currently doing functional Maths skills at college and it's Maths for things you need in life - rent, petrol etc.’

- They also think Maths teaching could be more closely related to the way it would be used in the work place. The 16-18 age group agree that Maths taught in school is not relevant afterwards:

  ‘The way things are taught aren’t necessarily how they are applied really…’

- 45% of 14-16 year olds commented unprompted that Maths should be more relevant to Real life/Relevant scenarios

  ‘Make more of the work relevant to everyday life so that you can apply more of what you learn’

  ‘do things that are relevant today, like looking at bank statements. and all other personal finances.’

  ‘Put them into scenarios where I may use them when I leave school to show me that I will used them in the future’

- 54% of 16-18 year olds commented unprompted that Maths should be more geared towards Real life/Relevant/Practical/Functional scenarios

  ‘Up until the end of GCSE (at least), when Maths is still a compulsory subject, people should be taught useful things - like how to manage bank accounts, personal finances, savings, loans, etc. Somehow, I doubt I'll use trigonometry any time in the future’

  ‘Showing you relevant Maths not just that which is only useful to mathematicians. Link it to everyday math such as bills, loans, money related topics and remove the dullness around it, make it fun for students, not what teachers call fun’

  14-16 year olds were asked; ‘Which subjects will help you be successful?’
  • English 82% (Boys 78%,Girls 86%)
  • Maths 78% (Boys 76%,Girls 79%)
  • Reading 71% (Boys 67%,Girls 76%)

  16-18 year olds were asked; ‘*Will it be useful when you leave school?’,* 63% said yes

- 62% of 14+ respondents tend to describe Maths as being useful although 40% also find it boring and 35% find it difficult. By the older age bracket 16-18, there is a greater distinction between boys and girls with 10% more finding it boring and difficult.

Specific comments on the questions:
There is much excellence in Maths and science education in the UK, the key issue is that it is not consistent. The dominant performance of the independent sector in STEM education,

especially post-16 is perhaps the greatest concern because although young people in independent schools are receiving high quality teaching and achieving highly, they are only a small percentage of the total cohort.

The evidence indicates that attitudes to science become less positive across the period of secondary education, declining most sharply between the ages of 11 and 14. This was very clear in the findings of the Maths Task Force Report (2011). The early years of secondary education appear to be crucial in a number of ways. Interests and views on future career directions begin to shape in this period. Students also see their teachers as being particularly influential at this time, expressing a desire to learn from enthusiastic and knowledgeable teachers who provide them with variety in activity and make them think in lessons. Negative attitudes are linked to a view of the science curriculum in England as overly full, fact-laden and hard. Relating science to everyday life increases student enjoyment of lessons, but there is some evidence indicating that it does not necessarily affect levels of participation beyond the compulsory period. The evidence on attitudes to mathematics parallels that to science in several respects. Attitudes worsen across the period of secondary schooling, but mathematics is seen by students as a particularly important subject in the school curriculum as it leads to a valuable qualification. Teachers are seen as very influential by students, with teacher effects being more influential than the use of any particular materials. Negative attitudes are associated with a perception that studying mathematics is isolating, over-individualized and involves a high reliance on dull repetition and rote learning. In England, together with Wales and Northern Ireland, about 85% of students give up mathematics after GCSE.

We are aware that governments are very keen on international comparisons and we fully suspect that most responses to this question will list Finland and South Korea as examples of excellence, based on OECD league table results. We also see the value in looking to other countries and regions to learn from their examples of good practice. Indeed, we have set up our own independent not-for-profit research and development organisation – the City & Guilds Centre for Skills Development (CSD) to investigate international good practice and lessons learnt in vocational education and training.

Part of our learning from CSD is how important local conditions can be in determining the relative success of any programme. So it is very important when considering what is felt to be ‘high quality’ that we do not think that this can be replicated and achieve the exact same results. For example, we look to Finland for their high quality teachers but many teachers are educated to PhD level in Finland. If the UK were to follow this example, it would take a considerable amount of investment and a change in mindset.

Financial incentives are one obvious route towards reaching this, perhaps even more important is recognition. Requiring higher entry standards to the profession would do much in this respect. Primary Teachers Maths should have, as an absolute minimum, GCSE grade B, though A level would be preferable. Secondary Maths teachers should be expected to have a good degree in their subject.

As much training as possible should be spent gaining experience in the classroom, in a wide variety of teaching settings.

Subject-specific CPD should be undertaken on an annual basis as a minimum and this should be mandatory- it is for many if not all professions.

Advice on careers in or related to science, technology, engineering and mathematics is critical. A good place to start is **STEM Careers** (http://www2.warwick.ac.uk/fac/soc/ier/ngrf/stem/ which brings together a wide range of resources as an online learning tool to help us move towards the aspiration of all professionals working in career guidance and in STEM teaching and learning, which is that high quality careers guidance can be delivered in respect of science, technology, engineering and Maths to all young people.

CLEAPPS

General questions

1) Science and mathematics education in the UK

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

The practical basis of UK science education is one of its distinctive features – this approach promotes technical competence as well as high level problem solving skills. It is currently under threat from a number of directions. A loss of confidence amongst new entrants to science teaching to do practical activities, driven in part by a reduced experience of practical science during their own education, is in danger of creating a downward spiral of diminishing practical activity. Add to this the reduction in technical support stemming from a fundamental undervaluing by school leadership of the contribution made by skilled science technicians and the future for practical science looks very bleak – CLEAPSS worries that science could cease to be a practical subject without anyone even realising.

3) Continuing Professional Development (CPD) for teachers

a) What are the benefits of subject-specific CPD for science and mathematics teachers? Hands on practically based subject CPD enable teachers learn new skills and techniques – the consequence is increased confidence to deliver practically based lessons with activities that work, are safe and promote learning. Such CPD is essential to tackle the current downward spiral of reduced experience of practical activities in teachers own education leading to a reduced repertoire of activities leading to a further reduction in practical activities for the next generation of learners.

b) How should science and mathematics teachers best keep up with their subject and with new approaches to teaching, assessment and the curriculum? Opportunities to share good practice are important however there is a need to inspirational input from external professionals to ensure that local networking does not become inward looking and end up simply recycling mediocrity.

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

d) Should CPD be voluntary or mandatory? Why? It needs to remain voluntary – however it needs come with much greater incentives - There are currently few if any extrinsic drivers for engaging in CPD. The original intrinsic motivation has diminished with the rise of a new professionalism – a new generation of teachers have been encouraged to see teaching as job rather than a vocation. Many teachers have become deliverers of someone else's curriculum rather than being actively involved in its development to meet local needs.

e) Are there key obstacles preventing science and mathematics teachers from accessing subject-specific CPD? If so, how can these be overcome them? Currently subject based CPD has low value in schools as a result school leaders are reluctant to release teachers to attend. The link between subject based CPD, teacher's motivation and commitment and pupil outcomes has been lost. Generic CPD focusing on aspects of teaching and learning or assessment is seen as having more impact on pupil outcomes.

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?

g) Should CPD be accredited (eg through the awarding of Masters-level credits)? This option is attractive to a proportion of teachers but by no means all – It is unlikely to be attractive unless there is a clear indication of what the benefits of engaging in the process are to the individual/institution.

4) The wider workforce

a) How and where should we be training laboratory technicians? The school technician workforce is very diverse ranging from individuals with First Degree and above qualifications in science to those with no formal science qualifications at all. All of these individuals have the potential to make a valuable contribution to practical science in schools but have very different training needs. Access to appropriate training needs to be provided in through a variety of models ranging from off-site (possibly residential) training to shorter, peer support based, local activities run through technician networks. Some of the most effective training (both in terms of cost and relevance) for technicians is organised and run by local technician clusters. There is a pressing need for a recognised career entry route to being school/college science technician – above all this would establish school/college technician as a genuine career choice – apprenticeship schemes may be one way to achieve this.

b) What CPD needs will laboratory technicians have and how will these best be accommodated? CLEAPSS has identified a number of training needs as well as a range of approaches to meet these.

1. Training in Health and safety legislation and how it applies to a school context including roles and responsibilities and appropriate approaches to risk assessment.

2. Technical skills – for example how to make up solutions safely, how to work with glass, how to repair science equipment (for example microscopes) as well as ideas for making new equipment for themselves.
3. Subject based expertise – focusing on how to get key practical activities to work. Technicians can benefit from CPD that gives them an insight into how activities run in the classroom – There are opportunities for technicians to support teachers in developing their practical expertise by showcasing new techniques and approaches learnt on training. It is easier for technicians to access off site CPD that it is for teachers – there are for example no cover implications in releasing a technician to attend training.
1. 4 Leadership and management training for senior technicians designed to support them in running efficient technical support and leading a team of junior technicians effectively. An effective senior technician can be viewed as working in partnership with the head of department to deliver a high quality, practically based science curriculum.
2. The accreditation of training is an important issue – Many accreditation models place too much emphasis on skills of reflection – appropriate to masters level study in academic subjects but not necessarily relevant to successfully completing a technician role on a day to day basis.

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?

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?)

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; There is a need for a bank of properly trialled, H&S checked, practical activities that are safe and work. Currently much of the published resource available is based on dimly remembered activities drawn from innovative curricula of 40 years ago. Many resources assume that the teachers have grounding in basic practical activities and focus on novel approaches or 'left field' activities. CLEAPSS believes that this assumption is invalid and that many teachers need clear easy to access guidance on how to complete activities that form part of an entitlement experience for all pupils.

ii. teachers are able to use what they judge to be the most effective pedagogical methods and approaches to learning? There is a need to revisit the purposes behind including practical activities in lessons. Practical experiences are incredibly rich in their potential to support learning however they are often deployed with only limited thought as to what learning they are intended to facilitate on a specific occasion – the result is often a poor match between intended learning in the lesson and the focus of the task selected. The

Getting Practical project (ASE/CLEAPSS 2010/12) made a well-focussed if small scale attempt to address this issue – there is scope for much more work in this area.

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?

e) What characteristics of assessment best serve learning in its various forms in school science and in mathematics? Repeated attempts to design assessment structures that accurately assess pupil's abilities in the procedural aspects of science have broadly failed to deliver meaningful outcomes. At best these have been formulaic and, being driven by an overwhelming need to be seen as rigorous and comparable, they have lost any sense of really measuring a pupils ability to 'do science'. The repeated failure to devise a successful strategy to assess procedural understanding suggests a significant need for more research into new and innovative approaches in this area.

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? Practical science will continue to need specialised teaching environments. However the concept of each teacher having their own lab leading to a suite of identical multipurpose laboratories each able to support the full range of practical activities may no longer be affordable – in fact it could be seen as wasteful of resource. In designing more varied teaching spaces for science it must be recognised that these demand a team based approach to teaching which in turn demands specific approaches to leadership and management. An appropriate emphasis on professional development for heads of subject and team members is essential in order to realise the efficiencies intended in these designs.

f) What other more general changes to school infrastructure would support excellent science and mathematics teaching and learning? How can we measure this? There is pressing need to develop a better understanding of the nature of science and science education and what it has to offer young people amongst school senior leaders and Governors. Such an enhanced understanding would enable these key people both to support good practice as well as to challenge poor, uninspiring provision.

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)?

Eden Global Consultancy

1. a) What is good about UK science and mathematics education?
No Response

2. 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?
Identifying different ability levels and interest of children very early in life (Foundation, Nursery, Primary). Support exceptional ability with OOSL (out of school learning) opportunities Create/ fund city wide Children's Universities (to recognise and consolidate "primary" young talents in different disciplines, not just STEM) Engage more with youngsters, create more opportunities for children/ young people to express their views about STEM/ Education system More benchmarking work against asian/ european/ us top-performing systems Increase interest in every child (no one is a statistic) Invest "heavily" and heartily in Dyslexia/ Dyscalculia (conditions affect 7-10 % of UK population; associated costs £4(6) billion p.a. - UCL, Educational Research) Make STEM more fun, engaging to create more interest amongst disengaged youngsters Review and enhance "good" technology use in schools

3. c) What, if any, broader educational issues concern you? (These may or may not relate directly to science and mathematics education)
Learning difficulties are getting minimal to no support. Infact, the current system penalises LD cases, rather than support them. Making pupils with Dyslexia/ Dyscalculia pay for the additional educational support is appalling in 21st century Western society. At best, treat as disability and offer full additional educational funding. At worst, not a disability but acknowledge and provide full additional support funding for learning and employability skills development. 10 year olds being locked up for antisocial/ criminal behaviour. Many of the youngsters fall in the bracket of educationally disengaged pupils. Full investigation on a case by case, region by region basis to find out real cause of offensive behaviour and alternative pathways to rehabilitation (prison is not the place for a 10 year old - Council of Europe) There's no reason why schools in 21st century Britain should still be performing below Ofsted standards; at worst good, at best exceptional should be the yardstick of educational outcomes.

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

Every child, and every school should be a matter of concern. Pupils and schools are not mere stats, but living systems to be accorded real social and economic attention in order to make sure they meet up.

5. Other comments
No Response

6. 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?
Germany, Scandinavia and South Korea

7. b) What specific aspects of other countries’ high-performing education systems should we be learning from?
Everything seems to work in these countries. Economy, Governments, and especially modern infrastructure reflecting high standards of scientific, engineering and technological transfer to the real economic and social systems.

8. Other comments:
Put your money, where your children are. They are the future of this nation. UN report (2008/9) points out the UK as the worst place in the West for a young person to grow up in. That was a warning short politicians did not heed until it was too late (Riots of August 2011). Some political quarters still class this occurrence as circumstancial and purely criminal. Well, well ...

1. a) What needs to be done to make teaching a top career choice for trained scientists and mathematicians?
Society, Politics, and Policies and laws need to be in favor of teachers. At the moment, the laws seem to stand in the way of teachers doing a good jobs. More social research needs to be carried out to trace root causes of behaviourally and educationally disengaged young people. Parents need to do more to improve parenting skills (that includes recognizing the need to sacrifice some time to support their children in learning/ study needs - Jubilee Parenting, 2012)

1. 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?
University Degree +, Social/ emotional intelligence

2. 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?
Only as a temporary solution. More longterm policy instruments.

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

No Response

4. d) What changes to these programmes (eg philosophy, content, or emphases) are needed?
Continual development programmes e.g. study sabbaticals every 5 years (even in business, the social, technological and economic paradigm is become shorter and shorter and requires a radical rethink of strategic options)

5. e) How can the standard of science and mathematics initial teacher training programmes be of a consistently high quality across the UK?
International benchmarks, encourage lifelong learning, encourage creativity and highlight bestpractice cases across the nation

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

7. g) In what sort(s) of institution(s) should science and mathematics teacher training take place? Why?
Universities, Specialist Training Institutes

8. h) How much of this training should be spent gaining experience in the classroom?
a fiftth to a third

9. i) How long should courses be for training (i) primary; and (ii) secondary science or mathematics teachers to become fully qualified?
No Response

10. Other comments:
International experience
1. a) What are the benefits of subject-specific CPD for science and mathematics teachers?
No Response

2. b) How should science and mathematics teachers best keep up with their subject and with new approaches to teaching, assessment and the curriculum?
lifelong development + study sabbaticals

3. c) At what times throughout their teaching careers and with what regularity should teachers undertake subject-specific CPD?
every 3 - 5 years

4. d) Should CPD be voluntary or mandatory? Why?
mandatory knowledge paradigms are increasingly becoming shorter. Technologies, social and economic norms are changing equally rapidly making it imperative for instructors (teachers, tutors, mentors, and other leaders) to update their skills and knowledge base constantly.

5. e) Are there key obstacles preventing science and mathematics teachers from accessing subject-specific CPD? If so, how can these be overcome them?
staffing pressures, current austerity cuts and resulting underfunding

6. 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

7. g) Should CPD be accredited (eg through the awarding of Masters-level credits)?
Maybe - as a incentive and additional motivation

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

2. b) What CPD needs will laboratory technicians have and how will these best be accommodated?
No Response

3. 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?
Mainly behavioural and organisational support

4. 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 advisors alongside school based general staff (IAG support information)
1. a) Where will/should science/mathematics primary and secondary school learning take place, both within and outside school?
Schools, good technology support, and special Children's Uiversities out of school (EUCU)

Engineering Professors' Council

1. a) What is good about UK science and mathematics education?
The investigative nature of teaching in the best examples of both science and maths teaching

2. 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?
make triple science GCSE available in all schools, & promote it to able pupils

3. c) What, if any, broader educational issues concern you? (These may or may not relate directly to science and mathematics education)
need for better training of primary teachers, & more emphasis on basic numeracy skills in teaching

4. d) How can a science and mathematics education system best meet the needs of employers and higher education?
producing better-qualified school-leavers, who also show more maturity & a better work ethic

1. a) What needs to be done to make teaching a top career choice for trained scientists and mathematicians?
pay more; sort out discipline in schools (and/or public perceptions of latter); make it possible for engineering graduates to qualify as maths & physical sciences teachers

1. 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?
primary: higher standards than at present; secondary: OK at present, but need to encourage more for maths & physical sciences

2. 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?
Yes - because of current shortage of maths and physical sciences teachers; pay more, & pay full costs of retraining

3. c) What is good about initial teacher training programmes in science and mathematics in the UK?
No Response

4. d) What changes to these programmes (eg philosophy, content, or emphases) are needed?
No Response

5. e) How can the standard of science and mathematics initial teacher training programmes be of a consistently high quality across the UK?
No Response

6. f) What types of courses (full and/or part-time) should be provided for training new science and mathematics teachers. Why?
Close liaison with industry and commerce - i.e. where the sciencs and maths is actually used - is vital to create enthusiasm for the study. Seeing the relevance of a topic increases both understanding and interest.

7. g) In what sort(s) of institution(s) should science and mathematics teacher training take place? Why?
All types of institution have their role to play if they are suitably supported and respected by the general public.

8. h) How much of this training should be spent gaining experience in the classroom?
Classroom experience is important but should not be at the expense of a thorough grounding in the fundamentals of the subject.

1. a) What are the benefits of subject-specific CPD for science and mathematics teachers?
It is essential in order to keep up with recent advances in the subject. CPD should be mandatory for all in the teaching world at all levels.

2. b) How should science and mathematics teachers best keep up with their subject and with new approaches to teaching, assessment and the curriculum?
No Response

3. c) At what times throughout their teaching careers and with what regularity should teachers undertake subject-specific CPD?
Regular CPD throuhgout their careers - e.g. I week annually at a minimum.

4. d) Should CPD be voluntary or mandatory? Why?
mandatory (but see below) otherewise budget cuts will inevitably cut it back.

5. e) Are there key obstacles preventing science and mathematics teachers from accessing subject-specific CPD? If so, how can these be overcome them?
require schools to release staff for CPD, or encourage voluntary CPD in holiday time linked to career progression

6. 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

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

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

2. b) What CPD needs will laboratory technicians have and how will these best be accommodated?
Best achieved through consortia of schools and colleges.

3. 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?
No Response

4. 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?)
Agree that we need national network of careers advisers with specialist knowledge &c; we understand that some work is in hand on this in maths involving Sheffield Hallam.

5. Other comments:
No Response

1. 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?
Leadership is important to change the attitude to a subject. Maths in particualr suffers from the universal "its hard" perception!

1. 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?
Basic numeracy - which can only be developed by practice!

2. b) How may the acquisition of such skills best be assessed?
Testing the understanding (rather than rote learning) by setting questions in the context of realistic applications.

3. c) How important is the impact of the transition between primary and secondary phases in terms of pupils' progression in (science and mathematics) education?
Very important; IMechE study has shown worrying extent of pupils keen on science & maths at primary level being put off in secondary

4. 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?
No Response

5. e) What characteristics of assessment best serve learning in its various forms in school science and in mathematics?
Non-routine tests to explore understanding rather than recall of standard techniques.

6. f) To what extent can/should science and mathematics be effectively assessed through other subjects?
Maths is the "language of engineering" and can be assessed through simple engineering applications.

7. g) At what age(s)/stage(s) should public examinations and testing be conducted during students' school careers?
No Response

8. h) What evidence of learning is needed for assessment to operate effectively?
Again understanding not recall of standard techniques.

9. Other comments:
share widespread concerns about teaching for modules / exams not imparting the background understanding needed for working at university level

1. a) Where will/should science/mathematics primary and secondary school learning take place, both within and outside school?
for sciences, more laboratory & better-equipped provision is needed, allowing for "live" teacher demonstrations & practical work

2. b) Will science and mathematics education benefit from having more, or less, diverse types of 5–19 educational institutions (eg primary, secondary, middle, all-through schools)? Why?
The present landscape is too complex and inconsistent for the public to understand. It should be simplified.

3. c) What kinds of specialised facilities, linked to key areas of learning in science and mathematics, should be available in the future?
see (a) above

4. 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?
Maths in particular can be applied in virtually any subject and should thus be widespread throughout the curriculum. Similarly, othe subjects (e.g. use of English) may be explored in maths classes.

5. e) What other resources and systems should be used to support science and mathematics?
No Response

6. f) What other more general changes to school infrastructure would support excellent science and mathematics teaching and learning? How can we measure this?
The 'silo effect' whereby teachers in many schools do not mix across subjetcs must be dismantled. The interest in Science and Maths at primary level is assisted by a single teacher covering all subjects.

7. g) What evidence is there of the effect on their learning of science and mathematics of separating cohorts by (i) age and (ii) gender (eg should there be single sex classes or schools)?
No Response

1. 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?
No Response

2. b) How should qualifications in science and mathematics be regulated?
No Response

3. c) How can we ensure that all students can access the science and mathematics courses they wish to?
Make them available in all schools. If this is unrealistic, then schools need to cooperate in local consortia.

4. d) What are (i) the advantages and (ii) the disadvantages of performance targets and do any apply particularly to science or mathematics education?
league tables are reported as discouraging schools from encouraging pupils to take "grade-harder" STEM subjects; therefore higher UCAS weighting for harder subjects is needed

5. e) How should measures of performance best be reported to different audiences? What other measures of performance may be required?
No Response

Institute of Physics

Please find attached a summary of the Institute’s responses to your questions and some previous consultations that you might find helpful.

This is a very wide- ranging call for views in a large and complex area of policy. It would be possible to write at some length under each heading. However, it would be impossible to produce such a response in the time available. We have therefore provided brief responses to your questions with links to previous evidence, reports and policy responses that express our views in more detail. We suggest that we can pursue these in more depth in discussions if that would be helpful.

The Institute is active in all of these areas; working for over twenty years conducting research, running pilot projects, informing policy and, currently, managing two major national programmes for the Department for Education (the Stimulating Physics Network and ITT scholarships in physics). Its education department has 20 full-time staff and a network of over 70 field workers providing CPD and support for teachers.

The Institute is a partner in SCORE and has worked closely with other SCORE partners, including the Royal Society, in developing policy and responses.

For a broad overview of the Institute's position, covering many of the questions in this call for views, please see our response to the Education White Paper of 2010.

The Institute of Physics is a scientific charity devoted to increasing the practice, understanding and application of physics. It has a worldwide membership of over 40,000 and is a leading communicator of physics- related science to all audiences, from specialists through to government and the general public. Its publishing company, IOP Publishing, is a world leader in scientific publishing and the electronic dissemination of physics.

Yours sincerely
Prof. Peter Main
Director of Education and Science

1) Science and mathematics education in the UK

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

- There is a lot that is good. However, in most areas, there is a lot of variability and therefore room for improvement
- Strong tradition of high quality teaching in the sciences and maths
- Strong tradition of using practical work to teach the sciences and develop skills
- Some very high quality teachers, teacher trainers and educational researchers
- A tradition of successful innovation in science education
- Good, and stable, performance in international comparisons

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 dire shortage of physics specialist teachers. Of the 30,000 science teachers (in England), we would expect about 10,000 of them to be physics specialists; it is more like 5,8002 – a shortage of ~4,200. We reckon that there are at least 500 state secondary schools (out of 3,300) that have no specialist physics teacher.
- To correct the shortage (of ~4,200) we need to recruit specialist physics teachers at a rate of about 1000 per year; happily, there is movement towards this.
- Even then, it will take about 15 years to correct the imbalance, so we also need to work with non-specialist teachers to improve their knowledge of, interest in and enthusiasm for physics; this is something the Institute is doing effectively through the government-funded *Stimulating Physics Network3*.
- We need clear and useful pathways for all leaners. This is particularly true up to the age of 16 but also applies beyond that. It is also particularly true for those wanting to follow a

vocational pathway but, again, it also applies to academic routes.
 Related to that, we need clear purposes for each of the GCSE study schemes (Science; Science plus Additional Science and 'Triple Science'). The time is right to have a rethink of what options are available, what they are for and where they lead.
 Physics A-level would benefit from being more mathematical (*Mind the Gap* report, attached). And it would be useful to structure the A-levels in the sciences and maths so that students can follow useful and coherent programmes in which they can use, develop and be credited for mathematics that supports their science studies, without necessarily taking A-level maths.
The system will only respond if HE asks for more mathematical sophistication in the A levels.

c) What, if any, broader educational issues concern you? (These may or may not relate directly to science and mathematics education)
 The combination of competition between awarding organisations, arbitrary performance measures and high stakes examinations, which has led to a reduction in the quality of assessment items, in teaching and learning and in standards.
 The difference in grading severity between subjects at A-level. Physics is more than a grade harder than some other subjects. When this is combined with school performance tables (based on A-level grades) and the fact that schools can provide predicted grades (based on GCSE results) to students when they make their choices, there is an incentive on both schools and students to avoid physics. The only students who are predicted the same grade for physics as, say, Media Studies A-level are those with 10 A*s at GCSE.
 The lack of diversity (relating to gender8, ethnic origin and socio-economic background) in the population of students who take physics beyond GCSE.
 The National Curriculum Review; we are concerned about the pace of the review, the structure of the review bodies and the review process.
 The reporting requirements (league tables) are so blunt that they are leading to many unintended consequences, distorting what schools are trying to do.
 We need better statistics on the workforce and their deployment; i.e. the qualifications and experience of teachers in schools and what they are teaching.
 We need the ability to track students throughout the educational system (particularly at the interface into HE) and even into employment.
 There is a lack of stretch and systemically low expectations.

2) Science and mathematics education internationally
 We should be very careful about selectively picking (and then mixing) individual attributes from a collection of high performing jurisdictions. As an example, the high-performing Finnish education system is very different in its structure and philosophies to our own; its success in international comparisons is as likely to be related to those differences than to its science curriculum.

Teachers (and the wider workforce)
The biggest single external influence on learners' progress in, engagement with, understanding of and enjoyment of the subject is their teacher. It is essential, therefore, that

there is a complete, professionalised, engaged and satisfied workforce that includes enough accomplished teachers with expertise in teaching physics.

Please note that a number of the answers in this section relate to physics, rather than science, teaching.

1) Teaching as a career

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

- Improved status; better professional recognition, less regulation.
- Closer links to their subject communities and career progression that stresses links to the subject without taking them out of the classroom into management.

2) Initial Teacher Training

a) What should the minimum entry requirements be for entry to primary and secondary science and mathematics teacher training courses?

- Primary: this is a big question. The first step is to get the curriculum right (it currently contains too much inappropriately high level content). Once that is set, then we can determine what the needs of the workforce are. However, there is a real problem with a shortage of science graduates.
- Secondary[12]: There are two main routes to teacher training in physics:
  - o Physics/ Engineering Degree
  - o Other degree + Subject Knowledge Enhancement course

b) Should diagnostic tests be applied to test the suitability of candidates? If so, what types?

- It has been difficult to develop tests which predict aptitude for teaching[13]
- A typical is a study in the Chicago area (Aaronson et al, 2007) which found that "gender, race, teaching experience, undergraduate university attended, advanced degrees, teacher certification and tenure explain less than 8% of teacher quality".
- We remain convinced that the aim should be to recruit subject specialists. As well as being more likely to have (or be able to quickly acquire) the necessary subject knowledge, they are more likely to be inspirational. This is supported by UPMAP[14].
- Subject knowledge is amenable to testing and we have on-line tests that could be used diagnostically within training and as a measure of knowledge on completion.

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?

There is some evidence that incentives have aided recruitment. Smithers[15] shows the effects of recruitment incentives (typically £6000) on PGCE recruitment in England on applications and acceptances. This has to be set against the background of general new graduate unemployment.

- It would be more productive (especially on retention) to offer better career progression – possibly through links to professional bodies; and to offer teachers of sciences opportunities to explore other interests (either educational or scientific) whilst remaining a

teacher.
 More people with higher degrees will raise the status of teaching; the IOP ITT scholarships (funded by the DfE) are contributing to this.

c) What is good about initial teacher training programmes in science and mathematics in the UK?
 Tutoring is based on the needs of the individual and not distorted (or narrowed) by the needs of a particular school

d) What changes to these programmes (e.g. philosophy, content, or emphases) are needed?
 Not all physics and engineering graduates want to teach the other two sciences. 25% of physics graduates who go into teaching choose to teach maths. We hope that some of them will be kept in physics by the new Physics with Maths PGCE.
 PGCE providers are unique, within HE, in the way that they are subjected to two inspections: Ofsted and the REF.
 The current, sequential system for admission to ITT is inefficient and off-putting (many applicants drop out after their first rejection). A parallel, or central, application system would be more efficient, consistent and effective at keeping potential teachers in the system.

e) How can the standard of science and mathematics initial teacher training programmes be of a consistently high quality
across the UK?
 Currently, there is no requirement to test subject knowledge for QTS16.
 The Institute has found (from the IOP ITT scholarships applications) that degree class is not a good predictor of subject knowledge at school level.

g) In what sort(s) of institution(s) should science and mathematics teacher training take place? Why?
 It is important that trainees have contact with someone outside school; and that that person is connected to research in educational good practice.
 The current model where university-based teacher trainers are expected to do original research themselves is poor and should be rethought. Their primary role should be training and good trainers will not necessarily have the experience or skills to do the research; in most other subjects, typical academics appointees have at least 6 or 7 years of research training and experience after their first degree.

h) How much of this training should be spent gaining experience in the classroom?
 The current amount of time is about right. However, the missing piece is the subject knowledge (see below).
How long should courses be for training (i) primary; and (ii) secondary science or mathematics teachers to become fully qualified?
 PGCE programmes are too short to enable trainees to acquire the subject knowledge they need to go into teaching. We advocate a longer (by at least 6 months) PGCE which includes a subject knowledge primer
 There should also be adequate time to develop pedagogical content knowledge (PCK).

3) Continuing Professional Development (CPD) for teachers

 From the remit of the National CPD committee:

The biggest single external influence on learners' understanding of, achievements in and enjoyment of the sciences is their teachers. Good teachers need to be nurtured, supported and developed to provide the best possible experiences for their learners. Effective, **subject-based Continuing Professional Development** plays a crucial part in having accomplished teachers with strong expertise in teaching the sciences.

 CPD can have a number of purposes for a teacher of physics:

o Improve subject knowledge (particularly acute for the thousands of non-specialist teachers)

o Improve pedagogical content knowledge (PCK)

o Provide a shot in the arm about cutting edge developments in physics

 There is more to CPD than one day, off-site courses. Observing lessons, team teaching, inschool work with whole departments are all likely to be more effective. The key to engagement and success is participation rather than delivery.

 The delivery and cascade model is flawed and, in some cases (notably for non-specialist teachers) cannot work; we find that bespoke, continued, in-school, group (often whole department) CPD is most effective.

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

 Improve subject knowledge (and therefore satisfaction of learners)

 Improves the quality of lessons – more confidence etc.

 Developing confidence in using apparatus and practical work in teachingl

 Enables teachers and learners to gain an overview and a deep understanding of the subject at school level

 Improve retention

 Develop capability within the system

 Develops PCK

 Overcome the temptation for teachers simply to do what was done to them (especially important for non-specialist teachers)

 It can build a team spirit in a department and engender a culture of physics (in which physics is valued, discussed and part of teachers' pedagogical thinking) within science departments.

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

The Institute runs a series of *Physics Updates* for established physics teachers. These are based in a university department and include lectures in cutting edge physics and engineering (from the academic staff) and pedagogical issues (from CPD providers). The Updates give teachers a welcome shot in the arm and a reconnection with the subject at university level.

 The Institute is embarking on a project called *Translating Research into Practice*. The aim of this project is to link CPD providers and teacher trainers with education researchers. We have run a conference along these lines in each of the last two years.

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

 Throughout; but more intensively at the start. We advocate mentoring of early career teachers and will be supporting 400 physics NQTs in 2012.

d) Should CPD be voluntary or mandatory? Why?

 It should be an entitlement – i.e. it should be mandatory for schools (and their leaders) to provide CPD opportunities for teachers when they need it.

 It is worth exploring the possibility of, say chartering (see below), which would require continued engagement with the chartering organisation. This might take the form of CPD but in its broadest definition. The aim is to ensure reflective practice and the continued development of teachers' competencies; CPD will be one way of achieving this.

 Chartering – or other accreditation - will be most effective if it is at the subject level, not at a general teacher level (such as MTL) or even at the level of science – CSciTeach. Most physics teachers will identify themselves with physics rather than science or a general teaching accreditation.

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

 Senior leaders tend to fund CPD that supports whole school issues rather than professional development as a subject teacher. Whole school issues are often highlighted in Ofsted reports and senior leaders are, quite rightly, expected to address them.

 However, there are no external drivers to prioritise subject-based CPD. It might be highlighted through internal performance management, but it will be given a lower priority (within the limited budget) than the Ofsted-highlighted issues – because they are public.

 The cost of providing time for teachers to take part in CPD; i.e. the cost of providing cover.

 Some schools put limits on how much time teachers are allowed to access cover – this includes for school trips, meetings and CPD.

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?

 The development of subject knowledge and PCK within a school science department should be part of every school's strategy. It makes sense for senior leaders – through heads of department – to be responsible and accountable for developing these competencies as part of their leadership strategy.

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

 This is an area that the Institute is investigating. However, we are looking at a chartering route rather than Masters level credits.

 One difficulty with using Masters-level credits is that it requires an element of research. Whilst some teachers are suited to, enjoy and benefit from research, it is important to engage (and develop professionally) those who are not. Scholarship is as valid as (and in some cases more valid than) direct research in developing professional competencies. The fundamental need is the on-going development of professional competencies. Research represents only one route to developing some of those competencies for some people. So an accreditation that relies on research is not going to cover all types of development and engagement, whereas chartering could do so.

4) The wider workforce

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

- School lab technicians are a vital part of the workforce. We would like to see a registration system to provide and recognise basic and continued training and development.

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?

- Teaching Assistants are often seen as a way of providing additional staff whilst saving on the cost of teachers. Research recently reported by the Sutton Trust has shown that their effect on learning is questionable and may be detrimental. Replacing part of the role of the teacher in a science laboratory with someone who is neither a teacher nor a scientist is a particular concern.

d) Who should be responsible for providing advice on careers in or related to science, technology, engineering and mathematics (STEM)?

- We have found ourselves in a position where STEM subjects are the only ones that promote specific careers to students. This can be counterproductive (teenagers do not necessarily have a self-image that involves, for example, working in a factory for the rest of their life). Careers advice in schools should cover all subjects.
- The emphasis for the advice should not be on specific jobs (which are unlikely to appeal to many, if any, students in a class); instead it should promote the idea that STEM subjects open doors for the next step. Taking STEM subjects keeps open the most possibilities.

Leadership and ethos

- There need to be routes for excellent classroom teachers to be promoted but to remain in the classroom. It is likely that this would have to be through a national scheme and would relate to the chartering described above. One possibility would be to allow promoted or chartered teachers time to take on national roles (CPD, curriculum development, research, working on assessments). All of these are currently possible but they do not form part of a leadership structure. So, for example, there might be ‘leaders in physics education’.
- The AST scheme became too fragmented; there is no central register, for example. As a result, it is often used as a retention device without producing any local or national impact.
- The Institute’s experience with the Stimulating Physics Network has shown that it is vital that schools (and therefore their leaders) recognise the importance of STEM subjects and that this culture is shared across the school. A culture in which the sciences are undervalued by the senior leaders and/or by other subject teachers is off-putting and undermines the efforts of the science teachers. There needs to be a whole school attitude that is positive about the sciences and maths (and, of course, history, geography, English and languages etc.)
- This is particularly true if we are to encourage girls to take physics (we have come across examples of teachers of other subjects saying to girls that it is a boys’ subject). Getting girls

to take physics is a whole school issue rather than an issue for physics.

Skills, Curriculum and Assessment

The biggest single external influence on learners' progress in, engagement with, understanding of and enjoyment of the subject is their teacher. The physics curriculum is the structure that allows teachers to engage learners and help them get better at physics. The curriculum can only ever be built around content, contexts and ideas. It cannot in itself stimulate interest or understanding; this comes from excellent teaching. However, it must provide the framework that allows teachers to make the subject engaging, stimulating and comprehensible.

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?

- This is a huge question. It is best addressed through our response to the National Curriculum Review.
- However, one particular area of concern is the primary phase. There has been a trend for more and higher level science content to be introduced at primary school; on the basis that the sooner they grasp it the better. This is flawed and counterproductive. Much of the physics content in the primary National Curriculum is at too high a conceptual level for learners to grasp it in a way that is satisfactory to them and gives them lasting understanding. Instead, they are drilled in learning and labelling tasks which give a poor reflection of science, leaving them frustrated and demotivated. They often (have to) repeat them later – which further dulls their experience of science.
- If there is any physics at primary school, it ought to be chosen so that it develops useful attitudes (including inquisitiveness, enjoyment and an appreciation of the explanatory power of science) and some skills (including literacy, numeracy, manipulative skills, using scales). In other words, science at primary school needs some content through which to develop these attributes. But the content should not be the driver – there is plenty of time to study such conceptual content properly at the appropriate age.
- We would like to see more coherence between mathematics and the sciences in schools; both in the way that they are taught and when mathematical ideas are taught and used.
- A common complaint about students entering physics and engineering courses in HE is that they lack fluency in the use the mathematics: they have usually met most of the relevant mathematics but are not well-practiced in its application. The comment applies particularly to the use of mathematics in modelling a physical problem.

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

- Assessment of pupils should be disentangled from school accountability and performance measures. Only then will students' study programmes and learning be driven primarily by their needs.
- Assessment also plays a major role in influencing what is taught and learnt and assessment schemes are important for setting the ethos of a subject. So, for example, it is important to retain some form of practical assessment.

f) To what extent can/should science and mathematics be effectively assessed through other subjects?
 For physics, not at all.
 However, there should be coherence with maths and the way that, for example, mechanics, is taught.
g) At what age(s)/stage(s) should public examinations and testing be conducted during students' school careers?
 Not at 11 or 14; 16 and 18 seems fine.

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.

c) What kinds of specialised facilities, linked to key areas of learning in science and mathematics, should be available in the future?
 Clearly, the sciences need laboratories and technicians to enable practical work – which is an essential part of the sciences. These can be costly to run. Therefore, we have grave concerns about the changes to the funding formula for post-16 education and the loss of the 12% weighting given to the teaching of the sciences – through the funding of complete study programmes rather than individual qualifications.

f) What other more general changes to school infrastructure would support excellent science and mathematics teaching and learning? How can we measure this?
 Bringing physics and maths closer together, perhaps in a "faculty" structure" allowing for cross over for individual teachers. But also cross-fertilisation and improved coherence between the subjects.
 Move away from the notion of a subject called science beyond Year 7. Similarly, move away from the notion of a 'science' teacher – unless they are a specialist in teaching science in Year 7. Above that level, they should be a recognised specialist (or additional specialist) teacher in the discipline (physics, chemistry or biology) that they are teaching.
 We have found through our work on the *Stimulating Physics Network* that there needs to be a positive culture of physics in school science departments. This can come about through the department having a full complement of committed specialist teachers of physics. But it can also be developed through effective CPD with a whole department of non-specialist teachers. Many adults (who have now become biology or chemistry teachers) had a poor experience of physics at schools but, once they revisit the subject through effective CPD, they find it immensely rewarding and interesting. Consequently, they discuss it amongst themselves and bring the evangelism of the convert to their students, thereby improving student motivation and success.

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)?

 No evidence that single sex classes improves the uptake of physics by girls.
 Although single sex schools get better uptake, this is probably more to do with the can-do attitude within the school rather than the fact that all the classes will be single sex.

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?
 Schools should be judged on what they are trying to achieve. Blunt measures associated with simple examination passes in GCSEs and A levels will simply reinforce differences between schools and lead to students taking inappropriate qualifications. We have worked in schools where even a hint of a change in the reporting criteria led to a wholesale change in the qualifications offered by the school.
 What is really required is not accountability but involvement and commitment. If parents, students, employers and HE took more interest, the world would be a better place.

b) How should qualifications in science and mathematics be regulated?
 The professional bodies have a role in setting the criteria for A-levels and accrediting specifications. The professional bodies are well placed to act as a guardian for their disciplines by bringing together a single committee for their subject that includes academics from higher education, professionals and teachers
 We think that proposals from Awarding Organisation through which each AO would have its own committee are unworkable and likely to lead to widespread duplication and dilution of quality.
 The objection that some subjects, such as Media Studies, do not have a professional body can be countered with the fact that there is a good mapping between the subjects that do professional bodies and that require a core of required knowledge and skills to allow progress to the next stage.
 Exams should be regulated by Ofqual; but it needs to be given greater powers.
 In particular, Ofqual should be able to look at exam papers before they have been taken – to act as an air traffic controller rather than their current, limited, role of crash scene investigator.

c) How can we ensure that all students can access the science and mathematics courses they wish to?
 By having a complete, well trained and updated workforce
d) What are (ii) the disadvantages of performance targets and do any apply particularly to science or mathematics education?
 They have completely wiped out the notion of a useful grade below C (at GCSE); in most schools, D is seen as failure, which, among other consequences, means that much of the teaching is focused on the C-D border, often at the expense of stretching the more able pupils.
 There is a danger of the E-Bacc morphing from a school performance measure to a

certification that all students will be expected to get; that change would not be appropriate for a great many students.

e) How should measures of performance best be reported to different audiences? What other measures of performance may be required?
 Progression rates (by gender)
 Some measure of appropriateness of study programmes for students

Mathematics and Science Education Research Centre, School of Education, University of Southampton

Response from the **Mathematics and Science Education Research Centre, University of Southampton** The Mathematics and Science Education Research Centre (MaSE) at the University of Southampton is a leading centre for research in mathematics and science education across all sectors of education and is well-placed to provide evidence on the development of mathematics and science education. This submission focuses on outlining the contribution that research conducted in MaSE can make to the Royal Society's project. We would welcome the opportunity to expand on this evidence, should that be helpful.
For more information on our research centre, please see:
http://www.soton.ac.uk/education/research/groups/mathematics_and_science_education.page

All the research papers referenced in this submission are available via the University of Southampton ePrints server at:
http://eprints.soton.ac.uk/cgi/search/advanced?screen=ANY&divisions=uos-cj-mase

General questions
1) Science and mathematics education in the UK
There is much that is good about UK science and mathematics education, yet a range of aspects that need changing and improving. To develop a scientifically-literate society that engages meaningfully with socio-scientific issues, now and in the future, pupils need to discuss science knowledgeably and effectively through the use of dialogic learning and argumentation in the classroom at primary as well as secondary level (Grace & Byrne, 2010; Ratcliffe & Grace, 2003). The language utilised to present science in the classroom is an important element of how pupils come to understand, use and view science. Thus, pupils need to be exposed and engaged in the epistemic processes of construction, justification and evaluation of knowledge claims, and to situations where discussions about evidence, negotiation of ideas and explanations are present. Yet, our work would suggest that currently this is not common practice at secondary schools in the UK (Christodoulou & Osborne, 2011; 2012). With appropriate classroom tasks, pupils in the 10-12 age range can become sophisticated thinkers able to negotiate real-world science of the kind used by engaged citizens, and are able to work together creatively on problem-solving tasks. Honing these skills within a school science community of practice, by specific training and guidance, can facilitate pupils' scientific literacy and empower them as citizens, and we should therefore encourage changes to pedagogical practice that enable all children to engage in such socio-scientific discussions (Byrne, Ideland, Malmberg, & Grace, submitted article). Even so, there

has been a decline in the amount of practical enquiry-based learning that takes place in classrooms in the UK. Pupils need to understand 'how science works' by engaging in handson practical activities and genuine enquiry that promotes pupils' understanding and interest in science (Gatt *et al*, 2010). What is more, changes to the national curriculum, and government priorities that focus on literacy and numeracy, mean that primary science is vulnerable as a school subject. It is essential that primary pupils have opportunities to develop their understanding of scientific concepts alongside interest in, and curiosity about science. This will help to ensure that misconceptions are addressed before they become entrenched and more difficult to change (Byrne, 2011; Byrne, Grace and Hanley, 2009).

Byrne, J. (2011) Models of micro-organisms: children's knowledge and understanding of micro-organisms from 7 to 14 years-old. International *Journal of Science Education*, 33(14), 1927-1961.
Byrne, J., Grace, M. and Hanley, P. (2009) Children's anthropomorphic and anthropocentric ideas about micro-organisms: do they affect learning? *Journal of Biological Education* [Special Issue], 44(1), 37-43.
Byrne, J., Ideland, M., Malmberg, C. & Grace, M. (submitted) Negotiating a socio-scientific issue within a 'normal' life framework. *International Journal of Science Education*.
Christodoulou, A., & Osborne, J. (2011). Epistemic features of science teachers' talk during argumentation and non-argumentation instruction. Presented at the *Annual conference of the National Association of Research in Science Teaching*, April 3-6, 2011. Orlando, FL.
Christodoulou, A., & Osborne, J. (2012). Comparing epistemic features of student and teacher talk during argument-based instruction. Paper to be presented at the *Annual conference of the National Association of Research in Science Teaching*, March 25-29, 2010. Indianapolis, IN.
Gatt, S. et al. (2010) *Networking Primary Science Educators on as a means to provide training and professional development in inquiry based teaching*. FP7-SCIENCE-IN-SOCIETY-2010-1. Proposal №: 266647
Grace, M. and Byrne, J. (2010) Engaging students in decision-making about biodiversity conservation issues. School Science Review, 9, 336, 73-80.
Ratcliffe, M. & Grace, M. (2003).Science Education for Citizenship: Teaching Socio-Scientific Issues. Maidenhead: OUP.

In mathematics education, especially at the primary school level, children's understanding of number, and their development of meaningful problem-solving strategies in arithmetic, depends on a well-connected knowledge of concepts, procedures and facts. Primary mathematics education will be improved by providing a system that enables all young children (those of high attainment as well as those who do not achieve their best in mathematics) to develop and apply flexibly more than one type of arithmetic knowledge to problems. Within such an approach to mathematics education, young children can bring the procedural and conceptual aspects of number into interaction, thereby enhancing the development of their procedural as well as conceptual knowledge. Being able to connect knowledge of concepts with knowledge of procedures and facts is an essential skill that is particularly important for young children's progress in mathematics and supports the development of adaptive and flexible thinking. It is such kinds of thinking that are favoured by employers and Higher Education Institutions (Voutsina, 2011; 2012; in press; Voutsina

& Ismail, 2009; 2011; Voutsina & Jones, 2003; 2005).

Voutsina, C. (2011). Low attaining children's understanding and use of the additive composition principle in problem solving. In, *EARLI 2011: Conference of the European Association for Research on Learning and Instruction*, Exeter, U.K., 30 Aug - 03 Sep 2011.
Voutsina, C. (2012). Procedural and conceptual changes in young children's problem solving. *Educational Studies in Mathematics*, 79(2), 193-214.
Voutsina, C. (in press). A micro-developmental approach to studying young children's problem solving behaviour in addition. *Journal of Mathematical Behaviour*.
Voutsina, C. & Ismail, Q. (2009). Young children's approaches to solving conceptually linked addition problems. In, *Proceedings of the 33rd conference of the International Group for the Psychology of Mathematics Education*, vol 1, 487-488.
Voutsina, C. & Ismail, Q. (2011). The use of additive composition in arithmetic: the case of children classified as low-attainers. *Research in Mathematics Education*, 13(3), 287-303.
Voutsina, C. & Jones, K. (2003). Moving beyond success: changes in young children's successful problem solving behaviour. In Gagatsis, A. and Papastavridis, S. (eds.) *Proceedings of the 3rd Mediterranean Conference on Mathematical Education*. Greece, University of Athens, 717-724.
Voutsina, C. & Jones, K. (2005). The process of knowledge redescription as underlying mechanism for the development of children's problem solving strategies. In, Constantinou, C.P. and Demetriou, D. (eds.) *Integrating Multiple Perspectives on Effective Learning Environments. 11th Biennial Conference of the European Association for Research in Learning and Instruction*. Cyprus, University of Cyprus, 477-478.

2) Science and mathematics education internationally

From our research, and as reflected in the publications that we list below, jurisdictions where mathematics and science education could usefully be examined include China (specifically Shanghai and Hong Kong SAR), Japan, and Singapore. Our research suggests that these jurisdictions provide useful examples of practice in geometry teaching, in lesson planning and design, and in assessment practices.

Ding, L. & Jones, K. (2006). Teaching geometry in lower secondary school in Shanghai, China, *Proceedings of the British Society for Research into Learning Mathematics*, 26(1), 41-46.
Ding, L. and Jones, K. (2007). Using the van Hiele theory to analyse the teaching of geometrical proof at Grade 8 in Shanghai, China. In D. Pitta-Pantazi & G. Philippou (Eds), *European Research in Mathematics Education V* (pp612-621).
Fan, L. (ed.) (2011). *Performance Assessment in Mathematics: concepts, methods, and examples from research and practice in Singapore classrooms*. Singapore: Pearson.
Fan, L. and Sheng, D. (2008). A comparative case study of master teachers in primary mathematics between Mainland China and Singapore. *Taiwan Journal of Mathematics Teachers*, (14), 1-12.
Fujita, T. and Jones, K. (2002). Opportunities for the development of geometrical reasoning in current textbooks in the UK and Japan, *Proceedings of the British Society for Research into Learning Mathematics*, 22(3), 79-84

Fujita, T. and Jones, K. (2003). Interpretations of National Curricula: the case of geometry in Japan and the UK. Paper presented at the *British Educational Research Association Annual Conference,* Heriot-Watt University, 10-13 September, 2003.
Huang, X. and Fan, L. (2009). Instructional practice in mathematics classroom driven by curriculum reform: a case study of model lesson from Shanghai "Second Curriculum Reform". *Journal of Mathematics Education*, 18(3), 42-46.
Jones, K., Fujita, T. and Ding, L. (2005). Teaching geometrical reasoning: learning from expert teachers from China and Japan, *Proceedings of the British Society for Research into Learning Mathematics*, 25(1),89-96.
Jones, K., Fujita, T. & Ding, L. (2006), Informing the pedagogy for geometry: learning from teaching approaches in China and Japan, *Proceedings of the British Society for Research into Learning Mathematics*, 26(2), 109-114.
Jones, K., Kunimune, S., Kumakura, H., Matsumoto, S., Fujita, T. & Ding, L. (2009), Developing pedagogic approaches for proof: learning from teaching in the East and West. In Fou-Lai Lin, Feng-Jui Hsieh, Gila Hanna & Michael de Villiers (Eds), *Proceedings of the ICMI study 19 conference: proof and proving in mathematics education*. Taipei, Taiwan: National Taiwan Normal University. Vol 1, 232-237.
Quek, K. S. and Fan, L. (2009), Rethinking and researching mathematics assessment in Singapore: the quest for a new paradigm. In, Wong, Khoon Yoong, Lee, Peng Yee, Kaur, Berinderjeet, Foong, Pui Yee and Ng, Swee Fong (eds.) *Mathematics Education: The Singapore Journey*. Singapore, SG, World Scientific, 413-436.

Teachers (and the wider workforce)

1) Teaching as a career

We have yet to conduct research related to what needs to be done to make teaching a top career choice for trained scientists and mathematicians.

2) Initial Teacher Training

There is much that is good about initial teacher education programmes in science and mathematics in the UK, yet there are changes that are needed.

Training primary teachers who are confident and competent to teach science has been a matter of concern for several decades. Many primary trainees do not have a science background, and despite requiring GCSE at grade C to be eligible to train as a primary teacher they are not confident about their science subject or pedagogical knowledge. Good subject and pedagogical knowledge is a pre-requisite to be able to teach with confidence and to effectively answer pupils' questions and address their misconceptions. Initial Teacher Training courses must include these essential aspects of science (Byrne, 2005).

A factor in less than satisfactory mathematics teaching is weak subject knowledge of mathematics held by the teacher. There is research suggesting that the subject knowledge of generalist primary trainees in the area of geometry needs particular attention, and some evidence that the topic of probability would similarly benefit from attention (Jones, Mooney and Harries, 2002; Mooney, Fletcher and Jones, 2003; Mooney and Jones, 2002), As part of initial teacher education programmes, new mathematics teachers need to learn to make effective use of digital technologies in their teaching. Whilst trainee teachers need some support in developing technical skills with appropriate software and hardware, they have a greater need to learn how to make effective use of digital technologies to enhance teaching and learning through understanding how technologies affect the mathematics they teach and how it is learnt. Learning experiences are most effective when they form an integrated part of training courses (Hyde and Edwards, 2011).

One of the roles of the University provider in ITE is to provide trainee teachers with access to relevant theory that is modelled in practice in training sessions. Such modelling can lead to significant impact on teaching, not just for pre-service teachers but also for the secondary mathematics departments in which the trainees undertake their placements (Edwards J., 2010: Edwards, R. 2010; Jones, 2010). The importance to trainee teachers of access to this type of modelling of the theoretical bases to teaching mathematics, often not seen in the busy environment of schools, should not be lost in national policy shifts that currently appear to privilege more school-focused ITE.

In shortage subjects such as mathematics and science, some trainees benefit from additional personalised support in order to develop and fulfil their potential to teach effectively. Where experienced University based tutors, working together with school-based mentors, provide innovative tailored support and creative training experiences, trainees are seen to progress. Such support can involve tracking the progress of trainees to enable better-targeted interventions and, more recently, the use of online social networking to provide peer support for trainees (Edwards & Hyde, 2010).

Paired placements have been used very successfully in mathematics and science ITE across the University of Southampton Partnership with schools. Greater trainee satisfaction, sense of security and enjoyment of the school experience is evident. These pairings also result in an increase in higher-achieving trainee teachers, both in terms of level of performance against the standards for the award of Qualified Teacher Status and early successful appointment as newly-qualified teachers in Partnership departments (Wilson & Edwards, 2009). Evidence suggests that training of pre-service teachers by the Provider HEI, prior to the paired placement in school, enhances these benefits.

The need to recruit able and committed people to train as teachers has been, and continues to be, a major focus for policy-makers and providers, as well as for employers who want to appoint these new teachers to a post. Whilst good entry requirements are an essential criterion of the recruitment process, our evidence suggests that admission tutors need to be vigilant to ensure that a holistic picture of candidates' qualities is scrutinised. Assessment to indicate a candidate's potential to become a highly-effective teacher, and to discriminate between candidates of high calibre and filter out candidates less likely to perform well, is required as part of overall admission procedures (Byrne & Challen 2004).

Byrne, J. (2005). Confident and competent: Going beyond the standards in learning to teach primary

science? *European Science Education Research Association*, Barcelona. Proceedings and MaSE working paper.
Byrne, J. & Challen, D. (2004). *To what extent does outcomes of specific admissions procedures act to ensure the admission of quality trainees?* London: TTA
Edwards, J. (2010). Using a Bowland activity to develop group work. *Case study for ITE Matters*. London: NCETM. Available at: https://www.ncetm.org.uk/resources/33549.
Edwards, R. (2010). Using subject knowledge to enhance pedagogical practice. *Case study for ITE Matters*. London: NCETM. Available at: https://www.ncetm.org.uk/resources/33549.
Edwards, R. & Hyde, R. (2010), ESCalate Developing Pedagogy and practice grant 2010-11. *Supporting STEM: providing intervention strategies for borderline ITE students in STEM subjects to increase their success.*
Hyde, R. & Edwards, J. (2011) Pre-service teachers' understandings of learning to use digital technologies in secondary mathematics teaching. *Proceedings of the British Society for Research into Learning Mathematics*, 31(3), 83-88.
Jones, K. (2010). Progression in Mathematical Reasoning Skills. *Case study for ITE Matters*. London: NCETM. Available at: https://www.ncetm.org.uk/resources/33549.
Jones, K., Mooney, C. and Harries, T. (2002), Trainee primary teachers' knowledge of geometry for teaching. *Proceedings of the British Society for Research into Learning Mathematics*, 22(2), 95-100.
Mooney, C., Fletcher, M. and Jones, K. (2003), Minding your Ps and Cs: subjecting knowledge to the practicalities of teaching geometry and probability, *Proceedings of the British Society for Research into Learning Mathematics*, 23(3), 79-84.
Mooney, C. and Jones, K. (2002). Lost in space: primary trainee teachers' spatial subject knowledge and their classroom performance. In: A. D. Cockburn and E. Nardi (Eds), *Proceedings of the 26th Conference of the International Group for the Psychology of Mathematics Education*, Vol 1. p363.
Wilson, P. & Edwards, J. (2009) Paired ITE teaching placements: implications for partnership development.
Proceedings of the British Society for Research into Learning Mathematics, 29(2), 82-87.

3) Continuing Professional Development (CPD) for teachers

Professional development of teachers lies at the heart of educational improvement and reform. A more dynamic approach to continuing professional development of teachers is needed in which learning communities are created so that a culture of collaborative learning can be fostered. This approach requires teachers to work together cooperatively where ideas and pedagogical experiences can be shared and developed to improve teachers' practice and therefore be of benefit to their pupils' learning. Networks can provide support for teachers to engage actively with like-minded professionals, not only to share information, but also to interact in professional dialogue and discussion through the exchange of resources and experiences and the sharing and disseminating of good practice that addresses common classroom concerns (Byrne, Christodoulou, Griffiths & Rietdijk, 2012; Simon, Richardson, Howell-Richardson, Christodoulou & Osborne, 2010).

An increased focus on cross-curricular work and the changes to the Key Stage 3 curriculum, particularly in Science and Mathematics, have created new opportunities to explore the potential for cross-curricular work. When pupils have the opportunity of learning in subjects where compatibility and synergy exists, such as in science and mathematics, can increase pupils' cognition. However, teachers need CPD to be cognisant of the possibilities of working across subject departments in secondary schools to facilitate these approaches that are advantageous for pupils' learning (Dillon et al., 2009). Moreover, both beginning and experienced science teachers need to engage in CPD. Time allowed for CPD is essential as the process of changing pedagogies and practice is inevitably slow and requires support and commitment by the teachers for the CPD to have positive outcomes on pupil attainment (Osborne et al. under review). Our analysis of classroom talk during everyday science teaching of both beginning and more experienced teachers shows that both types of teachers mainly focus on talk and instruction that was not challenging pupils' reasoning and higher-order thinking (Christodoulou & Osborne, 2011).

Byrne, J., Christodoulou, A., Griffiths, J. & Rietdijk, W. (2012). *Cluster Networking: Developing science teachers' pedagogical expertise through communities of practice*. Bid to Astra Zeneca Teaching Trust project (under review).

Christodoulou, A. & Osborne, J. (2011). Epistemic features of science teachers' talk: comparing the discursive practices of two science teachers. Presented at the *9th biannual conference of the European Science Education Research Association* 2011, September 5-9, Lyon, France.

Dillon, J., Glackin, M., Grace, M. & Byrne, J. (2009). *Border Crossings: Developing science and mathematics teachers' cross-curricular competence: An innovative one-year CPD programme delivered by a consortium of King's College London, Southampton University, the Field Studies Council and Hampshire Outdoor Service Final Report*. October 2009

Osborne, J., Simon, S., Christodoulou, A., Howell-Richardson, C., & Richardson, K. (2012). Learning to Argue: a study of four schools, their attempt to develop the use of argument as a common instructional practice and its impact on students. (under review).

Simon, S., Richardson, K., Howell-Richardson, C., Christodoulou, A., & Osborne, J. (2010). Professional development in the use of discussion and argument in secondary school science departments. In M.F. Taşar & G. Çakmakcı (Eds.), *Contemporary science education research: pre-service and in-service teacher education* (pp. 245-252). Ankara, Turkey: Pegem Akademi.

In mathematics education, our research suggests that compared to pre-service training, CPD has unique advantages and is likely to more effective in the area of pedagogy (Fan, 2002, Fan 2003, Fan & Cheong, 2005). It appears that the benefit of CPD (or in-service training) is closely related to its unique advantages including in-service teachers' better professional background, relatively strong practical need and motivation, and the immediate applicability of the knowledge they learn in the training to their actual classroom teaching (Fan 2002).

Classroom-based research by teachers can provide a rich medium for CPD. Whether undertaken as part of a Masters-degree award or as self-initiated teacher enquiry, such research has significant impact on teachers' individual professional development, on their classrooms, their pedagogies and on consequent pupil learning, and on the wider life of the school and the local authorities within which they teach (Edwards, 2008, 2009). A longitudinal study over six years, exploring the impact of studying for an MSc in Mathematics Education on the professional life of a group of mathematics teachers, is demonstrating that when a school financially supports a teacher to undertake high-quality research at Masters level, the benefits to the school are evident beyond the mathematics department, impacting on both the wider learning of pupils and the assessment of their progress, and on retaining high-quality mathematics teachers in the teaching profession (Edwards, submitted article).

Primary teachers' mathematics subject knowledge continues to be an issue nationally and a focus for research. Evidence that some primary teachers are unaware of shortcomings in their mathematics subject knowledge (Campton and Edwards, 2011) suggests that mathematics-specific CPD support is essential for these teachers. While these teachers exhibit pedagogical approaches which are well-intentioned and often differentiated for individual pupils, they are often underpinned by less well-informed levels of mathematics knowledge held by the teachers resulting in pedagogically-inappropriate strategies.

Campton, I. & Edwards, J. (2011) Relationships between the influences on primary teachers' mathematics knowledge. *Proceedings of the British Society for Research into Learning Mathematics*, 31(3), 13-18.
Edwards, J. (2008). The impact of Masters-level study on teachers' professional development. *Proceedings of the British Society for Research into Learning Mathematics*, 28(3), 30-35.
Edwards, J. (2009). The impact of teachers' sustained collaborative professional development. In M. Joubert and R. Sutherland *Teacher Enquiry: at the heart of raising attainment in mathematics*, University of Bristol, NCETM.
Edwards, J. (submitted). Narratives of change: Teachers' and a researcher's parallel constructions of knowledge. *Journal of Mathematics Teacher Education*.
Fan, L. (2002). In-service training in alternative assessment with Singapore mathematics teachers. *The Mathematics Educator*, 6(2), 77-94
Fan, L. (2003). *A Study on the Development of Teachers' Pedagogical Knowledge*. Shanghai, East China Normal University Press.
Fan, L. & Cheong, C. (2005). How mathematics teachers develop their pedagogical knowledge: a study of six secondary schools in Singapore. Paper presented at the *American Educational Research Association*
Annual Meeting 2005, Montréal, Canada, 52 pages.

One promising way forward for CPD is collaboration between mathematics teachers in schools and University-based mathematics educators in developing the teaching of particular elements of mathematics (eg Brown, Jones, & Taylor, 2003; Edwards & Jones, 2003) and in developing the use of digital technologies in mathematics teaching (Jones et al, 2009; Lavicza et al, 2010). It is the co-learning that is at the heart of such collaboration that makes the difference and that ensures that the collaboration is such a powerful form of CPD.

Brown, M., Jones, K. & Taylor, R. (2003), *Developing Geometrical Reasoning in the Secondary School: outcomes of trialling teaching activities in classrooms, a report to the QCA*. London: QCA.

Edwards, J. & Jones, K. (2003). Co-learning in the collaborative mathematics classroom. In Peter-Koop, A.,A. Begg, C. Breen, V. Santos-Wagner (eds.) *Collaboration in Teacher Education: examples from the context of mathematics education* (pp 135-151). Dordrecht: Kluwer.
Jones, K., Lavicza, Z., Hohenwarter, M., Lu, A., Dawes, M., Parish, A. & Borcherds, M. (2009), Establishing a professional development network to support teachers using dynamic mathematics software GeoGebra, *Proceedings of the British Society for Research into Learning Mathematics*, 29(1), 97-102.
Lavicza, Z., Hohenwarter, M., Jones, K., Lu, A. & Dawes, M. (2010), Establishing a professional development network around dynamic mathematics software in England, *International Journal for Technology in Mathematics Education*, 17(4), 177-182.

4) The wider workforce

Relationships between classroom teachers and their teaching assistants (TAs) are crucial to the successful learning by pupils. Research on the nature of successful models of mathematics teachers and TAs working together in the classroom suggests that a subject-focused and highly-trained TA provides an improved learning setting for pupils. Other factors impacting on successful models include the availability of time for teachers and their TAs to discuss a planned lesson, agree feedback on pupil progress, or evaluate a lesson. What is important is mutual trust between teacher and TA regarding planned and unplanned interactions each has with specific pupils during lessons, and for them to agree classroom ‘coverage’ by both the teacher and the TA (Spencer and Edwards, 2011).

Spencer, P. & Edwards, J. (2011). A data collection process for an embedded case study focusing on the teacher-teaching assistant partnership in the mathematics classroom. *Proceedings of the British Society for Research into Learning Mathematics*, 31(3), 144-149.

Leadership and ethos

We have yet to conduct research on the impact that 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.

Skills, Curriculum and Assessment

In science education, research on teachers identifying and challenging young children’s misconceptions supports the view that science should be generic during much of the primary school years, rather than taught as separate subjects. This is because children’s misconceptions in science are interlinked across the sciences at this age. Separating the subjects would cause repetition when addressing misconceptions.

Knowledge about sustainable development is an essential part of science curricula around the world (see www.desd.org) and a key science component that underpins this is biological conservation (ie education about conservation of plants and animals) (Grace and Byrne, 2010). Professional conservation scientists have identified a number of science concepts that they consider essential for school science programmes, but the main ones are basic ecology and genetics concepts so that pupils can understand the reasons how and why species become endangered and what society can do to protect them (Grace and Ratcliffe, 2002).

Genetics concepts are comparatively difficult to understand, so this should be taught at Key Stage 4 before pupils leave compulsory schooling.

Grace, M. & Byrne, J. (2010). Engaging pupils in decision-making about biodiversity conservation issues. *School Science Review*, 91(336), 73-80
Byrne, J. (2011) Models of micro-organisms: children's knowledge and understanding of micro-organisms from 7 to 14 years -old. *International Journal of Science Education*.
Byrne, J., Grace, M. & Hanley, P. (2010) Children's anthropomorphic and anthropocentric ideas about micro-organisms. *Journal of Biological Education*, 44, (1), 37-43.
Grace, M. & Ratcliffe, M. (2002). The science and values that young people draw upon to make decisions about biological conservation issues. *International Journal of Science Education*, 24(11), 1157-1169.

At the primary school level in mathematics, children's understanding of number, and their development of meaningful problem-solving strategies in arithmetic, depends on a well-connected knowledge of concepts, procedures and facts. An effective curriculum enables children to apply more than one type of arithmetic knowledge to problems. With such a curriculum, young children can bring the procedural and conceptual aspects of number into interaction, thereby enhancing the development of their procedural and conceptual knowledge – something which occurs iteratively, rather than one preceding the other (Voutsina, 2012; Voutsina, in press; Voutsina & Ismail, 2011).

Voutsina, C. (2012). Procedural and conceptual changes in young children's problem solving. *Educational Studies in Mathematics*, 79(2), 193-214.
Voutsina, C. (in press). A micro-developmental approach to studying young children's problem solving behaviour in addition. *Journal of Mathematical Behavior*.
Voutsina, C. & Ismail, Q. (2011). The use of additive composition in arithmetic: the case of children classified as low-attainers. *Research in Mathematics Education*, 13(3), 287-303.

Measurement in mathematics is a topic that connects and enriches the two crucial mathematical domains of geometry and number (and thence algebra through measurement formulae). It also connects mathematics and science. Because of this, the placing of measurement (and its links with decimals, geometry, algebra and statistics) can be problematic for curriculum designers and policy makers and equally tricky for teachers to teach in the most effective way (Jones, 2010). Perhaps as a result, measurement can either seem all-pervasive within school mathematics, or, alternatively and probably more likely, sometimes appear as a somewhat neglected topic at the secondary school level in comparison to more overt and apparently sophisticated components of mathematics such as, say, algebra. When measurement in secondary school mathematics lacks focus (both in the specification of the curriculum, and in its teaching), then this might be storing up problems for learners as they more towards more advanced mathematical concepts such as functions, loci, vectors, and so on.

Jones, K. (2010), Measurement: everywhere and nowhere in secondary mathematics. *Proceedings of the British Society for Research into Learning Mathematics*, 30(3), 67-72.

Geometry is a key component of the school mathematics curriculum, and, if anything, is becoming more important in the 21st Century. During the primary school years, much geometry teaching focuses on the development of language for shape (for example, the names of polygons) and location (for instance, left and right). Such knowledge of mathematical terminology is, of course, essential for modelling, visualising and communicating in all areas of mathematics, yet the issue can be that a heavy emphasis on descriptive language at the expense of geometrical problem solving might mean that children's progression in geometry is somewhat limited (Jones & Mooney, 2003). In contrast, see Sinclair and Jones (2009) for what might be possible. At the secondary school level, geometry education needs to attend to the twin aspects of geometry across both 2D (plane) and 3D (solid) geometry: the spatial aspects, and the aspects that relate to reasoning with geometrical theory. The former involves spatial thinking and visualisation, while the latter involves deductive reasoning using approaches employing, where appropriate, congruency or transformations. These twin aspects of geometry are not separate; they are entwined (Jones, 2000a; 2001; 2002a; 2010). The use of appropriate software, used in appropriate ways, can be highly beneficial (Jones, 2000b; 2002b; 2011)

Jones, K. (2000a). Critical issues in the design of the geometry curriculum. In: Bill Barton (Ed), *Readings in Mathematics Education* (pp 75-90). Auckland, New Zealand: University of Auckland.
Jones, K. (2000b). Providing a foundation for deductive reasoning: students' interpretations when using dynamic geometry software and their evolving mathematical explanations. *Educational Studies in Mathematics*, 44(1-3), 55-85.
Jones, K. (2001). Spatial thinking and visualisation. In *Teaching and Learning Geometry 11-19* (pp55-56). London: Royal Society.
Jones, K. (2002a). Issues in the teaching and learning of geometry. In: L. Haggarty (Ed), *Aspects of Teaching Secondary Mathematics* (pp121-139). London: Routledge.
Jones, K. (2002b), Research on the use of dynamic geometry software: implications for the classroom, *MicroMath*, 18(3), 18-20 & 44-45.
Jones, K. (2010), Linking geometry and algebra in the school mathematics curriculum. In Z. Usiskin, K. Andersen & N. Zotto (Eds), *Future Curricular Trends in School Algebra and Geometry*. Charlotte, NC: Infoage.
Jones, K. (2011), The value of learning geometry with ICT: lessons from innovative educational research. In Adrian Oldknow and Carol Knights (Eds), *Mathematics Education with Digital Technology* (chapter 5; pp39-45). London: Continuum.
Jones, K. & Mooney, C. (2003). Making space for geometry in primary mathematics. In: I. Thompson (Ed), *Enhancing Primary Mathematics Teaching* (pp. 3-15). London: Open University Press.

Proof is central to mathematics and can feature in the teaching of both algebra and geometry across secondary school mathematics (eg Kunimune et al, 2009; 2010). For the teaching of proof to be successful at the school level, attention to the nature of teacher-pupil

interaction is important (Jones & Herbst, 2012), as is the provision of suitably-designed classroom tasks including the use of digital and online resources
(eg Fujita, Jones & Miyazaki, 2011)

Fujita, T., Jones, K. & Miyazaki, M. (2011). Supporting students to overcome circular arguments in secondary school mathematics: the use of the flowchart proof learning platform. *Proceedings of the 35th Conference of the International Group for the Psychology of Mathematics Education* (PME35). Ankara, Turkey, July 2011. Vol 2, pp. 353-360.
Jones, K. & Herbst, P. (2012), Proof, proving, and teacher-student interaction: Theories and contexts. In Gila Hanna & Michael de Villiers (Eds), *Proof and Proving in Mathematics Education* (the 19th ICMI Study). New York, Springer.
Kunimune, S., Fujita, T. & Jones, K. (2010), Strengthening students' understanding of 'proof' in geometry in lower secondary school. In Viviane Durand-Guerrier, Sophie Soury-Lavergne, Ferdinando Arzarello (Eds), *Proceedings of the Sixth Congress of the European Society for Research in Mathematics Education*
(CERME6). January 28th - February 1st 2009, Lyon, France. Institut National de Recherche Pédagogique, pp756-765.
Kunimune, S., Kumakura, H., Jones, K. & Fujita, T. (2009), Lower secondary school students' understanding of algebraic proof. In: M. Tzekaki, M. Kaldrimidou & H. Sakonidis (Eds.), *Proceedings 33rd Conference of the International Group for the Psychology of Mathematics Education* (PME33), vol 3, pp441-448.

When pupils are provided with opportunities to work in small groups on open-ended problem solving tasks, the need for them to learn specific mathematics concepts and knowledge is generated. Our studies in such settings provide evidence of high-level mathematical reasoning for pupils aged 11-15 at all levels of attainment, with all consistently achieving above their expected level of attainment. The research also challenges the need for specific year-by-year specification of the curriculum at the secondary level; rather, it supports ideas of pupil 'readiness' to understand mathematics concepts (Edwards, 2007; Edwards & Jones, 2001, 2003).

Edwards, J. (2007). The language of friendship: developing socio-mathematical norms in the secondary mathematics classroom. In D. Pitta-Pantazi & G. Philippou (Eds), *European Research in Mathematics Education V* (pp 1190-1199). Nicosia, Cyprus: University of Cyprus.
Edwards, J. & Jones, K. (2001). Exploratory talk within collaborative small groups in mathematics. *Proceedings of the British Society for Research in Mathematics Education*, 21(3), 19-24.
Edwards, J. & Jones, K. (2003). Co-learning in the collaborative mathematics classroom. In Peter-Koop, A., A. Begg, C. Breen, V. Santos-Wagner (eds.) *Collaboration in Teacher Education: examples from the context of mathematics education*. Dordrecht: Kluwer (pp 135-151).

Infrastructure
We have yet to conduct research that specifically addresses all the identified issues of infrastructure, apart from pointing to the evidence cited above that one promising way forward for CPD infrastructure lies in supporting collaboration between teachers in schools and University-based education researchers in developing the teaching of particular elements of science and mathematics (eg Brown, Jones, & Taylor, 2003; Edwards & Jones, 2003) and in developing the use of digital technologies in science and mathematics teaching (eg Jones et al, 2009; Lavicza et al, 2010). An infrastructure that supports such colearning would help ensure that such collaboration is a powerful form of CPD.

Brown, M., Jones, K. & Taylor, R. (2003), *Developing Geometrical Reasoning in the Secondary School: outcomes of trialling teaching activities in classrooms, a report to the QCA*. London: QCA.
Edwards, J. & Jones, K. (2003). Co-learning in the collaborative mathematics classroom. In Peter-Koop, A., A. Begg, C. Breen, V. Santos-Wagner (eds.) *Collaboration in Teacher Education: examples from the context of mathematics education* (pp 135-151). Dordrecht: Kluwer.
Jones, K., Lavicza, Z., Hohenwarter, M., Lu, A., Dawes, M., Parish, A. & Borcherds, M. (2009), Establishing a professional development network to support teachers using dynamic mathematics software GeoGebra, *Proceedings of the British Society for Research into Learning Mathematics*, 29(1), 97-102.
Lavicza, Z., Hohenwarter, M., Jones, K., Lu, A. & Dawes, M. (2010), Establishing a professional development network around dynamic mathematics software in England, *International Journal for Technology in Mathematics Education*, 17(4), 177-182.

Accountability
We have yet to conduct research that specifically addresses the identified issues of accountability.

MEI

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.*

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.*

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.*

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

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.*

Leadership and ethos

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.*

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.*

Skills, Curriculum and Assessment

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.*

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.

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.*

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.*

Myscience

General questions

1) Science and mathematics education in the UK

Myscience notes that the Royal Society review process is examining some areas which have been the subject of other reviews of evidence in recent years. Among these, a number of expert groups reported to the Department of Business Innovation and Skills in 2010 on various aspects of science and mathematics education. In particular of the recent reviews and enquiries, Myscience is in broad agreement with the analysis and recommendations of the Science and Learning Expert Group chaired by Sir Mark Walport (Science and Learning Expert Group, 2010, *Science and Mathematics Secondary Education for the 21st Century Report of the Science and Learning Expert Group*).

Teachers (and the wider workforce)

1) Teaching as a career

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

In order to enable trained scientists and mathematicians to see teaching as a rewarding career which uses their knowledge and skills, it is helpful if there is, and is seen to be, a real focus on using specialist subject knowledge in teaching and learning, rather than any implication that teaching deals with social problems. Clear opportunities for career progression through specialist science and maths pathways in schools and colleges would be beneficial.

It would be encouraging if teaching is seen as a true profession, with all that entails with regard to professional standing within the wider community, professional autonomy and regard in society. There should be enabling mechanisms for teaching to be a profession that is self-regulating, within government guidelines and appropriate checks and balances. Professional development should be integrated throughout a teacher's career - as an entitlement and obligation (in the same way as other professions in which scientists and engineers are required to have chartered status)

2) Initial Teacher Training

A major and valid concern of initial teacher education is ensuring there is sufficient time and focus for beginning teachers to:

- develop their pedagogical content knowledge in their specialist areas in particular;
- understand the construction of science and maths curricula; and
- develop understanding of broader educational issues in subject-specific rather than general contexts.

It is important to ensure that leadership of ITE is by **subject specialists** with expertise in developing teachers' knowledge, understanding and skills; having a broad understanding of science /mathematics education in the UK and its context internationally (e.g. a variety of teaching experiences) and an ability to use research and other evidence to inform ITE. It is not evident that all teachers in initial teacher education are taught and mentored by experts with these attributes.

Indications of the length of time that should be spent in classroom experience need to be considered alongside aims and objectives of initial teacher education. There needs to be a balance between: understanding the rationale for and practice of science education, gained through activities outside the classroom and reflections on experiences gained within the classroom; and practical experience of teaching in a variety of contexts – e.g. different types of learning activities, different year groups, and different curriculum topics.

3) Continuing Professional Development (CPD) for teachers

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

We note that there is a growing tendency for schools to provide internal CPD events focussed on subject independent needs such as behaviour, classroom management etc. Although needed by teachers this should not be seen as a substitute for subject-specific CPD.

International research evidence indicates that the quality of learners' classroom experiences of science, their achievements and engagement in science is directly related to the quality of the teaching they receive[9]. Teachers' development starts in initial teacher education but is a continuum throughout their career. Subject specific professional development enables the quality of teaching and learning to be high.

The National Science CPD forum has recently produced a document outlining the rationale, benefits and priorities of subject-specific CPD (appendix 1).

The impact of CPD in science as delivered by the national network of Science Learning Centres has been extensively evaluated through independent, external research[10] and

[9] E.G. McKinsey and company (2007) How the world's best performing school systems come out on top
[10] E.G. Educating the next generation of scientists. National Audit Office November 2010
Successful Science – An evaluation of science education in England 2007-10, Ofsted, January 2011 p51

through internal collection and analysis of evidence provided by teachers and their line managers. All evidence points to improvements in the quality of teaching both by CPD participants and their wider colleagues, and, importantly, an increase in learners' achievements and engagement with science.

b) How should science and mathematics teachers best keep up with their subject and with new approaches to teaching, assessment and the curriculum? At what times throughout their teaching careers and with what regularity should teachers undertake subject-specific CPD?

All teachers should be encouraged and expected to continuously maintain and develop their subject knowledge and expertise through ongoing engagement with a wide variety of subject-focused CPD activities. This includes personal approaches to updating knowledge – e.g. membership of professional bodies and learned societies and relevant publications; informal and formal activities within schools and colleges to share experiences, gain new knowledge and reflect on practice; formal and informal activities undertaken outside school – e.g. in venues designed to focus on subject-specific knowledge, skills and teaching expertise through working with experts in the discipline and in subject-specific professional development. The full variety of these experiences is important as together they develop a fully rounded professional with significant subject expertise. A focus on one type of CPD activity alone limits the development.

d) Should CPD be voluntary or mandatory? Why?
Mandatory – as described above, career long CPD should be seen by teachers and those supporting them as an entitlement and an obligation. An entitlement to professional development recognises that there is no ceiling to professional development of knowledge, skills and expertise and encourages ambition and high quality in science and mathematics education. An obligation on behalf of the teacher recognises that their knowledge skills and expertise are not static but always capable of further improvement. Without the entitlement, teachers can be deprived of genuine opportunities to further the quality of learners' classroom experience and achievement. Without the obligation, teachers can become complacent about their expertise. Mandatory professional development also protects teachers' opportunities to engage in this important activity, and avoid other pressing priorities that often tend to squeeze professional development out.

Scott, P., Ametller, J., Edwards, A. (2010) Impact of focused CPD on teachers' subject and pedagogical knowledge and pupils' learning. Leeds: University of Leeds
Bennett, J., Braund, M., & Lubben, F. (2010). *The Impact of Targeted Continuing Professional Development (CPD) On Teachers' Professional Practice in Science. Main Report.* York: University of York, Department of Educational Studies.
Evaluation of action research for physics programme Rietdijk, W., Grace, M., and Garrett, C. 2011 University of Southampton.
Irina Kudenko, Mary Ratcliffe, Alison Redmore & Catherine Aldridge (2011): Impact of a national programme of professional development in science education, Research in Science & Technological Education, 29:1, 25-47

e) Are there key obstacles preventing science and mathematics teachers from accessing subject-specific CPD? If so, how can these be overcome?
Obstacles relate to the value put upon subject-specific CPD by schools and colleges (and lack of understanding of the benefits it brings to pupils as well as teachers); and to concerns about the timing of professional development and its impact on learners.

Teachers of science show a strong preference for formal CPD activities to take place during the working day (independent teachers' panel evidence.) If subject-specific professional development is valued by the institution's senior management, then plans can be made to take full advantage of teachers' preferences and the opportunities on offer, particularly the heavily subsidised professional development through the national network of Science Learning Centres.

Finances within schools and colleges to support professional development are not ring-fenced. It can be understandable but not defensible if professional development takes a lower priority within an institution's budget than curriculum resources, building maintenance, support staffing etc.

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?
All broad development strategies, such as leadership and assessment, are rooted in the teaching of subjects and should not be divorced from subject teaching nor subject-specific CPD. It is important that subject-specific developments in curriculum, teaching, leadership and assessment contribute to the wider school and college priorities. The subject specific CPD development strategy should be undertaken in parallel with broader school/college development.

g) Should CPD be accredited (e.g. through the awarding of Masters-level credits)?
If CPD is seen as an entitlement and an obligation, then the recording of CPD undertaken and its impact on practice is a means of tracking the development of individuals and the collective workforce. Chartered status is a mark of professional practice in many professions, with a requirement to maintain the charter designation through on-going professional practice. Thus accreditation can, and should, take a number of forms – a record on ongoing activity (formally through charter status, or informally through CV and records which follow a teacher through their professional experience); - a recognition through professional or academic accreditation of significant experiences of short or long term focussed professional development (e.g. through the Professional Award in Science Teaching and Learning – PASTL, achieved through undertaking 60 hours of professional development through the national network of Science Learning Centres, coupled with reflection and analysis of impact; Masters-level accreditation of courses through the national network of Science Learning Centres.)

Accreditation will only be fully recognised and valued, however, if professional development is seen as necessary for career advancement by school and college leaders and the profession as a whole. There is still significant progress to be made across teaching and education in this regard.

4) The wider workforce

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

Unlike teachers where professional qualifications are essential to employment, technicians often have a wide range of qualifications from those with no science specific qualifications to those with degrees, masters and PhDs. In the last ASE survey of technicians (2010) 37.1% held degrees, but in the same survey 53.9% reported that GCSE or A levels were the only thing asked for; very few were asked for or held profession specific qualifications. This causes issues for employers as these qualifications will not be completely relevant to the role of the school/college science technician. As a result role-specific CPD is very important to make sure science technicians are competent and confident in their role, which has a direct impact on effective practical work. In most institutions there may be none, one or two other technicians who may not have had any formal training, this means that internal CPD can be ineffectual and may not be current best practice. Therefore we believe that external CPD provided by the national network of Science Learning Centres provides up to date, practical, specific and relevant training for technicians. This CPD can be delivered both in local schools and purpose built centres.

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

Technicians' CPD needs are varied and relate to levels of experience and responsibility. For example new technicians need the basics in skills and health and safety information whilst more experienced technicians need specific practical courses to support teaching and learning and advising teachers. Senior technicians responsible for a technical service need leadership and management courses.

There has also been a demand for CPD in technicians supporting in the classroom or performing demonstrations. From the ASE survey of 2001 to the latest ASE survey of technicians (2010) there had been an increase from 27% to 73% of technicians involved in assisting in practicals in the classroom and a 17% to 66% increase in technicians demonstrating. The national network of Science Learning Centres have successfully developed courses to support this change in the technician's role and cover a range of other CPD needs for technicians. This CPD should be available for all technicians and this requires acknowledgement from institution that it is required. There is also a need to recognise this training through accreditation. In a questionnaire (March 2010) carried out by the Science Learning Centres 76% of technicians stated that they would be very or quite interested in accredited courses, this would give recognition and professionalism to individuals and the role. As of 2010 the National Science Learning Centre has developed an accredited course for senior technicians with a 60 credit Level 4 qualification.
Technician CPD is best supported by external organisations which specialise in the knowledge and skills technicians need, with the CPD mapped onto a career structure with recognised qualifications.

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?)

Both careers professionals and teachers have a role in providing STEM careers guidance.

Careers professionals need to be well-informed about careers open to people with STEM qualifications and skills, and be familiar with relevant labour market information regarding such careers. It is also vital that all careers professionals are sufficiently prepared to challenge stereotypes regarding STEM careers, and are aware of the high value that employers place on science and mathematics qualifications for all individuals across all sectors, not just 'traditional' STEM industries. Initial and in-service training of careers professionals should address these requirements.

In addition, careers professionals should have access to accredited training that enhances this basic provision, thus ensuring that organisations and individuals providing careers information, advice and guidance (IAG) services to schools and colleges can include this in depth expertise in their offer. Following the recommendations of the Careers Profession Task Force[11], such a specialist Advanced Careers Practitioners qualification in STEM should be developed through collaboration across the STEM and careers professionals communities.

However, at the same time, it is well-recognised that young people draw on a wider range of sources to shape their view the potential career pathways that are open to them. The opinions of peers, family, and teachers are highly valued. Better efforts should be made to provide subject teachers with the necessary training and resources to sustain the provision of accurate information at appropriate and very regular instances throughout the curriculum. In 2010 a review of STEM careers IAG provision in England recommended that, "teachers of science, mathematics and design & technology should take opportunities where appropriate to embed elements of STEM careers awareness to contextualise their teaching and help bring their subject to life. This should become second nature to the teacher and appear seamless with the subject content by students."[12] This proposal is supported by other findings, for example, "Better STEM careers activity arises where subject teachers see the preparation of young people for work, as an integral part of their professional role, and where they have the professional skills and confidence to act on this."[13] The National STEM Centre, funded by the Gatsby Charitable Foundation, is working with partners, including the Science Council, to take forward several of these recommendations - including the development of tools to support teachers and careers professionals in providing accurate and enticing STEM careers information, advice and guidance, including training modules.

It is definitely not our intention to suggest that teachers of STEM subjects act as sole providers of careers IAG in schools and colleges. However, a one-size-fits-all approach to STEM careers IAG is insufficient to address its complexity, and research findings

[11] Towards a strong careers profession: An independent report to the Department for Education, the Careers Profession Task Force, chaired by Dame Ruth Silver October 2010
[12] STEM Careers Review, Holman and Finegold, Gatsby Charitable Foundation 2010
[13] Good Timing: Implementing STEM careers strategy in secondary schools, Centre for Education and Industry, University of Warwick 2011

recommend a coherent, and consistent, programme of interventions to engage young people with work-related learning, “Given the wealth of evidence suggesting that ‘one-off’ interventions have little long-term or widespread impact on science choices and participation rates”[14]. Closer collaboration of subject teachers and careers professionals working with schools is necessary to achieve this aim.

Leadership and ethos

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?

There is a strong link between leadership and the impact on the quality of education. Evidence from a recent national perspective can be seen in the Successful science report January 2011, HMI No. 100034:

Secondary schools
The quality of the leadership and management in science was good overall in more than four out of five of the secondary schools visited. In around one in five of the schools, leadership and management were outstanding and were having a very positive impact on teaching, learning and students’ achievement. Common features in these schools included:

- *clear systems for tracking the progress of individual students*
- *effective intervention and planning informed by the tracking data*
- *collaborative planning and sharing of good practice*
- *clear roles and responsibilities*
- *the setting of clear standards for the quality of teaching.*

.... In the schools where leadership and management were good or outstanding, the head of department had an accurate and balanced view of strengths and weaknesses and had clear plans for improvement.
... In the last year of the three-year inspection cycle, only one in five of the heads of departments visited had received subject-specific training on leadership and management. Training had a positive impact on the confidence of heads of departments who also reported that they had gained a clearer understanding of issues such as effective communication, collaborative working, and monitoring and evaluation. It was also evident from inspectors’ discussions with heads of department that subject-specific training had promoted a more coherent and broader understanding of issues affecting standards.
...More secondary than primary teachers in the survey had received appropriate professional development. While four out of five secondary science departments felt that the professional development they had received was satisfactory, only one in five thought it was good. ***The quality of professional development received from external providers was variable but that provided by the national network of Science Learning Centres was consistently reported to be good****.*

[14] Ten Science Facts & Fictions: The Case for Early Education about STEM Careers, ASPIRES Project, King’s College London

... Where teachers had attended externally provided subject training, evaluation of the impact showed improved teaching and a sharing of good practice in their department.
The characteristics seen evidenced in the HMI report are, plus others, covered in the leadership programmes delivered by the national network of Science Learning Centres. These courses are extremely popular and well received by participants.
As well as this external evidence of the impact of subject-specific leadership training on the quality of science education, Myscience has conducted internal evaluation of the science leadership courses it offers. These provide evidence of high levels of impact at not only class but whole school level by those who have had subject specific leadership training as a result of their greater confidence, autonomy and status, making them able to have a greater and wider impact in the work that they do.

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

The role of middle leaders in any educational establishment is crucial in bringing about change, inspiring others and promoting success. Leaders should be able to gain and share ideas and strategies for leading and running a department so that they are able to promote engaging teaching and learning of their subject, work effectively with large numbers of colleagues, keep abreast of changes within their subject and be aware of a wide range of issues that affect science/mathematics and the teaching of it.

These skills will include being able to:

1. acquire deep understanding of subject knowledge, pedagogical content knowledge and curriculum planning;
2. employ a range of methods to strategically lead and manage the department;
3. evaluate the skills they personally have and identify areas they need to develop to become a highly effective leader;
4. implement change within their school that they can evaluate;
5. explain what outstanding teaching and learning in their subject is and use this to provide effective feedback to colleagues;
6. use a variety of strategies to make teaching and learning in their subject more engaging and inspiring for pupils and colleagues;
7. employ a range of techniques to enable them to create a high performing team;
8. describe a variety of methods they can employ to develop the members of their team; and
9. articulate how a range of approaches can be employed to support and enrich pupils' experiences in their subject.

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

Collaboration and a culture of sharing of learning are the best ways of ensuring that leadership qualities are developed within and across departments and these occur most effectively where a culture of coaching pervades. Where coaching practices are at the heart of this collaborative learning there is then the possibility of not only continued development of practices but also the possibility of impacting on beliefs and values and a possibility of high level leadership practice being developed - ‘only when coaching principles govern or underlie all management behaviour and interactions, as they certainly will do in time, will the full force of people's performance potential be released'.[15]

Natural History Museum

General questions

1) Science and mathematics education in the UK

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

The current National Curriculum has a number of key strengths which we have outlined below:

- **Science education.** In the current Science Curriculum, the focus is not only on facts and theories but also processes and skills. All of these are key to an understanding of the nature of science. This provides opportunities for those who wish to carry on in further education and train as scientists, but also gives others a strong scientific literacy which helps support those in professions that need scientific knowledge, but not necessarily science specialism, and also to develop well-rounded citizens. Science, as a subject, is more than a body of facts and theories; it also contains a significant element of skills, such as objectivity, problem-solving, planning, interpreting data, practical skills, communication, modelling and analysis. Students also need to understand the relevance of science to daily life and their role as citizens. Teaching scientific process is as important as teaching scientific theories. To train future scientists and also to produce scientifically-literate and well-rounded citizens we need to teach all these key elements of the subject through all Key Stages. We know that sectors of business require the skills and an understanding of the scientific process from their new recruits. At the Museum, we support the teaching of scientific skills in a range of our educational activities. Feedback from teachers and students on its worth and impact has been extremely positive in this regard.

- **Opportunities to learn outside the classroom.** The Natural History Museum strongly believes in the value of learning outside the classroom and the enrichment opportunities it provides teachers and students. The current Curriculum allows some contingency for these visits which provide inspiring experiences where students can apply their skills and knowledge in a new context and see the relevance of what they are leaning. There is a significant body of evidence that shows that museums provide powerful and potentially transformative opportunities for additional learning, enrichment and inspiration.

- **Access to education**. The current National Curriculum offers a framework by which all students have access to a baseline entitlement of education, regardless of their ability, geographical location, gender or socioeconomic status. This reduces inequalities and enables educational and job opportunities for all. This can be further

[15] Whitmore, J. (2002) *Coaching for Performance – GROWing People, Performance and Purpose* Nicholas Brearly: London

supported outside the classroom, and at the Natural History Museum through a wide range of activities which support the National Curriculum.

- **Progression.** The spiral progression through the Key Stages is a good model that allows students to review past learning and extend it further. Good teaching and planning ensures that there is no unnecessary duplication of knowledge and allows students then to build on concepts and skills at a level which is appropriate. The Natural History Museum is well placed to support key progression points and the Primary/Secondary transfer point in particular.

- **Cross curricular links.** The current Curriculum allows for cross-subject links – disciplines are rarely isolated and it is valuable for students to see how topics fit into the "bigger picture". Feedback from teachers participating in our education programme shows that cross curricular links make for a well-balanced and beneficial experience for their students.

- **Transparency.** The National Curriculum allows transparency and gives students, parents and the wider community a clear understanding of the content and requirements. It enables them and other external organisations to enhance teaching and learning in and out of the classroom.

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?

Whilst the current National Curriculum has its strengths, there are certain areas in which we recommend revision, based on our experience working with schools and families:

- **Meet employers' needs with particular reference to science.** The new National Curriculum must be able to recognise the needs of further education institutions and employers. Students must be given as fair an entitlement as possible to access further education and careers through the teaching of transferable skills. Through conversation with university tutors and ecological consultancy professionals, it is clear that baseline competencies of first year biology undergraduates are lower than they have been; very few students enter university with even basic field competencies, including survey methods, species and habitat identification skills. There is a clear skills gap here that the National Curriculum should look to close.

- **Recognise the value of and promote out of classroom learning.** The Natural History Museum believes that teachers should have the flexibility to undertake field trips where appropriate to their class work because of the benefits it provides – inspiring further study, raising aspirations, building confidence, demonstrating relevance and developing knowledge, understanding and skills. Out of classroom learning can provide contexts in which key concepts are explored. The Natural History Museum is well placed to support these contexts through our galleries, educational activities and scientists. We also recommend a formal entitlement for out of classroom learning to narrow the educational gap particularly for disadvantaged children. Whilst selection of destinations for field trips should be at the discretion of schools and teachers, relevant to their class work, we are concerned that an inequality, where some schools take part and others do not engage, could leave some students disenfranchised from their scientific and cultural heritage and the inspiring learning opportunities that it provides.

Biology curricula for secondary students need a strong emphasis on fieldwork and support for teachers to approach this with confidence. Field-based outdoor learning (whether within school grounds or at a dedicated field centre) is highly effective and the associated field skills training would greatly support the generation of adequately trained scientists. Students need exposure to all aspects of the science process at an early age; so that they can appreciate what's involved (hence make informed decisions on careers or higher education choices) and so that biology students enter university with a broader science skill set than currently occurs. It is well known that very few e.g. ecology undergraduates now enter university with any field skills whatsoever (incl. species survey and identification). This hasn't always been the case.

- **Enable teachers to decide the most relevant context for teaching the content.** We support the idea that the National Curriculum should contain the key content required for students to learn. The contexts in which these concepts are based should be at the discretion of schools and teachers who are best placed to address the learning needs of their students. This would give more freedom to allow teachers to use their professional training and judgement, and improve the creativity of teaching and learning. It would also allow teachers to respond to changing contexts and keep lessons relevant and fresh. This in turn requires flexible resources, external support from examination boards and education authorities and rigorous teacher training to ensure that this is done to a high standard. The Natural History Museum is also able to support these contexts in a number of subjects with our galleries, educational activities and scientists. We also assist with ITT training.

- **Enable both vocational and academic qualifications to be recognised.** Also, there should be options for students to take examinations and courses best suited to their particular interests, abilities and learning needs in the form of vocational and applied qualifications to sit alongside academic qualifications.

- **Preventing subject overlap.** While there is considerable benefit in cross-subject learning, within the Curriculum itself, there should be as little overlap as possible. Currently there are some Earth Science concepts which overlap the Geography and Science curricula and there should be a view taken on this to avoid duplication.

- **Key Stages as opposed to Year Groups?** Organising the programmes of study around Key Stages, as opposed to Year Groups, would allow more freedom for teachers to cater for students of different abilities. It is important that young people's learning is not limited by the programmes and that there are opportunities for the most-able students to be challenged.

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

There is a perception of burden of assessment currently on teachers, restricting their ability to take students out of the classroom to experience the diverse range of informal environments available to them. The emphasis on testing could prevent teachers from being able to explore content beyond what is tested and find how informal environments can support key concepts and provide the relevance and real-world applications of science.

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

Such an education system would allow employers and higher education providers an opportunity to feed into the specific skills, knowledge and understanding needed by individuals employed in certain industries and professions, and ensure their needs are met. The Museum is ideally placed to make recommendations for a system that meets such needs as an employer of 329 research science, curatorial and technician staff. In addition, the Museum hosts a number of Masters courses, which includes a course of between 20-30 students a year, in collaboration with Imperial College, London. Last year we also hosted 129 PhD students.

The Natural History Museum is part of a strong regional partnership of natural history museums that aim to unlock the potential of their collections to enhance and enrich the National Curriculum for secondary students – the Real World Science (RWS) programme. This is a partnership between the NHM and Oxford University Museum of Natural History, The Manchester Museum, The Great North Museum: Hancock and Stoke-on-Trent Museums. The RWS partners are ideally placed to provide such informed feedback due to the close ties with universities and as employers of staff who utilise a wide variety of science skills in a variety of roles.

Other comments:

The UK science and mathematics education system needs to support and foster not only general scientific literacy skills for informed citizens and more highly skilled specialist staff such as research scientists, but also the vast majority of people employed in other science technology roles that lie in the middle of this continuum. This majority needs more than a general understanding and level of skill for science and mathematics, but also careers guidance and role models to raise aspirations beyond solely 'science to be a scientist'. It also needs to acknowledge that some skills, knowledge and understanding that may be needed in future careers are unknown and therefore the importance of developing transferable skills to increase confidence and nurture creativity.

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?

Encourage the restoration of respect for the teaching profession and promote an awareness of the range of careers available in education. Initiatives such as 'ASE Chartered Science Teacher' encourage professionalism and recognition of science teachers and 'Teach First' encourages top graduates to consider the option to teach. Those who do choose to make teaching a career choice should be supported to keep in touch with their science profession and institutions such as the Natural History Museum are ideally placed to provide opportunities for such teachers to do so.

Adding a clear research project element into the curriculum may encourage trained scientists further as it would be an opportunity to continue 'doing science' in addition to communicating science to their students. There is a risk that by only having the opportunity to teach content that is already well understood and not actively researching or progressing the body of scientific knowledge, trained scientists who change careers to teaching would be restricted from doing the very thing that attracted them to science in the first place.

2) Initial Teacher Training

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

Currently trainee teachers are not required to provide evidence of field trips, just the content covered, logistics, health and safety issues etc involved in trip planning. Actual experience of taking students on field trips could work in tangent with any increased practical time spent in class rooms to ensure this is valuable experience that increases teacher confidence in planning and undertaking trips. The Museum hosted 97 PGCE students in 2010/11 in an endeavour to disseminate the value and wealth of curriculum-linked activities available to school groups at the Museum and to encourage these students to include field trips to museums in their future teaching careers.

It may be beneficial if a compulsory field skills component was considered for Biology secondary school teacher training. NHM scientists participating in outreach activities have been told by both primary and secondary school teachers that they would love to take their students outdoors, but don't feel that they have the confidence and knowledge to do so, for example survey and identification skills.

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

Universities have the specialist knowledge to train teachers, and the White Paper proposed Teaching Schools could work well in partnership for teacher training to take place. A third partner from an informal environment could support both, in a relatively minor capacity, and ensure that the resources and opportunities that can be provided in out of classroom learning are best utilised. Informal environments provide the relevance and contexts where school content is brought to life and can support trainee teachers to find ways to engage their students beyond the classroom.

3) Continuing Professional Development (CPD) for teachers

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

CPD inspires and engages teachers, allows them to maintain contact in areas of specialism and gives up-to-date information and knowledge to share with their students and colleagues. It provides opportunity for teachers to engage with current research in science and in science education and share best practice between institutions, encouraging peer to peer networking and support.

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

The best way for teachers to keep up-to-date with their subject is to get out of the classroom and into environments where they can meet researchers, find out about real world applications of current research and form new partnerships that allow them to participate in research programmes. This could extend to citizen science projects where members of the public use scientific procedures to collect data used in real research projects. The Open Air Laboratory (OPAL) project is one such example. Such projects could involve teachers and their students, sharing the experience and the engaging and inspiring both in real contexts of science. Such experiences could provide new opportunities for assessment in addition to new ways of teaching curriculum content. The Natural History Museum would be ideally placed to provide such opportunities with the rich sources of scientific expertise and authentic objects, spaces and other resources it has access to.

Citizen science projects represent an interesting and potentially very powerful way to directly demonstrate and involve students in the science process. Through the development of, and participation in, the OPAL Project, NHM scientists have found teachers value this approach and flexibility in the curriculum could encourage teachers to involve their students in such projects. Participating in genuine science discovery is a powerful motivator and citizen science can be a holistic approach to learning how science works.

d) Should CPD be voluntary or mandatory? Why?

We believe CPD should be a normal component of teacher development and career progression that encourages school management to ensure it is funded and accessible.

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

Some visiting teachers have anecdotally commented that Rarely Cover is a key obstacle in preventing them from leaving school to participate in CPD. The Rarely Cover Policy protects teachers' vital lesson preparation and marking time, but a consistent interpretation of the Rarely Cover Policy across schools is required, freeing up teachers ability to participate in activities out of school.

g) Should CPD be accredited (eg through the awarding of Masters-level credits)?
CPD should be accredited and closely linked to career progression. It is a means to keep teachers engaged and inspired in their profession.

4) The wider workforce

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?)

We support the idea of careers advisors with specialist knowledge who could be supported by employers associated with STEM related careers. As an example, the Natural History Museum has research scientists and curatorial staff who could provide advisors with knowledge of their careers. There are opportunities for classes to be involved with citizen science projects, benefiting all parties involved - teachers through intimate career knowledge to advise their students, students with practical experience of 'hands on' science and researchers who have support for their projects.

Real World Science (RWS), the Museum's aforementioned regional partnership, aims to develop learning products for secondary students that embed information about a range of science careers, from researchers to curators and beyond. These aspirational role models are a vehicle for students to discover personal pathways to science. By showcasing museum and university science staff and their work in learning activities, students are exposed to a range of role models from diverse backgrounds to help deconstruct popular stereotypes of who a scientist is and what a scientist does, making science more accessible. The science and curatorial staff of the Natural History and those affiliated with RWS partner museums are essentially fulfilling a similar role as STEMNET Ambassadors.

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 ASPIRES project (DeWitt et al., 2010) has found evidence that attitudes to school science, in addition to parental attitudes to science, have the strongest correlation with the aspirations of 10-14 year old students in England to study science and in science-related careers. Those students with positive experiences of school science are likely to have higher aspirations in science. The leadership qualities and attitudes of teachers are imperative in supporting and inspiring their students and encourage this ensuing interest in subjects.

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?

From a museum's perspective, the value placed on out of classroom learning by the leadership and ethos of a school or college impacts whether a teacher can take a group out of school or not. If the benefits of informal environments and the opportunities they provide for learning and supporting the National Curriculum is not valued, it is going to be difficult to justify a school visit.

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?

It is imperative a young person's progress in science and mathematics education is supported and continued from the first day. Individuals bring their own observations, questioning and constructed meaning of the world around them and need to be encouraged to continue to do so. Objectivity, communication, the ability to critically analyse, question and evaluate are some of the essential skills in the scientific process and have valuable transferability across subject disciplines.

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

It is crucial that pupils' progression is supported across the primary and secondary transition. There is a risk that a lack of communication between a secondary school and its feeder primary schools can result in students been treated as 'blank slates' when they begin secondary education. This can waste precious teaching time and reduce engagement in subjects as students are expected to repeat content.

This transition stage can be particularly challenging for students as this also involves a change of environment. Strong relationship between secondary schools and their feeder primary schools need to be encouraged to ensure students are given the most productive transition into secondary education.

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;

The Natural History Museum understands that curriculum balance is key to producing well-rounded individuals and that there is benefit in cross- subject links and teaching. However, different subject areas will have different time demands, particularly those with a more practical nature.

Science practical lessons and field trips are invaluable for teaching the scientific skills required for the subject and for embedding this within the facts and theories introduced (and vice-versa). Science is both practical and conceptual and is about analysing ideas and evidence. Effective teaching of these observational, data gathering, and analytical skills should be supported in a structured curriculum. Science should be at the core of the taught week in schools, and opportunities to visit world-leading scientific institutions, like the Natural History Museum, should be part of this core entitlement provided by the National Curriculum. In Science specifically, the teaching of scientific skills and understanding to produce scientifically-literate individuals is particularly important, particularly for those students who do not decide to pursue science as a career path.

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

A curriculum catering to diverse types of students needs to allow flexibility to include socio-cultural contexts and cultural subject matter where appropriate. Teachers need this flexibility to be able to respond to contemporary issues that have cultural significance or applicability. This highlights the need for a curriculum to outline the key content required for students to learn which then allows teachers and schools to tailor and personalise schemes of work depending on their students' needs and backgrounds.

There is also incredible value in providing opportunities to build confidence by applying learning in a new setting – an area in which the Museum can provide support for students to consolidate their learning and see its relevance. Students will also benefit from the opportunity to access inspiring diverse role models, which the Natural History Museum can provide in activities and contact with our scientists.

High-attaining students will require support to further enhance and develop their learning. It is important for them to have opportunities to ask questions and take part in facilitated discussions with professional experts. The Museum provides these opportunities for school groups to meet world-class scientists, relate to them as role models and get advice on possible career paths in this subject. The Curriculum needs to have enough rigour to be able to support students who wish to pursue Science in further education and to become the next generation of scientists.

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

There needs to be opportunity to include response to real world applications and contexts, again where informal environments such as the Museum can support teachers. By ensuring

the curriculum includes the specifics of scientific process for 5-19 year olds, particularly components such as the secondary focused How Science Works, there is scope for the specific skills, procedures, contexts and applications of science to be showcased. If teachers have the freedom to react to new discoveries and advances, students can benefit from the motivational and aspirational experiences such environments can provide.
The Museum and its regional Real World Science partners are uniquely placed at the forefront of cutting edge research and can support teachers in creating relevant and topical content if there were such flexibility and responsiveness possible in a curriculum.

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?

- Any teacher CPD event numbers at all?

Not well recorded but we had 97 PGCE/CPD contacts for NHM RWS in 10/11 so with other teacher events at NHM it will be over 100.

The school environment can provide a wealth of opportunities for students learning mathematics and science. The classroom, school laboratories, school grounds all have the advantage of being accessible and facilitate learning.

Beyond school, informal environments offer a wealth of resources and expertise to engage students in a diverse range of subjects. In 2010/11, a total of 153,283 students, of which 88,409 were primary and 64,874 were secondary, visited the Natural History Museum. Of these, 59,907 students, 42,784 primary and 17,123 secondary, had the opportunity to participate in booked learning activities with Museum staff. By participating in a schools workshop or visiting a gallery such as the Darwin Centre, students at the Museum have the chance to see the relevance of the science they learn at school by encountering real scientists practising real scientific research outside the classroom. The Museum's mission is to inspire our visitors about the natural world and science, combining collections and interpretation expertise to engender an understanding of humankind's place in and impacts on the natural world and the essence of scientific endeavour.

Museum visits assist students' conceptual development in science by providing extraordinary, memorable experiences, which target certain curriculum concepts. Many of these experiences are mediated through talk with our trained science educators. The Natural History Museum is uniquely positioned to support conceptual understanding of evolution, the diversity of life and earth sciences. Teachers have told us that nothing communicates the timescale of evolution quite like a dinosaur skeleton, or geological processes quite like our rare rock collections. The Museum's collection of over 70 million specimens from the natural world provides a unique resource for revealing the sheer diversity of life on Earth. As well as using the collections themselves, interactive exhibits and props are used to support specific scientific concepts. Memorable Museum experiences can also take the form of practical workshops, debates or shows, facilitated by specially-trained Museum educators using the Museum's unique resources that are unobtainable at school or elsewhere.

Practical experiments carried out by pupils at the Natural History Museum where real science takes place, using the same procedures as the Museum's scientists, is a particularly powerful, inspiring experience. Students position themselves as the scientist, making the role more attainable and appealing as a career. Students find it easier to understand curriculum concepts addressing scientific process when carrying it out themselves in an authentic context. They also have the motivating experience of achieving success as doing 'real science'.

Due to the access the Museum and its regional Real World Science partners have to museum and university scientific expertise, we have the capacity to cover a extensive range of content, practice and research that students can be involved in.

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?
No comment

c) What kinds of specialised facilities, linked to key areas of learning in science and mathematics, should be available in the future?
All students need access to top quality laboratory facilities which is vital to support their practical work in science. It is crucial that students are able to develop technical skills as part of the science curriculum which they can then use in future careers.

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

References

DeWitt, J., Archer, L., Osborne, J., Dillon, J., Willis, B. and Wong, B. (2010). *Poverty of Aspirations? Roots of the aspirations-careers paradox*. BERA Symposium 2010 http://tisme-scienceandmaths.org/wp-content/uploads/2011/01/DeWitt-et-al-paper-BERA-2010-Symposium.pdf (needs to be referenced properly)

OCR

1. Introduction
OCR welcomes this opportunity to submit evidence to the Royal Society's call for views to support its 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. We are part of Cambridge Assessment, the world authority on assessment and a non-teaching department of Cambridge University. OCR as an Awarding Body delivers a wide

range of science and mathematics qualifications including entry level qualifications, GCSEs and GCEs through to adult numeracy qualifications and the more practically based OCR Nationals in Science. We provide tens of thousands of CPD support events for teachers, and have strong but non-partisan links with providers of text books and e-learning materials. This document provides an overview of OCR's key activities and research projects in the delivery of 14-19 education and assessment with particular reference to science and mathematics education, which we consider will make an important contribution to the Royal Society's project

2. Engaging with HE and the Science and Mathematics Communities
During the past two years OCR has implemented a wide-ranging Higher Education engagement programme. The programme consists of a Higher Education (HE) Consultative Forum, together with a number of subject consultative forums including science and mathematics. Some 242 representatives from learned societies, professional associations, schools and colleges, employers and education charities, of which 96 are HE representatives, are now attending our forums.

The purpose of our Higher Education Forum is to inform a strategic understanding of the requirements of qualifications designed to prepare young people for higher education. The forum meets three times a year.

The purpose of our Science and mathematics subject forums is to identify key requirements and issues relating to qualifications in science and maths and to share and discuss relevant information about emerging policy developments which may impact on the future design and purpose of qualifications and the curriculum. The forums meet twice a year and OCR has gathered a substantial range of views from these forums about A Levels as well as the 16–19 curriculum.

Our Science Forum comprises 37 members (see appendix 1) including 12 HEI representatives, 11 teachers and representatives from a broad range of external stakeholders. Our Mathematics Forum comprises 42 members (see appendix 2) including 11 HEI representatives, eight teachers and again, representatives from a broad range of external stakeholders.

In addition to the above, Cambridge Assessment's Research Division is supporting OCR with a significant programme of research to investigate systematically the views and concerns raised in the forums and to provide evidence to support developments in qualifications and curricula.

The 2011/2012 research programme (see appendix 3) includes:

- reviews of the academic literature
- empirical projects (e.g. questionnaires, interviews, think aloud, stimulated recall)
- desk-based analyses of assessment materials
- qualitative data collection and analysis from forums.

To support the above work, an online questionnaire has been sent to 3,500 academics. This project will compare the views and experiences of lecturers/tutors of first year undergraduates on the preparedness of new undergraduates for study at this level in three subjects: biology, mathematics and English. The research questions focus on:

- the perceived preparedness of new undergraduates for degree level study
- new undergraduates' strengths and weaknesses
- aspects of teaching and assessment in HE that pose transitional challenges
- adaptations to lecturers' teaching approaches to cope with under-preparedness.

A detailed analysis of the data is currently underway and a full report will be available in April 2012 which Cambridge Assessment and OCR will happily share with the Royal Society.

3. Implications of the changes to delivery of Key Stage 3

OCR is concerned that since the Key Stage 3 tests were stopped there have been a growing number of candidates taking GCSEs early. There are many possible reasons for a candidate to take a GCSE before Year 11, many of which may be valid. However, the concern is that candidates may not be fulfilling their potential - they may be 'banking' a grade early in order to concentrate on other subjects in Year 11. A second issue is that if the early-takers go on to study the subject at A level then the gap of a year may impact on how they perform. Consequently, both OCR's Research and Technical Standards team and Cambridge Assessment's Research Division will be carrying out research into early entry data. OCR's research will involve an analysis of outcomes by entry profile, and will be linked where possible to a measure of prior attainment to enable the outcomes to be linked to ability. Early findings should be available in April 2012, and the more substantial findings will be available in late spring.

Cambridge Assessment's research will investigate the performance at GCSE of candidates who take a subject early in comparison to those that take it in Year 11 (whilst taking account of background variables such as prior attainment). Further analysis will be undertaken of A level uptake and performance in subjects that are taken early by candidates, again after accounting for background variables. To begin with, this project will concentrate on a quantitative analysis only, without investigating script quality or what students and teachers think about early entry. The three research questions are:

- How do candidates who take a GCSE in Year 9 or Year 10 perform relative to candidates taking the GCSE in Year 11, after accounting for background characteristics?

- What effect does taking a GCSE early have on uptake and performance in the same subject at A level, after accounting for background characteristics?

- What effect does taking a GCSE early have on uptake and performance in different subjects at A level, after accounting for background characteristics? This might include, for example, looking at uptake and performance on A levels that have a strong mathematical content for candidates who took GCSE Mathematics early.

The research will be conducted in April and May, with a draft report available by mid-June 2012.

4. Specific work in respect of Mathematics
OCR has, with its sister organisation, the University of Cambridge International Examinations (CIE) recently established a Mathematics Council (see appendix 4). The purpose of the Council is to provide independent, expert views and guidance to OCR and the University of Cambridge International Examinations on the development of a 'vision' for transforming the teaching, learning and assessment of mathematics. At the recent meeting of the Council in March 2012, we presented a document for discussion entitled *What do we want 16 year olds to be able to do?* (see appendix 5).

OCR is also pleased to attach independent research (see appendix 6) from Cambridge Assessment on teaching A level Mathematics beyond the syllabus. The research demonstrates evidence that efficacious teachers were more likely to take the view that teaching beyond the syllabus strengthens and expands students' existing knowledge.

5. Concluding comments
OCR welcomes the Royal Society's call for evidence and is pleased to provide a resume of the work we are currently engaged in to develop and deliver high quality curricula and assessments in respect of both science and mathematics. The work of our HE and subject forums has demonstrated to us that there is a strong desire by a wide range of stakeholders to ensure that such developments are based upon the best evidence. OCR therefore welcomes this opportunity to provide the Royal Society with the outcomes of any research undertaken and to work closely with the Royal Society to develop the shared vision referenced.

RCUK

Background
1. Research Councils UK is a strategic partnership set up to champion research supported by the seven UK Research Councils. RCUK was established in 2002 to enable the Councils to work together more effectively to enhance the overall impact and effectiveness of their research, training and innovation activities, contributing to the delivery of the Government's objectives for science and innovation. Further details are available at www.rcuk.ac.uk

2. This evidence is submitted by RCUK and represents its independent views. It does not include, or necessarily reflect the views of the Knowledge and Innovation Group in the Department for Business, Innovation and Skills (BIS). The submission is made on behalf of the following Councils:
Arts and Humanities Research Council (AHRC)
Biotechnology and Biological Sciences Research Council (BBSRC)
Engineering and Physical Sciences Research Council (EPSRC)
Economic and Social Research Council (ESRC)
Medical Research Council (MRC)
Natural Environment Research Council (NERC)
Science and Technology Facilities Council (STFC)

3. RCUK, as part of its Public Engagement with Research strategy[16] has a commitment to '*inspiring young people to help secure and sustain a supply of future researchers to support the research base that is critical to the UK economy by encouraging engagement between young people and researchers*'. A key aim of this strategy is to enhance the experience of contemporary research for young people and school teachers, encouraging more people from a diversity of backgrounds to pursue relevant studies beyond 16 and follow R&D careers and enabling more to act as informed citizens. Alongside the collective RCUK ~ £1 million schools programme which focuses on post-primary, individual Research Councils also have a number of schools activities under this aim.

4. As requested by the Committee RCUK have not sought to respond to every question. The RCUK submission responds to the general question relating to science and mathematics education in the UK, continuing professional development (CPD) for teachers, careers advice and cross-curriculum linkages.

General Questions

5. RCUK consider that bringing contemporary research into the classroom is of key importance. Enrichment and enhancement should play a significant role in establishing and supporting a high-performing and well-respected science and mathematics education system. Contemporary research contexts and access to inspiring researchers as role models should be embedded and valued within this system.

6. The Roberts Review and ESRC funded Teaching and Learning Research programme show the effectiveness of including contemporary research contexts. There is also evidence to show that researchers make excellent role models for young people and can play a key role in motivating students, raising ambition and bringing subjects to life with their expert knowledge and enthusiasm for a topic. The Royal Society survey which will be familiar to the committee showed that half of the scientists surveyed had been influenced in their career choice by a visit to a scientist's or engineer's place of work, and nearly a quarter had been influenced by a scientist or engineer visiting their school.

7. RCUK funds a programme of Teacher CPD aimed at science teachers, which is delivered by the Science Learning Centre Network. The programme uniquely brings together researchers and teachers to bring curriculum-relevant contemporary research into the classroom. RCUK has also sought to connect researchers and young people formerly through its Researchers in Residence (RinR) scheme (established in the 90's) and now through a new initiative currently under development. The Previous independent evaluations of the RinR and a report by the NAO[17] have shown that these types of engagements have a real impact in schools: ***"****When considered separately a number of the programmes were associated with positive results which were significantly significant, including the RCUK Researchers in Residence Scheme. Analysis indicated that schools using these*

[16] Research Councils UK Public Engagement with Research Strategy http://www.rcuk.ac.uk/documents/scisoc/RCUKPERStrategy.pdf

[17] Department for Education: Educating the next generation of scientists (NAO report, November 2010) http://www.nao.org.uk/publications/1011/young_scientists.aspx

programmes saw higher absolute take-up and greater increases over time in the proportions of children taking separate sciences at GCSE, as well as higher achievement. For example, on average across all schools, all other things being equal, there were over two per cent more of the year group achieving grades A-C in separate sciences in a school that had a 'STEM club' than in a school that did not, and three per cent more in a school participating in the Research Councils UK (RCUK) Researchers in Residence scheme."*

Continuing Professional Development (CPD) for teachers

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

8. Research has shown that teachers with good subject knowledge are more effective (Whelan, 2009). The Government White Paper 'the importance of teaching' also highlights the need for teachers to have the opportunity to deepen their subject knowledge to renew their passion for their subject. This is particularly important for teachers without a degree in science and mathematics. The independent evaluation of the RCUK courses provides evidence that the contemporary science element has the potential to be truly inspirational for teachers. The up-to-date nature of the scientific knowledge provided by the courses satisfied teachers' own desires to learn and to pass on this enthusiasm to their students. Indeed, the involvement of active researchers is seen as a key strength by all involved in the programme.

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

9. RCUK consider that teachers should have access to initial and on-going subject-specific CPD.

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

10. The evaluation of the contemporary science courses run by RCUK highlights that the government's 'rarely cover' policy has had a noticeable impact on some schools in England. In comparison teacher recruitment has been highest in Scotland which does not have this policy. In response to this RCUK has piloted online CPD, and running CPD during school holidays, or during evenings and weekends, as well as at venues such as Colchester Zoo. Nevertheless there is an emphasis on 'essential courses' such as those which update teachers on new exam courses and assessment, where in comparison contemporary science courses are seen as a luxury. The evaluation also shows that teachers' attendance is constrained by the extent of support and budgets available within the school, to this end RCUK offers bursaries to help cover teaches attendance. RCUK would like to see a change in culture whereby subject CPD is supported and teachers are incentivised to take part.

The Wider Workforce

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?)

11. Careers advice should be well-informed. Vitae provides a career portal which illustrates the wide range of employment undertaken by researchers and labour market information to provide context, data and practical information to inform the career decision making process. The Vitae careers portal includes a searchable database of career stories from a wide range of researchers. The "What Do Researchers Do?" series of publications provides evidence of the employment undertaken by researchers, explores how researchers create innovation and growth and contribute to UK society, culture and economy, brings together career stories and, through analysis of the career paths of doctoral graduates, also provides evidence of the stability, mobility and progression of researchers' early careers. Whilst these resources are primarily for researchers, they might also be used to inform and illustrate advice for those earlier in education. Complementary to this RCUK are also producing researcher career case studies aimed specifically at young people.

Infrastructure

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

12. RCUK would also highlight the importance of cross-curriculum linkages and collaborative teaching. BBSRC sponsored a small-scale study[18] in two local Swindon schools exploring maths and biology teaching, and looked at collaboration between the biology and maths teachers when delivering lessons to KS3 pupils. It recognised that there is a need to embed mathematics within the biology curriculum, and some joint planning of maths and biology curricula is desirable in order for the teachers to become more aware of where there are cross-curriculum linkages. However, collaborative teaching is a significant investment and schools need be supported to think creatively to ensure opportunities like this are available to teachers in the future.

Royal Statistical Society

1) Science and mathematics education in the UK

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

A key strength of the present National Curriculum (NC) is that statistics forms a required part of the mathematics curriculum which is compulsory. Thus this meets the Royal Statistical Society's (RSS) conviction that it is essential that all learners should be have the opportunity to study the principles of probability, risk and statistics. In addition, the science curriculum promotes scientific enquiry, which is a paradigm of good practice that is very close to the problem solving approach used by practising statisticians.

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?

[18] http://www.bbsrc.ac.uk/organisation/structures/panels/skills-careers-panel.aspx

The content of the current statistics curriculum needs to be revised – it is often seen as repetitive and boring. A recent report commissioned by the RSS, 'The Future of Statistics in our Schools and Colleges'[19] makes a very clear case for a review of the NC in relation to the provision of statistics. School students need to be taught about the applications of statistics and be exposed to the statistical problem solving approach; they need to meet challenging problems in statistics that use reasoning skills rather than routine questions. Further, and perhaps most importantly, they need to experience handling real data in the context of their own life experiences and favourite topics. There is emerging evidence[20] that most teachers of statistics (within the mathematics curriculum) in schools do not think about the pedagogy of the subject and often regard the teaching of it as 'a bit of a nuisance'. This is usually through no fault of their own but because the pedagogy of statistics is rarely covered in PGCE mathematics teacher training courses.

Mathematics and statistics are used in most other subjects that therefore need to know what has been covered and when, in order to plan their own curricula. Thus there is a case for requiring links between subjects to be properly made at school level. This could be achieved by, for example, establishing a statistics coordinator within each school – someone who would have the "big picture" of what statistics is for and about. This is one of the recommendations in 'The Future of Statistics in our Schools and Colleges'.

c) What, if any, broader educational issues concern you? (These may or may not relate directly to science and mathematics education)
The four types of curriculum: (1) intended; (2) taught; (3) learned; (4) assessed are rarely matched. The assessed curriculum drives everything before it.

In practice, the taught curriculum is largely governed by how it is assessed. Thus the regulatory authorities and examination boards need to ensure that how and what is assessed in statistics is appropriate for the 21st century.

From emerging evidence[2] it seems that the quality (and quantity) of statistics education depends on the teacher and his/her interest, so not all children have the same opportunities.

d) How can a science and mathematics education system best meet the needs of employers and higher education?
The ACME Mathematical Needs project[21] noted the increasing quantitative demands of almost all university courses and the shift in employment patterns towards higher-skilled and problem-solving jobs. Not only is a sound basis in mathematics required, but also an appreciation of the ubiquity of its application, even in areas not traditionally thought of as

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[19] http://www.rss.org.uk/uploadedfiles/userfiles/files/The%20Future%20of%20Statistics%20in%20our%20Schools%20and%20Colleges.pdf
[20] Winter/Spring 2012 Connections article 'The Extent and Form of Statistics Pedagogy in British University Mathematics Teacher Training Courses'.
[21] http://www.acme-uk.org/news/news-items-repository/2011/6/launch-of-the-acme-mathematical-needs-project

mathematical. In practice, and again as noted by ACME, "mathematics" in this context very often means statistics.

All employers that use or produce data need to properly understand the information in those data in order, for example, to optimise activities to increase profits. Therefore the workforce needs to have a minimum level of knowledge and skills in statistics so that trustworthy decisions can be made from the evidence in the data.

Statistics are of great and increasing importance in many subjects in science and social sciences as well as mathematics at HE level.

At the wider level it is clear statistical literacy is required by all citizens to make informed and thoughtful decisions on a daily basis. This is the aim of the RSS's 10-year getstats campaign [22].

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?

We draw attention to the situation in New Zealand where statistics is taught in every year of school from age 5 to (approx) age 18 within the curriculum area Mathematics and Statistics[23]

Strategic reasons for studying statistics (and mathematics) are given at the head of the first of these references. Consideration of international comparisons should bear in mind that this
curriculum is new and is not yet fully bedded down across the entire age range.

We also draw attention to the situation in Kuwait. Kuwait is actively seeking to build a post-oil economy based on high-value services and on becoming a key regional centre for general business and commerce. Statistics is now being introduced as a compulsory subject in its own right in the last two years of the high school curriculum; in the preceding year, it is becoming part of the compulsory mathematics curriculum. This is deliberately intended
to lead, in time, to a more statistically literate population, which is seen as an important ingredient in the country's future aspirations.

Our view is that the reasons for the success in mathematics and statistics teaching in these countries goes beyond the wider education system. It involves the general culture of the country,.for example, whether there is a highly directed approach to learning, perhaps with

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[22] www.getstats.org.uk

[23] http://nzcurriculum.tki.org.nz/Curriculum-documents/The-New-Zealand-Curriculum/Learning-areas/Mathematics-and-statistics

very centralised provision even to the extent of a single (for each subject) nationally specified text book. There are also issues around general diversity and the value attached to choice in provision. It is also important to appreciate that some countries traditionally give heavy emphasis to theory and less to problem-solving and data, whereas in others it is the other way round. All this, and more, needs to be taken into account when comparing the successes of different countries – it is much too simplistic to suppose that comparisons are simply of "like with like". This is of course an area for serious education research.

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

Teachers (and the wider workforce)

1) Teaching as a career

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

We need to increase the professional standing of teaching in general – good career structure, respect in community, proper remuneration etc.

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?

Although degree classification is not necessarily a good indicator of teaching ability, the requirement of normally a 2.2 degree or above in the subject should help to ensure subject knowledge. This might also help towards better professional standing.

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

From the research available it is clear there are some instances of very good statistics teaching (but they are rare and by accident and not design). We would like to draw attention to the RSS Centre for Statistical Education (RSSCSE) report to the QCA in 2006[24] which found that Heads of Mathematics and other maths teachers lacked confidence in teaching statistics. This finding informed the RSSCSE's current project on the content and extent of statistics pedagogy in British maths teacher training courses.

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

As any maths teacher may have to teach statistics as part of the NC they need exposure to good practice in teaching and assessing statistics. Also, there needs to links between the

[24] See Table 20 of 'The Future of Statistics in our Schools and Colleges' report the for 11 recommendations.

data produced and used in other subjects through consistency of the approach to teaching statistics.

e) How can the standard of science and mathematics initial teacher training programmes be of a consistently high quality across the UK?
Sharing good practice, enrolling on RSSCSE Certificate course or the MA in Teaching Pre-university Mathematics and Statistics, the latter available at Plymouth University from Sep 2012.

f) What types of courses (full and/or part-time) should be provided for training new science and mathematics teachers. Why?
The traditional teacher training courses with about half the time spent at University and half in the classroom seems about right. Students need to learn about the philosophy, history, sociology etc of education and the background to educational studies in their discipline to become fully professional. Learning in the classroom is not enough to give the broad background required. The Mathematics Enhancement Courses are, in theory, a sensible way to alleviate the problem of the shortage of mathematics teachers in our schools; however their original purpose – to enhance mathematical, including statistical, skills and knowledge must be paramount, in order that the graduates are fully equipped for the mathematics classroom

g) In what sort(s) of institution(s) should science and mathematics teacher training take place? Why?
University teacher training departments See f) They would be the best equipped to deliver this, with local schools, to give the broad background necessary, so that teacher training students receive both an academic and practical course.

h) How much of this training should be spent gaining experience in the classroom?
About 50%.

i) How long should courses be for training (i) primary; and (ii) secondary science or mathematics teachers to become fully qualified?
One academic year followed by a year's probationary period in the first year of teaching

3) Continuing Professional Development (CPD) for teachers

a) What are the benefits of subject-specific CPD for science and mathematics teachers?
Subject specific CPD enables teachers to think about statistics per se and their use in applications in other disciplines and life in general. The subject helps us make sense of the world around us.

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

CPD - see courses developed by RSSCSE at Plymouth University[25].(2e above)

e) Are there key obstacles preventing science and mathematics teachers from accessing subject-specific CPD? If so, how can these be overcome them?
It is difficult for teachers to get time out of the classroom; hence some continuing study such as the RSSCSE Certificate and MA in Teaching Pre-university Mathematics and Statistics available at Plymouth University from Sep 2012 are ideal.

g) Should CPD be accredited (eg through the awarding of Masters-level credits)?
Yes – to give it currency within and between schools.

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?
There are several stages to statistical investigations - planning, data collection, analysis, interpretation of results and communication of the outcomes. All of these are important skills in young people's progress. For example, it is important that scientific/mathematical/statistical work can be properly disseminated to non-experts as well as to experts. This requires a very sound basis in English, both in structure of language and in its use. The cognitive skills needed to communicate statistical outcomes are surprisingly high, but this is often neglected by teachers of the subject in schools.

Generally, statistical skills are increasingly important in young people's progress in maths and science. A curriculum that enables the development of statistical reasoning from an early age is important

b) How may the acquisition of such skills best be assessed?
In practice, the taught curriculum is largely governed by how it is assessed. (see general questions 1c)
It is hard to assess problem solving skills and understanding in a formal time-constrained examination.

Students need access to graphic calculators and/or up-to-date statistical software if the more exciting aspects of statistics are to be taught, learned and assessed. The proper use of technology enables the higher level skills and understanding of statistical modelling and interpretation of results to be assessed, rather than just routine calculations. As an example, the WJEC QCF AS-level qualification 'Statistical Problem Solving Using Software' (to be launched in Sep 2012) is a radical departure from traditional ways to teach, learn and assess aspects of practical statistics.

[25] http://www.rsscse.org.uk/

c) How important is the impact of the transition between primary and secondary phases in terms of pupils' progression in (science and mathematics) education?
Mathematics, including statistics, is a cumulative subject where new topics build upon earlier work and lay foundations for further developments. The transition between primary and secondary schools needs careful thought.

In primary schools there is more scope for cross disciplinary work, whereas classes at secondary school are more subject specific; hence, it is less conducive to achieve an all round appreciation of statistics per se or its uses in many other disciplines.

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;
Statistics is a subject which can be applied in many other disciplines. It is widely believed that applications with real world problems and realistic data of interest to the students themselves motivate and enthuse. For example, there is strong evidence from the international CensusAtSchool project[26] (now being run in nine countries) that using real data for and about schoolchildren is a spark for improving enjoyment of, and skills in, data handling. However, statistics is also an academic discipline and there has to be some theoretical underpinning, as required.

The scientific method is based on experimentation; hence, the science curriculum should include some understanding of experimental design and that results of experiments will show variability and how to deal with this variability.

ii. teachers are able to use what they judge to be the most effective pedagogical methods and approaches to learning?
A major problem with teaching mathematics including statistics is the very wide ability range of the learners (ample evidence in the maths and stats education literature). Most students are motivated by problems and data of interest to themselves when they can understand that statistics is a useful and applied subject in ordinary life, in employment and in further study. This can be helped by the way in which statistics is taught.

iii. diverse types of student acquire the specific knowledge, understanding and skills they will need for their adult lives:
The RSS believes that it is essential that all learners 5-19 are acquainted with dealing with real data, getting trustworthy conclusions from them through statistical ideas and thinking; indeed it is their right. This is partly to do with general education for ordinary life as a modern, informed citizen and partly to do with supporting the other subjects the learner may be studying.

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[26] http://www.censusatschool.org.uk/

Please see also the statistical literacy (getstats campaign) which addresses the increasing importance of statistical skills in adult life[27].

iv. there is flexibility to include new topics or react to new discoveries or advances in science that can enthuse and excite?
New applications of statistics in a number of other subjects.

c) What characteristics of assessment best serve learning in its various forms in school science and in mathematics?
Statistics is a "doing" subject with data and it follows that assessment regimes should reflect this, which currently it does not..

f) To what extent can/should science and mathematics be effectively assessed through other subjects?
Statistical skills, knowledge and understanding are essential for study in many other disciplines. Hence, the correct and relevant applications of statistics could effectively be assessed in other subjects.

g) At what age(s)/stage(s) should public examinations and testing be conducted during students' school careers?
Students are rather overburdened in years 12 and 13. Better to have a year (12) with no formal external examinations in order to develop understanding and knowledge in the subjects studied.

Schools and FE Committee of the IMA

General questions
1) Science and mathematics education in the UK
a) What is good about UK science and mathematics education?
At its best, teaching allows and encourages students to question what they are learning, to explore and investigate ideas for themselves. Material is often set in contextual situations (Functional Mathematics, Applied Mathematics, Probability, Statistics etc.) and students are encouraged to think about ways in which ideas may be applied. This more 'questioning' approach is *one* of the reasons many students from other countries come to study in English schools and Universities.

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?
Although the above epitomises what is good in mathematics education in the UK, there are increasing concerns that this sort of approach is less prevalent as teachers have become ever more preoccupied with what has become described as 'teaching to the test'. Assessment (and often poor assessment) has increasingly been driving the curriculum, and

[27] www.getstats.org.uk

this has had a largely negative influence. This is the wrong way around and needs to be addressed.

We need to reflect on *what* skills are important in the increasingly technological age in which we live. It is clear that the ability to think creatively and reason and clearly, and to be able to solve problems, are key skills (often across disciplines). One of the major reasons for teaching mathematics must be that it develops thinking skills. It is seldom taught in such a way that it does so. We must engage the full cross section of the academic and educational community to give thought to this issue and to work together to produce inspiring courses and resources. The academic HE sector must be re-engaged with what goes on in schools (and not simply with assessment). There is a strong case for a clearer vision, and increased leadership from some of our best minds.

There are few of our international competitors that allow most students to 'give up' mathematics at the age of 16. More students (most/all?) should continue with some form of mathematical education to the age of 18. This will require a clear rational about what we want to achieve for them, and a rethink of provision across the full 11-18 age range. It will mean that we have to ensure students have a good experience of mathematics *pre-sixteen* unless we are to have a recalcitrant group of unwilling participants post-sixteen! Equally, a range of properly designed and engaging courses will need to be written for post-16 provision. This will take time and careful planning, as well as more teachers and careful preparation of those we currently have in post. It is important that any such curricular planning takes the long view (11-18) rather than simply considering 16-18 in isolation of what went on before.

c) What, if any, broader educational issues concern you? (These may or may not relate directly to science and mathematics education)
Assessment (in GCSE mathematics especially). There is increasing recognition of many of our concerns regarding assessment, and changes have been made to GCSE assessment for the summer of 2012-we await to see exactly what these are, and how well they have functioned. The 'competition' between Awarding Organisations is a major issue which both we and the scientific community have expressed unease. There has been an increasingly mechanistic approach to mathematics, largely driven by equally mechanistic assessment. Other issues of concern are poor resources for teaching-dull textbooks, inadequate resources to support teachers, especially, but not exclusively, for enrichment. Lack of mathematical *content* based CPD (in addition to pedagogical CPD of course).

d) How can a science and mathematics education system best meet the needs of employers and higher education?
By ensuring a rigorous facility in the skills required and a confidence to use and apply them. By encouraging independence, and a willingness to respond to a challenge.

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?
We should look at some of the Scandinavian countries, the German system, Singapore and the US. We should look not just what is taught but how it is taught and, especially, how it is assessed-see below.

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

Other comments:
We should of course consider the approach adopted in other countries, but must not 'cherry pick' from them. It is highly likely that the most significant reason that there are such differences in performance internationally, are social and cultural. Many students in these high performing countries will have an unquestioning acceptance of authority (including that of teachers!), and their societies generally will have a high regard for education, teachers and teaching etc. Such characteristics are not always evident here! However, we should look at best practice with regard to the development of mathematical skills, to problem solving, to developing creative thinking wherever we find it. How mathematics is assessed would also be interesting. Equally, to what extent the curriculum and assessment is nationally driven, and how this works, would be of interest.

It is generally the case in other more 'successful' mathematical countries that there is a far greater stress on acquisition of basic core skills, combined with a rigorous assessment of them. The acquisition of these skills is often acquired through teaching techniques which would no longer be held in high regard here. Hence, care is needed over 'cherry picking'.

With the desire to see what is done elsewhere, we should not overlook where best practice is evident *in this country*, look to see how it works, and seek to implement it more widely. This in fact could be the most productive area to explore.

Perhaps more interestingly, we should look at how different skills are developed and assessed in *other* subject areas and activities. To illustrate: how are basic skills taught and assessed as students learn to play musical instruments, or play chess? How are higher-level skills fostered and assessed? In the 21^{st} century we need to think more creatively about what to teach and how to teach it, and we must learn from wherever we can.

Teachers (and the wider workforce)
1) Teaching as a career
a) What needs to be done to make teaching a top career choice for trained scientists and mathematicians?
We need to find ways in which teaching is held in higher regard. Salaries and general conditions of employment need to be competitive. The best teachers need to be encouraged to remain within the classroom to a large extent, and properly rewarded for doing so, and not to have to look elsewhere for career progression or higher salaries. There are too many posts in schools (which are well rewarded and generally afforded higher status) which take

some of our best teachers out of the classroom. The status of the classroom teacher, and especially the Head of Department, needs to be raised significantly. We appear to have our priorities wrong in this regard in schools.

Teachers need to be in contact with other professionals in their areas of interest. Teaching mathematics must be seen to be, and must be, about teaching children to think mathematically, and consequently enriching their lives in many ways.

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?
Class of degree in mathematics is not the ultimate criteria for teaching. Ultimately teachers need to be able to empathise with their students, and to have enthusiasm for their subject. In times of shortage of teachers, one with a weak mathematics degree is likely to be better than one with no appropriate mathematical backgrounds. At present much mathematics in schools is taught by teachers with very limited (or no) mathematical background, and this is of course unsatisfactory. Ofsted inspections indicate that about one in four teachers at KS3 is a non-specialist. Equally graduates with closely related degrees to mathematics, or degrees with a high mathematical content, should be readily accepted-they all add to the variety of experiences and skills within a good department. We should seek to recruit able and interesting people of sufficient calibre to engage with and inspire young minds.

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?
We should do everything that is necessary to seek to strengthen the profession by appealing to the best graduates, while recognising that a wide range of skills are necessary to make a good teacher. Teach First is a laudable attempt to do this, and does attract able students into the profession, but it must be stressed that teachers joining through this scheme should only be teaching mathematics if they have a suitable degree, and not simply an A-level in mathematics.

c) What is good about initial teacher training programmes in science and mathematics in the UK?
Evidence from Ofsted suggests that HEI based ITE programmes are rigorous, of high quality and represent value for money. Student teachers spend the bulk of their time in school and providers are challenged to ensure that the school experience is as good as it can be. Where strong partnerships exist, student teachers benefit from excellent mentoring and schools enjoy new ideas and the opportunity to reflect on their practice. In addition many partnerships include special arrangements for CPD and preferential rates for post-graduate study. All HEI based routes focus on developing critically reflective practitioners whose principal focus is on children’s learning and development. However, the dichotomy between ITE and CPD may be unhelpful to early-career professionals; consideration should be given to a significant programme of professional development for those in the early years of their careers before they gain full professional status akin to the preparation of an accountant or engineer to achieve chartered status.

d) What changes to these programmes (e.g. philosophy, content, or emphases) are needed?
We must ensure that all routes into teaching include theoretical aspects regarding theories of learning, teaching and child development, as well as practical experience in schools. More good schools should be encouraged to take part in ITE partnership schemes

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

Continued engagement with Higher Education Institutions is important as well as with school practice of course. It is important during the initial training (and indeed throughout ones career) to have the opportunity for reflection on practice and current thinking etc.
f) What types of courses (full and/or part-time) should be provided for training new science and mathematics teachers. Why?

A variety of options for those wishing to teach should be available.
g) In what sort(s) of institution(s) should science and mathematics teacher training take place? Why?
In both schools *and* Universities and colleges. Contact should also be maintained in universities with the academic subject department wherever possible.

h) How much of this training should be spent gaining experience in the classroom?
Currently 24 weeks out of 36 are spent in school during a secondary PGCE year, and 18 weeks out of 36 are spent in school during a primary PGCE year. This seems about right. Although many would say there is insufficient time to lay the foundations for subject specific pedagogy in primary even for the core curriculum.

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

It is unrealistic that a longer time than that currently available-one year for PGCE on a ft basis would be possible, and one year in any event is about right. However, there must be a raising of expectations to engage in *ongoing* CPD as discussed elsewhere to keep teachers professionally engaged.
Other comments:

3) Continuing Professional Development (CPD) for teachers
a) What are the benefits of subject-specific CPD for science and mathematics teachers?
Subject based CPD allows teachers to engage with colleagues from other schools and colleges to discuss matters of common concern, and to develop and share good practice. It encourages teachers to think about what they are teaching, and how they are teaching. It provides support mechanisms with other colleagues. It allows teachers to keep up to date with developments in their subject, for example, with the most effective ways to use computing technology in mathematics teaching. At its best it should encourage cross-curricular links, especially (but not exclusively) with science colleagues.

b) How should science and mathematics teachers best keep up with their subject and with new approaches to teaching, assessment and the curriculum?
There is a great deal of pedagogical CPD and this is reasonable. What has been lost however is academic and subject development, perhaps tailored to teaching. Teachers should be encouraged to continue to develop their own subject knowledge wherever possible. They should be in contact with HE Departments on a regular basis, and engage with professional subject associations. The professional subject associations should be strengthened. There are common issues between schools and HE in mathematics, and this can serve as a basis for establishing a network of practitioners, which can be developed into a subject-based CPD opportunity for teachers. BUT funding would be needed!

c) At what times throughout their teaching careers and with what regularity should teachers undertake subject-specific CPD?
Frequently and throughout their careers! CPD is not simply something that happens as a one off event in another place. It should be encouraged *on site*. Most departmental meetings-where they happen at all-will be about administration. Heads of Department are key to encouraging and *leading* CPD, reflecting on how the department uses ICT, how it teaches algebra, how it addresses the issues of weak/able students, what resources it can develop to enrich teaching and learning etc. etc. Heads of department are the key means to get this sort of *ongoing CPD* up and running, and the initial focus of future CPD should be to get them better prepared to lead on these issues in their departments. Unfortunately, in too many schools the role of the Academic Department head has diminished-this trend should be reversed.

d) Should CPD be voluntary or mandatory? Why?
We cannot think of any good reasons why teachers should not engage in CPD; it is a professional responsibility.

e) Are there key obstacles preventing science and mathematics teachers from accessing subject-specific CPD? If so, how can these be overcome them?
It is increasingly difficult for teachers to get away from schools, especially valuable science and mathematics teachers. Consequently there is a need to continue to stress the key role of CPD, and to encourage much on-site activity, and a wider use of the NCETM provision (and The Open University). Teachers have a great deal to learn from each other, even, dare one say it, across subject disciplines!

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?
Some of it will be and should be. This would form *part* of the department/school provision for CPD.

g) Should CPD be accredited (e.g. through the awarding of Masters-level credits)?
Ongoing CPD should not *need* to be, other than being recorded and acknowledged within the schools ongoing appraisal and professional development system. There might be a good

case for accreditation for some CPD activities. It is important to see CPD as an on-going process, often of quite small but significant events in schools/colleges.

Other comments
More cross-curricular CPD! We have a lot to learn from each other.

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?)
IMA (and others) provide the Maths Careers website. This is a valuable resource and should continue to be further developed. It needs to be made more widely known to teachers and students. Careers advisors, and all teachers of mathematics themselves, need to be aware of the range of opportunities in science and mathematics. In particular, what they should be saying to students to ensure that they study the right subject and subject combinations so that career opportunities are not closed off.

Leadership and ethos
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?
Departmental heads, or subject leaders are vital to the development of the subject in schools. The Ofsted report, *Understanding the score*, shows that effective leadership in a department matters. Subject heads provide leadership and vision for the subject in a school. They lead colleagues in designing teaching programmes to reflect that vision. They are key to making CPD an instrumental part of what happens in their departments. They manage the department and its staff in ways designed to bring out the best from them. They inculcate a sense of working together in a team. It is crucial that they have the right CPD themselves to engage in this range of activities.

They have a key role in explaining the role of mathematics and science education to other senior managers and parents. They must be able to articulate the rationale and vision for the teaching and learning of their subject, and ensure that the department teaches in such a way as to fulfil this vision.

b) What kinds of leadership skills should science and mathematics teachers be able to acquire?
There is a role for more teachers to be represented in higher-level decision making outside of the school, so that they are able to directly relate to and work confidently with organisations such as Ofqual, Ofsted and DES. They require structures in place for them to acquire the experience to do this. Subject associations are the obvious place for this experience to be acquired.

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

Firstly and perhaps most importantly, by recognising the key role played in schools by subject heads, and affording them high status in the school/college.

d) How can leadership pathways for experienced teachers be introduced into careers?
See b above.

Skills, Curriculum and Assessment
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 acquisition of basic skills and techniques is crucially important in mathematics. So also are developing thinking, and problem solving skills, and, of course, the ability and confidence to apply mathematical skills and mathematical thinking in a variety of situations. These *skills* are not simply 'add-ons', or 'enrichment'. They are at the heart of what the subject is about, and should be taught and encouraged *throughout* a child's development. Without developing such skills the subject is seen as a collection of unrelated facts designed for the sole purpose of passing a GCSE examination and then forgotten about as soon as possible. We need to provide challenges for students in mathematics and elsewhere -opportunities to try different things, and to make mistakes.

b) How may the acquisition of such skills best be assessed?
It is difficult to assess some of the higher-level skills, but we can certainly make a better job of it than we presently do, and to seek out better ways of doing so would be a worthwhile activity. The danger is that if such skills are not evident in the assessment process, then they are overlooked in schools, and the learning experience is diminished.

c) How important is the impact of the transition between primary and secondary phases in terms of pupils' progression in (science and mathematics) education?
This is very important. The transition at Year 7 needs to be carefully monitored, as does any point in the child's education where there is a transition. The impression often given, of treading water in the first years of secondary school must be overcome, so that students and their parents are conscious of continued unbroken progress. Ensuring greater continuity in content and method is crucially important at this point especially.

d) How should a curriculum be structured so that:
It should certainly be explicit in describing exactly what should be taught in terms of content and process. It should not describe how these should be taught, as this must be left to the professional judgement of teachers. Assessment should be developed alongside, and be integral to, the development of the curriculum.

i. science and mathematics are adequately incorporated as subjects which have both conceptual and applied contexts e.g. practical work in science;
Mathematics education in the UK, at all levels, has significant teaching of applications, and this is less common in other countries. The development of the linked pair of GCSE's in mathematics recognises this tradition, so too does the teaching of 'applied' mathematics in the sixth form, and the attempt to make a greater emphasis on 'functional' skills generally.

ii. teachers are able to use what they judge to be the most effective pedagogical methods and approaches to learning?
Teachers are in the best position to determine how to teach particular topics to particular groups of students. However, there is no reason why resource material should not be provided to illustrate particular approaches which teachers may try if they wish. In fact, this is likely to be useful and interesting for many, as it might explore avenues tried elsewhere that the teacher had not thought about.

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?
This is very important. Although perhaps less significant in mathematics in relation to content-the body of mathematics taught to the majority of students will be largely unchanged-it is important to encourage curriculum development more generally. The UK once had a fine tradition for innovation in teaching and learning in mathematics, particularly with the SMP, MEI and Nuffield in the sixties and beyond, and this has been largely lost in mathematics. The most recent addition of 'newer' mathematics has been the inclusion of discrete mathematics as a (possible) unit in AS and A2 Mathematics-not without its detractors either!

e) What characteristics of assessment best serve learning in its various forms in school science and in mathematics?
It is vital that the assessment assesses the intended curriculum-anything less distorts the curriculum as taught in schools. With the very high stakes involved for schools and students, the effects of this have never been more evident than they are at present. Examination papers are now very structured and appear to be set to very tight rules-as a consequence they have become predictable, and such predictability is increasingly expected by schools.

There is a case for a more holistic view of assessment than the bitty approach currently prevalent.

f) To what extent can/should science and mathematics be effectively assessed through other subjects?
It is important that science and other disciplines still encourage appropriate mathematics in their programmes, and in their assessment. This provides further stress on the importance and usefulness of mathematics at this level in other disciplines. A lot of mathematics has been removed from school science and this development should be considered again. It would be realistically very difficult for the assessment of mathematics to be done-even in part-through other subjects. However, there should be a proper role for mathematics in these other disciplines, and in their assessment.

g) At what age(s)/stage(s) should public examinations and testing be conducted during students' school careers?
In the secondary school programme, certainly at the end of the secondary age (presently GCSE) and sixth form (GCE etc.). We should seek a minimum level of external assessment with schools encouraged to work out their own regular assessment routines.

h) What evidence of learning is needed for assessment to operate effectively?
As far as teaching is concerned, a teacher is gaining evidence about the learning of the group and individuals within it all the time. There are countless interactions which inform about understanding during every class. These would be combined with regular more formal assessments within the class/year group as appropriate to give teachers a balanced picture. External assessments help inform across transitions (school to Sixth Form, FE college for example), but real understanding of a students level of learning, even in this case, will only happen more personal interactions.
Other comments:

Infrastructure
a) Where will/should science/mathematics primary and secondary school learning take place, both within and outside school?
Computing technology will clearly play an increasing role (You-tube, online university lectures, online resources generally etc.). Learning will still require personal interactions. Classes and schools/colleges will still have a function!

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?
Perhaps using high-grade technology packages for modelling and other exploratory work in mathematics. Rich resources to support teaching generally.
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?
In mathematics the teaching of mechanics is enriched by practical work to explore the modelling process. A clear link with science of course is possible. It is doubtful that much practical work, even in mechanics, now takes place in school mathematics departments.

e) What other resources and systems should be used to support science and mathematics?
Good computer software which encourages creative thinking and learning. Logo was an early example, the Raspberry Pi a potential current one.

f) What other more general changes to school infrastructure would support excellent science and mathematics teaching and learning? How can we measure this?
Some clear research on the most effective lesson length or mix of lesson length. Often this is decided for practical reasons which have nothing to do with effective learning. There is of course a need for pragmatism here, but consideration of what is most effective for learning needs a higher profile than it gets, and might well provide a rich source of possibilities to

explore. Some more unconventionally thinking with regard to timetabling is perhaps called for!

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)?
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?
Public examinations provide an important measure of course, but it is important that they measure what is intended, that what is intended is of some value, and that 'users' of this information have some confidence that this is so. Presently, at GCSE and GCE there are signs that this is not so. Universities are increasingly setting their own tests for students, and employers frequently complain about poor mathematical (arithmetical!) ability, and the inability to apply basic skills to common tasks. The type, structure and frequency of external assessment used in other countries would be an important component of any investigation of what is done elsewhere.

b) How should qualifications in science and mathematics be regulated?
Again, this should be closely examined against other countries. To what extent are the assessments and the curriculum centrally driven, and how many have different Awarding Organisations assessing the school/college curriculum for example would be most interesting to know. Examinations here, especially at GCSE and GCE have become poorly regulated, and with a very light touch. We have expressed in the strongest terms our concerns about the 'competition' between Awarding Organisations and how this is impacting on standards. We are absolutely sure that standards are not rising as a consequence of this competition. Poor monitoring of standards across the Awarding Organisations has been very evident. Ofqual should have sufficient authority (and expertise), to ensure that the examinations are assessing what the mathematical community regard as important. At the present time they appear to have neither.

c) How can we ensure that all students can access the science and mathematics courses they wish to?
Online provision should increasing provide support where a school cannot provide it. A good example here would be the online resources provided by the Further Mathematics Support Programme. Of course, schools must be of a viable size to make adequate provision for all there students. If they are not then they must make other provision -linking with other schools, using local colleges etc.

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

They have significant impact on where schools divert their resources, and not always in the best interests of providing a good mathematical education. Ofsted inspections should look not just at the numbers (targets) but at the manner in which these have been achieved across the school. We have been concerned, along with others, about the dramatic rise in the number of early entries at GCSE mathematics. Where once this was part of a planned part of a proper mathematical education for a small proportion of bright students, it is now often a hit and miss attempt to get more weak students a grade C and to ‘get mathematics out of the way.

e) How should measures of performance best be reported to different audiences? What other measures of performance may be required?
Clearly and simply! Where a profile of what a particular grade means is provided (and this can be useful to users), we should be pretty confident that the assessment measures what it says it does.

SEPNet

General questions
1) Science and mathematics education in the UK
a) What is good about UK science and mathematics education?

That science and maths are considered core subjects until 16 is important. That we have a curriculum including science at primary level is also important. These facts are not mirrored around the rest of the world, and it is important that the UK continues to prioritise this provision.

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 line of site through from primary school to PhD/Post-doc/working physicist is not clean. Qualifications are confusing and delivered in a way that can be incoherent. For example:

Double science is often taught by generalist science teachers, which can (but does not always) lead to unenthusiastic or bad teaching of some subject areas. We feel some teachers may be happier and more confident teaching Physics and Maths, rather than three science subjects. Where this is not possible then biology and chemistry top-up courses should be provided for physics specialist teachers. Equally, not all biology or chemistry specialist teachers have access to the top up courses that would support their teaching of physics and so more provision and encouragement needs to be made for this.

The optional nature of A-level mathematics modules means that students may choose, and be encouraged to choose, the options which they will do best in, rather than the ones that will prepare them best for their degree or careers. For example, some students coming to study Physics at degree level have not taken the mechanics modules in A-level maths. They were made to take the decision and statistics modules. There may also be the possibility that not all Mathematics teachers feel confident to teach the mechanics modules.

Primary science teaching is not regulated enough to ensure that students see the links between primary level physics and secondary level physics. Whilst we understand that these form part of a broader science curriculum at these ages, it is still important that concepts taught at primary school are taught well so that fundamental areas of science (electricity and circuits, forces and motion, energy transfer) are not relegated to being boring, and continue to make sense when they are revisited at older stages. This could be addressed through better connections between subject departments in HEIs and teacher training providers for subject specific outreach and enrichment activities, and by a more holistic treatment of the curriculum from KS1-5.

c) What, if any, broader educational issues concern you? (These may or may not relate directly to science and mathematics education)
Poor advice from schools/colleges on choosing subjects. There seems to be too much emphasis on choosing 'what students good at' rather than prepare them for future careers. Our partner departments have found that there are significant numbers of students who want to take physics at university but who have not done Maths A-level. This could be addressed by the inclusion of more maths in physics A-level rendering this improbable.

This may stem from a tendency to "teach to the exam", through pressure to perform well in league tables. This style of teaching does not prepare students for the difficulties of science subjects at university, as they need to better understand the scientific process, rather than recite, and hold on to, a list of facts.

Science teachers in particular need more space in their working week for preparation of lessons, and to ensure they are themselves up to date with current scientific thinking. Whilst we understand that they are now teachers of science, not scientists, for A-level in particular they need to be aware of current research. This should also help with inspiring the students to consider further study. An addition to this is the need for support for those science teachers that still professionally identify as scientists. These teachers need targeted professional development options that help them to immerse themselves in the skills of teaching and the educational research that accompanies it. More access to skilled technicians is also essential if school based practical work is to be a success.

d) How can a science and mathematics education system best meet the needs of employers and higher education?
A science education needs to include broader scientific literacy skills and the ability to apply transferable skills such as problem solving and communication to science. The memorised knowledge is not important compared to the skills needed to apply it well, although a level of memorised knowledge needs to be retained to allow progression. Confidence in a lab setting is essential, and could be encouraged through better integration of practical work.

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?

In Finland teaching is a high-status career, only accessible to top graduates, and this results in consistently high success rates of their pupils in international comparisons.

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

Other comments:
These questions were difficult to answer from the point of view of the universities that make up the SEPnet partners. We receive many students into our degrees from around the world, all of very high standard, but each has its own flaws. We may go back and look at our incoming cohorts to see if we can identify any trends.

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 appears from experiences of some of our recent graduates that it is already a top career choice for some good graduates. However they are getting frustrated by the system – there seem to be obstacles to getting into teacher training which seem to be posed by the training providers. Issues which have arisen are largely around poor communication of the process and key dates. Subject enhancement is required for secondary school science PGCE and applicants were not informed of the closing date for this although application had been made for the PGCE course. On the other hand, taking the GTP route requires no such subject enhancement, but in this case very little help is given in finding a suitable school. The process needs to be generally clearer and more supportive whatever route is taken.

Also, although some good graduates regard teaching as a top career choice, the number is far too low. Teaching has a very low kudos in the UK, intimately tied to low pay rates and low entry requirements.
More care should be taken over government messages in response to school achievements (such as A-Level results) to avoid the media backlash that ensues.

SEPnet address this particular issue by exposing our undergraduates to schools and teaching as a career option from their arrival. They are all encouraged to interact with schools through our dedicated outreach programmes, after CRB checking and thorough training. The benefit of this is that all activities are subject specific, and guided. We allow them to develop their own programmes but with help from our trained staff and teacher advisory board.

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?

Emphasis on application should be on teaching skills - communication, listening, planning - rather than a very high level of subject knowledge.

For Secondary science teachers an A-level in each subject they will be teaching should be required in addition to their undergraduate degree in a science or engineering subject. Physics and Maths should be a teaching option.

For Primary teachers it would be desirable to see them required to have at least one science A-level, but we feel this is unlikely to become a pre-requisite.

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

For scientists there needs to be more help in becoming an educationalist. Being a good teacher can be more about communication and empathy than subject knowledge.

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

Physics and Maths can be a better match than Phys/Chem/Biol for a generalist science teacher. More help needs to be provided for physics teachers in the teaching of biology.

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

Schools and FE colleges. They need as much classroom experience as possible. This requires the local teachers to be specially trained to support them though.

3) Continuing Professional Development (CPD) for teachers

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

There is lots of modern science in the news, and if you haven't done a degree in the last 5 years, some of what you were taught WILL be now wrong. CPD allows teachers to keep abreast of the latest developments.

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

Links with local universities for updating in subject area. Teachers also need updating on admissions requirements etc so that their students are given the best advice.

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

d) Should CPD be voluntary or mandatory? Why?

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

For c,d and e… All teachers at all stages should have access to CPD - subject specific as well as general. The main block to this at the moment is that teachers cannot get out of school for courses. INSET days are spent in school on specific school activities. Teachers should have at least 1-2 days per year to take part in subject specific CPD.

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.

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

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?
A and b… We feel that a similar programme to GTP might be useful in the training of technicians. UTCs might also be a useful route. Either way they need close association with the type of workplace they will be working in.

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?
Assuming that all of the student support needs are already being met, then additional Science and Maths TAs will only be useful if they have at least an –level in the subject they are supporting if used at secondary level. At primary such a TA might be able to take a development role for class content in conjunction with a science coordinator.

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?)
Information about careers should be provided throughout the curriculum. Most students now use the internet for research where there are good websites such as Future Morph. Perhaps careers lessons which encourage students to explore these ideas from a younger age could encourage them to engage in it further.

Other comments

Leadership and ethos

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

Head teachers affect the ethos of an entire school, and they should be trained on how to do this across subjects and for all staff, with appropriate support. Science and maths top-up courses for Headteachers to engage them with the department may be helpful for those who specialise in another subject area.

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?

We work closely with Simon Langton Grammar school for boys, and he impact of their headteacher and working ethos on all subjects is profound, but is particularly well demonstrated through their STAR centre, where students are able to take part in cutting edge research projects.

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?

Skills, Curriculum and Assessment

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?

Practical skills, maths skills and development of the scientific process. These should all be included and maintained from as early as possible.

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

acquisition of such skills should be assessed by teachers through frameworks similar to APP

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

Vitally important. The change in style of teaching and volume of content is particularly profound for science subjects.

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?

Curriculum should contain key topics of study but with the topics used to develop the skills in the curriculum. Less detail allows greater flexibility in teaching style and pupil progress.

e) What characteristics of assessment best serve learning in its various forms in school science and in mathematics?
Teachers are best placed to assess the students' progress. Exams need to focus on the skill requirement rather than memorisation.

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?
The bulk of learning should take place within school, in a lab or dedicated science/maths environment whenever possible. Visitors to the classroom and visits outside the classroom should be encouraged, in fact a compulsory fieldwork element would be invaluable.

c) What kinds of specialised facilities, linked to key areas of learning in science and mathematics, should be available in the future?
Science subjects need labs, and both science and maths need more specialist computing access and training. This will require access to well trained technicians.

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?
More cross curricular work should be encourage with the curriculums, particularly for science, maths, ICT and DT, supporting each other in a cohesive way with cross applications made obvious.

e) What other resources and systems should be used to support science and mathematics?
Universities often have lab and computing space that may be made available to schools. For example, the University of Sussex school of Maths and Physics run "Schools Lab", a programme where schools can access experiments for KS4 and 5 in a university lab setting. Other SEPnet partners have summer schools and work-experience programmes that allow extended access to labs, computing and the academics that could be built upon. The main barriers are the ability of school groups to come off-site, and the costs of teacher cover.

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)?

Accountability

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

Less emphasis should be placed on exam results and league table standing as it leads to teachers teaching to the exam rather than teaching for learning.

Society of Biology

Introduction

The Society of Biology is a single unified voice for Biology: advising Government and influencing policy; advancing education and professional development; supporting our members, and engaging and encouraging public interest in the life sciences. The Society represents a diverse membership of over 80,000 - including practising scientists, students and interested non-professionals - as individuals, or through the learned societies and other organisations listed at the end of the response.

The Society of Biology welcomes the opportunity to input to the Royal Society's Vision project and acknowledges its ambitious scope. Our individual members and member organisations consistently identify education as one of their key areas of interest, with many members undertaking their own work to support 5-19 education.

Over time we have produced a number of statements and consultation responses which, taken together, describe the Society of Biology's views on science and mathematics education. Given the wide-ranging call for views in this large and complex area of policy, we recognize that it would be possible to write at some length under each heading. However, given the response time, we have provided brief responses to your questions with links to any previous evidence, reports and policy responses that express our views in more detail. We would be happy to discuss any areas of our response in more detail if that would be helpful.

General questions

Science and mathematics education in the UK

What is good about UK science and mathematics education?

• In schools, biology is primarily taught by suitably qualified and high quality subject specialists.
• There are good Continuing Professional Development opportunities available for teachers
• World-leading science within the Higher Education sector plays a major part in developing initiatives.
• There is a tradition of successful innovation in science education.

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

• There should be a mandatory requirement for all teachers to undertake subject specific CPD

throughout their career.
• Better development of literacy and numeracy skills in students undertaking science qualifications should be supported. In particular our members raised concerns with the lack of confidence in student's knowledge of mathematics and the applications of it within the sciences.
• Better coherence between the mathematics curriculum and the science curriculum at both GCSE and A-level must be achieved. However it is important to note that whilst we are supportive of some continuation of mathematics qualifications post-16, we are not advocating a broad brush approach where all students studying A-Level Biology would be required to study A-level Mathematics as well.Thought should be given to appropriate combinations of qualifications for progression to a range of end points which include further study at HE or beyond, direct entry into industry roles, and non-STEM careers.
• We need clear and useful pathways for all leaners. This is particularly true up to the age of 16, but also applies beyond that. It is also particularly true for those wanting to follow a vocational pathway but, again, it also applies to academic routes1.

What, if any, broader educational issues concern you? (These may or may not relate directly to science and mathematics education)
• The narrow and very 'tutor'-led focus that has resulted in a 'tick box' ethos, as a result students enter higher education less able to work as independent learners. The reduction in content has increased the gap between Further Education and Higher Education. The focus on 'fact' has led students away from wanting to develop a deep approach to learning and recognition of the importance of understanding. The GCSE and A-level exams frequently reward a superficial (regurgitating of facts) approach to learning which again is not matched to HE.
• The combination of competition between Awarding Organisations, arbitrary performance measures and high stakes examinations, has led to a reduction in the quality of assessment items, in teaching and learning and in standards2.
• We are concerned about the pace of the review of The National Curriculum, the structure of the review bodies, and the review process3.
• Texts tied to specifications have become "bibles" and encourage students and teachers to use just the single source. It also imposes huge costs when preparing the delivery of a new specification because texts tied to previous specifications are seen as redundant. Members cited examples where in larger biology departments the cost of replacing all text books after a change in specification can cost up to £15,000, increasing the reluctance to change from one Awarding Organisation Specification to one more suitable one for their cohorts. This undermines the value of having competition in the system.
• There is some concern about flexibility of the curriculum requirements for free schools and academies, specifically from a science perspective, but not limited to it.

Teachers (and the wider workforce)
Teaching as a career
What needs to be done to make teaching a top career choice for trained scientists?
• In summary the key characteristics that make any career highly regarded are:
o entry requirements for the degrees are high (as with Medicine and Dentistry)
o pay once in employment is suitably high; there is vigilance about the employment costs of

these professions, but due regard to the importance of expressing value for and retaining expertise continual interest and challenge; the need for continuous professional development is key to retaining excellent individuals in the profession
o conditions of employment are excellent
o support from a network of ancillary staff (for example technical staff in the laboratory)

• Additionally, a clear career pathway which rewards excellent teachers and stresses the link to their subject without taking them out of the classroom into management.
• There should be better recognition for teachers who go above and beyond their everyday duties through the running of STEM Clubs, links with research institutions, and innovative practical and field activities. These activities should be recognised through the Ofsted Framework and career progression opportunities.
• Finally, better support for those who wish to link their teaching with research opportunities within FE and HE, to support their interest with the subject matter whilst they teach. This could inform their classroom practice and support any school aims of providing research informed teaching, retaining subject specialist staff and also keeping students engaged.

Initial Teacher Training
What should the minimum entry requirements be for entry to primary and secondary science and mathematics teacher training courses?
• Primary: At present the real problem is the shortage of science graduates applying, and so appropriate support to encourage more science specialists to enter the primary science profession is what is needed.
• Secondary: Due to the large number and variety of bioscience undergraduate courses it is hard to specify minimum entry criteria for teacher training courses. ITT institutions currently recruit from the top tier of biology graduates (2.2 and above) and we support the ambition to attract the very best graduates into the profession.

Should diagnostic tests be applied to test the suitability of candidates? If so, what types?
• Due to the range of undergraduate degrees in the biosciences, diagnostic tests might be a useful identify areas of weakness in incoming graduates' likely subject knowledge. However, we would not advocate using these sorts of tests as an interview tool, instead they could be used to tailor the subject-specific support given to PGCE and NQTs during their training.

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?
• It would be more productive (especially on retention) to offer better career progression – possibly through links to professional bodies; and to offer teachers of sciences the opportunities to explore other interests (either educational or scientific) whilst remaining a teacher.
• As there is a shortage of specialists in these subjects, there is definitely a need to offer inducements. However current Government policy4 has reduced the number of PGCE places available for Biology Specialist Trainees, and this risks sending the message to excellent biology graduates that teaching is not a viable career pathway under the current administration.

What is good about initial teacher training programmes in science and mathematics in the UK?
• There are different entry routes available to those wishing to undertake a teaching career through the Graduate Training Programme, PGCE, Teach First and Bachelors of Education (BEd).

What types of courses (full and/or part-time) should be provided for training new science and mathematics teachers. Why?
• Practical training courses are needed, as science graduates will have specialised in one area of science e.g. biology, and may need to be retrained in techniques used in other areas e.g. physics.
• Refresher courses are needed for areas of science not studied by trainees during their degree i.e. chemistry courses for biology graduates.
• Courses teaching trainees how to assess students in practicals and their written work are needed, as thseare important skills to have (and are not learned during a degree), these assessments can be difficult to get right, and are also important for evaluation of teaching
• There should be a good range of courses to cater for a diverse range of students, with plenty of opportunity to observe good teaching and to practice teaching.

Continuing Professional Development (CPD) for teachers
What are the benefits of subject-specific CPD for science and mathematics teachers?
• To improve subject knowledge (and therefore the satisfaction of their learners) and keep up to date with contemporary subject developments.
• It improves the quality of lessons by increasing teacher's confidence and enabling them to become more comfortable with the curriculum they are teaching.
• Developing pedagogical approaches to practical work and updating knowledge of new practical techniques has benefits.
• It may help to improve retention of subject experts by maintaining their enthusiasm for their subject and offering a clear progression route or reward system.

How should science and mathematics teacher's best keep up with their subject and with new approaches to teaching, assessment and the curriculum?
• Build in mandatory, ring-fenced time to engage with subject specific CPD ensuring a broad definition of that term. This should cover not just attending CPD courses but engagement with employers, research institutes, other educational establishments and the appropriate Professional Body.

At what times throughout their teaching careers and with what regularity should teachers
un Every year. A ring-fenced allocation of time for every teacher every year which is properly resourced and supported by senior management.

Should CPD be voluntary or mandatory? Why?
• Mandatory but with maximum flexibility to allow the individual teacher to design their own programme to meet their own requirements and interests

Are there key obstacles preventing science and mathematics teachers from accessing subjectspecific CPD? If so, how can these be overcome them? Links back to subjects-regional training with input from HE departments.

• Teachers find it increasing difficult to be allowed out given the costs involved, especially cover. Given financial constraints in schools and no ring-fenced funding for CPD, subject specific CPD is often a low priority for college managers.

• CPD often focuses on whole college, generic issues and not subject specific.

Other comments

• As stated by D Wiliam (2010)5, "Teacher quality can be improved by replacing teachers with better ones, but this is slow, and of limited impact. This suggests that our future economic prosperity requires improving the quality of the teachers already working in our schools. We can help teachers develop their practice in a number of ways; some of these will benefit students, and some will not. Those with the biggest impact appear to be those that involve changes in practice, which will require new kinds of teacher learning, new models of professional development, and new models of leadership."

The wider workforce

How and where should we be training laboratory technicians?

• In the appropriate institution which focuses on vocational training. Courses should involve partnership with local employers and where possible with a large on the job component.

• School laboratory technicians are a vital part of the workforce. The Society of Biology is piloting a Register for Science Technicians67 (under licence from the Science Council) which aims to provide and recognise basic and continued training and development for those in technical roles. dertake subject-specific CPD?

Who should be responsible for providing advice on careers in or related to science, technology, engineering and mathematics (STEM)?

• Better careers advice is necessary, providing information on a wide-range of science based careers (not merely academia). There are number of groups e.g. STEMNet, Professional Bodies, AGCAS and ICG who do this, but the coverage can be spread unevenly across geographic regions or too focused on specific areas giving students false expectations or inappropriate advice.

Leadership and ethos

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

• There needs to be routes for excellent classroom teachers to be promoted but to remain in the classroom. It is likely that this would have to be through a national scheme and could relate, for example, to Chartered Status (CBiol) as offered by the Society of Biology. One possibility would be to allow promoted teachers time to take on national roles (CPD, curriculum development, research, working on assessments). All of these are currently possible but they do not form part of a leadership structure.

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?

• Ethos evolves over time and relates to the wider context in which an institution operates.
• Leaders at all levels should share the common ethos.
• Part of this ethos should be the freedom to challenge accepted wisdom and be listened to.
• This requires careful handling by managers.
• Everyone should be heard and if possible, consensus in decision making is best but leaders have to lead and are paid to do so.

Skills, Curriculum and Assessment
What skills are particularly important to young people's progress in (i) science and (ii) mathematics, and when should they begin to acquire them?
• We are very clear on the importance of practical skills, which are central to biology8, and also provide an opportunity to develop knowledge and understanding of key concepts. SCORE's numerous responses and work in this area provides further detail on this topic in relation to 5-19 education9.
• We would also like to emphasise the importance of mathematical skills in biology. As stated earlier science and mathematics are intrinsically inter-linked and throughout 5-19 education it is essential that the two strands of science and mathematics work effectively alongside each other achieving coherence in the sequencing of topics.
• More details on this area can be found in the SCORE response to the National Curriculum Review10 and the Society of Biology response to House of Lords Science and Technology committee enquiry on higher education in STEM subjects11.

What characteristics of assessment best serve learning in its various forms in school science and in mathematics?
• Assessment of pupils should be disentangled from school accountability and performance measures. Only then will students' study programmes and learning be driven primarily by their needs.
• Assessment also plays a major role in influencing what is taught and learnt and assessment schemes are important for setting the ethos of a subject. So it is important to retain some form of practical assessment.

Infrastructure
Where will/should science/mathematics primary and secondary school learning take place, both within and outside school?
• In purpose build and fully resourced facilities, allowing for creative use of teaching methodologies and a degree of freedom and flexibility for teachers.
• In partnerships with the wider science communities, especially local STEM employers who have a vested interest in encouraging good scientists and mathematicians for their future workforce.
• Fieldwork and outdoor learning is particularly important to support the teaching of Biology and therefore appropriate consideration should be given to ensuring learners gain authentic and personal experience of biological thinking and application of knowledge both within the laboratory and the field.12
• Clearly, the sciences need laboratories and technicians to enable practical work – which is an essential part of the sciences13. These can be costly to run. Therefore, we have grave

concerns about the changes to the funding formula for post-16 education and the loss of the 12% weighting given to the teaching of the sciences
– through the funding of complete study programmes rather than individual qualifications14.

What kinds of specialised facilities, linked to key areas of learning in science and mathematics, should be available in the future?
• Well-maintained, well-equipped, well-designed, dedicated laboratory spaces and access to local functioning ecosystems.
• Equipment, software, training and technical support including the appropriate use of ICT. Staffing and equipment appropriate for class size.15
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)?
• Whilst related to HE, there is evidence that suggests that gender does make a difference in terms of learning with females statistically more likely to adopt a strategic approach to learning and males a deep approach.16 17 Research has also shown that fear of failure is higher in female students which may account for the adoption of a strategic approach.18 19

Accountability
How should qualifications in science and mathematics be regulated?
• The professional bodies have a role in setting the criteria for A-levels and accrediting specifications.
• The professional bodies are well placed to act as a guardian for their disciplines by bringing together a single committee for their subject that includes academics from higher education, professionals and teachers
• We think that proposals from Awarding Organisation through which each AO would have its own committee are unworkable and repetitive20.
• Exams should be regulated by Ofqual21; but they need to be given greater powers. In particular, Ofqual should be able to look at exam papers before they have been taken

Teach First

2. 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?
Teach First believes that the inequality in achievement and progression in maths between those from low socio-economic background and those from wealthier backgrounds urgently needs to be addressed. Students from low-income backgrounds are less likely to achieve well in maths and science than the rest of the population: • At age 14, there is a gap of more than a year's expected progress between students from low-income and high-income backgrounds (Sammons P, Sylva K, Melhuish E, Siraj-Blatchford I, Taggart B, Toth K, Draghici D & Smees R, 2012 and DfE, 2012). • The gap in expected progress between pupils on Free School Meals and those who aren’t is largest for maths at GCSE level – with 44% of pupils on Free School Meals meeting the level of expected progress compared to 68% of pupils who are not. For English these numbers are 55% and 75% respectively (DfE, 2012). • 62% of FSM-eligible students failed to achieve a science GCSE at A*-C (excludes BTECs) (Skills Commission, 2011). • 58% of FSM-eligible students failed to achieve a maths

GCSE grade A*-C (Skills Commission, 2011). Students from low-income backgrounds are also less likely to progress to study maths and science in further and higher education, even when they achieve as highly as their peers. For students with the same GCSE grades, those from low socio-economic backgrounds are less likely to progress to study a STEM subject at A-Level. There are many interlinked reasons for this gap, Outlined below are three of the strongest: Supply of high-quality teachers A recent report by the RS noted that shortages of highly-qualified STEM teachers in schools and teacher shortages in science and mathematics have persisted for more than 25 years (Royal Society, 2011). Inequality in teacher distribution Chronic shortages of STEM teachers are most severe in the schools in challenging circumstances, where more than 50% of pupils come from the country's poorest neighbourhoods. The best-qualified teachers are less likely to choose to teach in schools serving students from low-income backgrounds: • Maths teachers without a post-16 qualification are usually assigned to lower sets, in which students from low-income backgrounds are over-represented (Moor, H., Jones, M., Johnson, F., Martin, K., Cowell, E. and Bojke, C., 2006 and DfES Research Report 708). Inequality in opportunities Many schools do not offer the courses which best support achievement and progression in STEM subjects, including Triple Science and Further Maths: • GCSE Triple Science students are more likely to study and succeed in A-Level sciences. Almost half of state schools do not offer Triple Science (Broecke, S, 2010). • Some schools do not offer any GCSE Science courses at all, restricting students' access to rigorous academic courses (Ofsted, 2011) • Pupils eligible for FSM are three times less likely to study Triple Science at GCSE. They made up 14% of the GCSE cohort in 2010, but only 5% of Triple Science entries and only 10% of Double Science (excluding Applied) entries. This is mainly associated with FSM-eligible pupils' lower attainment at age 14, but even controlling for attainment, FSM-pupils are less likely to study Triple Science. (Homer, Ryder and Donnelly, 2012) Why does it matter? Enabling access: Studying maths and science enables access to a wide range of education and career opportunities: • Of eight A-Level subjects commonly required by universities, four are in maths and science subjects (Russell Group, 2011). • The effects of STEM education quality lasts into adult life: after controlling for other factors, people with maths A-Level earn £136,000 more over their lifetime than those without a post-16 qualification in maths (Reform, 2008). High demand: There is high demand for STEM skills from employers, and the current shortage is damaging our economy: • Almost half of employers currently report difficulty recruiting staff with STEM skills (CBI, 2011). • Most businesses see promoting maths and science in schools as the most effective method for tackling STEM shortages (CBI, 2011). What is Teach First doing to address this problem? Teach First is working to recruit large numbers of highly-qualified STEM teachers and placing them in schools serving low-income communities. Teach First primary schools currently have more than 50% of their pupils living in the lowest 30% of the IDACI (Income Deprivation Affecting Children Index), prioritising those schools with higher levels of deprivation. Teach First secondary schools currently have one of the following: • A first criterion based on the IDACI - Teach First works in schools that have more than 50% of their pupils living in the lowest 30% of the IDACI, prioritising those schools with higher levels of deprivation; • A second criterion based on attainment - Teach First prioritises schools with low attainment in regards to the 5+ A*-C (English & Maths) GCSE measure. Teach First works in schools whose results fall below the lowest 30% of the national distribution; Just half of secondary teacher trainees in maths, science, D&T and ICT have a degree class of

2.1 or above, compared with over three-quarters for History and English. Almost all Teach First trainees have a degree class of 2.1 or above, and have been recruited for specific competencies proven to be critical for those working in schools in challenging circumstances: • Humility, Respect, and Empathy • Interaction • Knowledge • Leadership • Planning and Organising • Problem solving • Resilience • Self-evaluation Over 40% of our participants teach STEM subjects. Over a third teach maths or science. For example, out of the 1224 participants in our 2010 and 2011 cohorts, 511 are STEM teachers, 474 of which are in maths and science. Of Newly Qualified Teachers in schools in September 2012, Teach First estimates that we will have trained almost 9% of maths NQTs, almost 6% of science, almost 3% of ICT and 1% of D&T.

3. c) What, if any, broader educational issues concern you? (These may or may not relate directly to science and mathematics education)
Teach First believes that a high quality education is one of the most powerful ways to improve the life chances of pupils from low socio-economic backgrounds. The independent education charity was created to break the link between low socio-economic background and educational attainment, founded on the belief in the power of great teachers to help a child succeed. We know there is already a gap between the achievement levels of pupils starting school from low socio-economic backgrounds, compared to those from higher socio-economic backgrounds. For example, research has shown that there is a gap of one year in 'school readiness' between 3 year-olds in the richest and poorest families (George et al. Centre for Longitudinal Studies. 2007) and there is a gap of 15 months in vocabulary development between five year-olds in the richest and poorest families (Millennium Cohort Study Briefing, 2010). Poor literacy levels in early years also make it difficult for pupils to access the curriculum when they go on to secondary school, including in STEM subjects. There is an attainment gap between pupils resident in the most deprived and least deprived areas in reading, writing and mathematics combined (23%), with 80% of pupils resident in the least deprived areas achieving the expected level compared with 57& of pupils resident in the most deprived areas (DfE, 2011). While a focus on early years is important, the evidence shows that even when children start school at age five on a reasonably even footing, those from disadvantaged backgrounds begin to diverge dramatically from their peers in terms of attainment. In 2009, 38% of pupils in schools in the 10% most income deprived areas gained five A*-C grades (including English and Maths) at GCSE. 63% achieved this benchmark in the 10% least income deprived areas. This is a gap of 25% (DCSF, 2010). We know that education levels can be linked to a person's quality of life. For example: • Through earnings, we can also see how education is linked to health: People living in the poorest neighbourhoods in England will, on average, die seven years earlier than those living in the richest neighbourhoods. The gap is bigger between some areas, for example the life expectancy of a male living in Chelsea is 88 years, whilst the same statistic for a male living in Tottenham green is 71 years (The Marmot Review, 2010) Education levels can also be linked to factors that directly affect social mobility, such as earning power, employment or time spent in prison. For example: • Earning power: Over the course of a lifetime, a graduate from a Russell Group university will earn on average £371,000 more than someone who left school with less than five good GCSEs (The Sutton Trust and Boston Consulting Group, 2010) • Employment: A person is more at risk of spending time out of education, employment or training if they have no qualifications - 28% of young people with

no qualifications spent more than 12 months NEET compared to 1% of their peers who attained eight GCSEs at A*-C level (DfE, 2010). Conversely, whilst only 7% of the population attended independent schools, well over half the members of many professions have done so. For example, 75% of judges, 70% of finance directors and 45% of top civil servants (Unleashing Aspirations Report, 2009) • Time spent in prison: Over 50% of all male and 70% of all female adult prison inmates achieved no qualifications at all at school or college (DCLG, 2008) We understand that the causes of child poverty and low social mobility are complex and multi-faceted. A good education can overcome disadvantage in some cases and social mobility cannot be addressed without improving the education of those in poverty. Teach First believes that raising the achievement, aspirations and access to opportunity of pupils from low socio-economic backgrounds will allow them greater access to the full range of life chances and contribute to breaking the cycle of poverty for future generations. There are many interrelated causes, but at the very heart of this issue is the gulf between pupils' access to opportunities, access to resources as well as the expectations society has of them. As outlined above Teach First believes that a high quality education, focused on raising a pupil's achievement, aspirations and access to opportunity, can transform the future of a child from a low socio-economic background. Poverty means that all of these are reduced. Equally, these 'three As' (Achievement, Access to opportunities and Aspirations) are required if young people are to escape poverty. Achievement We have detailed above the gap between the achievement levels of pupils from low socio-economic backgrounds, compared to those from wealthier homes. Aspirations The results of a Prince's Trust report on aspirations recently illustrated the tragedy of a generation of young people from poor homes in this country who feel that they have no future. A quarter of those from deprived backgrounds surveyed believed they would achieve few or none of their life goals, with a similar proportion expecting to end up on benefits for at least part of their life (Prince's Trust, 2011). Access to opportunities and resources Recent research showed that just five schools (four of which are private) sent more pupils to Oxbridge than two thousand state comprehensive schools combined (Sutton Trust, 2011). The pupils at these five schools undoubtedly have access to a wide variety of educational opportunities and resources (as well as parents and teachers who have high aspirations for them and high expectations of them). This gap is present in the homes lives of children as well, with 28% of those from low-income families having access to the internet, a huge educational resource, compared to 85% from high-income backgrounds (The Sutton Trust, 2010). 5% of three year olds from high-income families watch more than three hours of television a day, compared to 27% of children from low-income families (The Sutton Trust, 2010). 78% of three year olds from high-income families are read to daily, compared to 45% of those from low-income families (The Sutton Trust, 2010).

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

Teach First is currently the third largest graduate recruiter in the UK, number seven in the Times Top 100 list of graduate recruiters and was also named Graduate Employer of Choice in the Public Sector last year. One in twenty students applied for the LDP in a survey across 30 universities according to research done by High Fliers in 2012. Teach First's LDP attracts a large number of applicants, for example in 2010/11 over 5000 graduates applied for the 787 places in the 2011 cohort. Of those, 1,126 elected science as their preferred subject and

1,340 elected to teach maths. Last year Teach First and its university training partners had their first ever full Ofsted inspection. The teacher training provision was rated ‘Outstanding’ in all categories assessed. In particular the Ofsted report focused on the high quality of the Teach First participants, stating: “In all regions, the quality of the participants is exceptional, particularly their personal characteristics, personal attributes, self-motivation, critical reflection and their commitment to raising the aspirations and achievements of the students in their schools and addressing educational disadvantage.” Much of our appeal to graduates is derived from our alternative nature, our high entry requirements and our focus on leadership development. With a mission to address educational disadvantage, we are, at heart, a movement for change and, in that sense, quite distinct from other training routes. Attraction We are the only teacher training route that has an established presence on university campuses to attract trainees. It is on campus, at a wide range of universities, that students get the chance to learn what teaching in a school in challenging circumstances will involve. In this way, we are able to attract those high-calibre applicants who are well-suited to such an opportunity. We visit over 60 UK universities and work with a diverse range of academics and student societies to find the right graduates to join Teach First. The attraction team works year round on our target campuses, building the brand and spreading the message of the impact graduates can have on the programme. Recent research from High Fliers found that 75% of final year job hunters from 30 universities, seeking employment in all sectors, had heard of Teach First. For graduates, Teach First is an attractive career proposition on two fronts: the Leadership Development Programme (LDP) provides the opportunity to develop key skills (which enhance their employability both within education and in other sectors) and have an impact on the attainment, aspirations and access to opportunity of those pupils who stand to benefit the most from a great teacher. We invest in recruitment campaigns that appeal to a variety of motivations to encourage people to apply, and believe that this is a key to success. The Teach First University Campus Survey 2011, conducted online with 2000 students studying at 31 leading universities in the UK, gives a useful insight in to the motivations of graduates applying for Teach First. When asked ‘what key message would attract you to apply to Teach First’ the top four answers were: • Being considered to be an exceptional graduate • The fact that the Teach First LDP is a two-year commitment, allowing them to keep their options open • The desire to make a difference/working to address educational disadvantage/social inequality • The prestige of the organisation It is also worth noting that Teach First provides guaranteed employment for participants who obtain their PGCE ‘on the job’ for a minimum of two years (provided they meet the requirements of the programme), at the same time as earning a salary. This is not only attractive to undergraduates but also to career changers. Teach First is supported by many prestigious STEM-focused organisations and companies who seek talented STEM graduates for their roles. These employers often actively seek Teach First Ambassadors (graduates of the LDP) who wish, after the two years, to further their contribution to addressing educational disadvantage whilst becoming a leader in another field. This recognition of the calibre of individuals who complete the Leadership Development Programme and the skills they gain has also enhanced the prestige and reputation of Teach First, particularly amongst STEM students and graduates. Teach First’s recent STEM undergraduate study (Teach First/trendence, 2011) provides an insight into why STEM graduates are not choosing careers in teaching and particular STEM sectors, pointing to possible incentives. The key findings of the research included: • Motivations – ‘Personal satisfaction and fulfilment' was the most important characteristic influencing STEM graduates' choice of their first job • Influencers -74 per cent of the STEM respondents stated that the opinions of friends/family/lecturers affect their career choices • Competencies - STEM graduates are least confident in the competency areas of 'leadership' and 'self-evaluation'. Confidence levels decrease significantly across all competencies in a high pressure situation such as a job interview. Graduates cited 'extra-curricular activities' as the most influential factor outside of their degree in developing their competencies

1. 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?
Teach First understands the importance of considering both the academic and personal qualities of individuals. Teach First's own very high standards for acceptance onto the LDP include a 2.1 degree or above, and 300 UCAS points. As well as meeting certain academic criteria, Teach First candidates are assessed against eight areas of competency which demonstrate a candidate's potential to be an effective and inspirational teacher in a school in challenging circumstances. Those characteristics are: • Humility, respect and empathy • Interaction • Knowledge • Leadership • Planning and organising • Problem-solving • Resilience • Self-evaluation The selection process is rigorous as we need to ensure we hire the right people for the programme. Candidates complete an online application form and the Selection team screens each application twice, ensuring it is given the correct level of attention. The form includes Positions of Responsibility and Competency Questions. The second part of the selection process is the Assessment Centre. This is a one-day event that incorporates a 30 minute one-on-one interview, a group exercise, a seven minute sample teaching lesson and self-evaluation. During the course of the day, the applicant will meet four assessors (at least one of whom will have QTS and at least one is a Teach First ambassador), who will then make their hiring decisions at the end of the day. As part of the enrolment process candidates must pass the Subject Knowledge Audit, have their reference checked and complete one week's school observation. Their position on the programme is still dependable on successful completion of the Summer Institute. The selection process is centred on the eight Teach First competencies outlined above. These competencies are a pivotal focus for all of the selection team's efforts and are thoroughly tested from the application form through to the end of the Assessment Centre. Teach First is a values-driven organisation and together with our competencies, we expect candidates to demonstrate these throughout the application process and thereafter. Whilst no-one would dispute that having great initial subject knowledge (and updating and refreshing it through continuing professional development), our experience shows that having studied a STEM subject at degree level is not a prerequisite to being an effective STEM teacher. Many Teach First participants teaching STEM have an A-level in their subject rather than a degree. Our experience shows that, in terms of becoming qualified teachers, they are as good, if not better, than participants who are STEM graduates and contribute to positive effects on pupil achievement. We are looking into this further.

2. 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?

Inducements, if provided, should tackle the common barriers to preventing science and maths students and graduates entering teacher training. Teach First's recent STEM undergraduate study (Teach First/trendence, 2011) provides an insight into why STEM graduates are not choosing careers in teaching and particular STEM sectors. The following barriers were commonly stated amongst science and maths graduates: • Starting salary too low • Unlikely to provide personal satisfaction or self-fulfilment • Limited opportunities to use my technical skills • Limited opportunities to prepare for a future career • Limited opportunity to use my subject knowledge • Unlikely to have a good work-life-balance • Not enough variety of job work tasks • Not challenging enough Many of the features and benefits of Teach First's Leadership Development Programme address these barriers directly. Teach First participants use their subject knowledge daily; participants are able to personally develop for future leadership positions in or out of the classroom. Some STEM graduates stated that the teaching starting salary is too low to be attractive. However from the same research STEM graduates stated long-term earning potential as a more important consideration when choosing a career. Teach First provide inducements that specifically attract STEM graduates who otherwise would not have considered teaching. These inducements include leadership development, personalised coaching, high-levels of responsibility immediately in school as an a full-time employee, an immediate salary, Summer Projects and being part of an alumni movement of Teach First Ambassadors to address educational disadvantage so that no child's educational success is limited by their socio-economic background.

7. g) In what sort(s) of institution(s) should science and mathematics teacher training take place? Why?
In collaboration with our university training partners, Teach First has been placing and training participants in schools since 2003 to great success. In July, the quality of the participants' training - delivered by the network of higher education institutions with which we partner - was rated 'outstanding' by Ofsted. The inspectors highlighted the quality of Teach First's participants. Additionally, they highlighted the high quality of the training participants received and the high expectations Teach First has of them, stating: "As a result of the quality of the training they receive and their own ability to critically reflect, the overwhelming majority of participants make outstanding progress against highly challenging expectations, meeting or exceeding these expectations" (Ofsted, 2011). It is important to note that Teach First's LDP is highly supportive. It begins with an intensive six-week Summer Institute, which establishes the participants' understanding of their role in the Teach First community, and prepares them to begin teaching in September. Once in their school participants have a strong support network. In addition to school-based subject and professional mentors, participants are also visited and observed frequently by university-based, subject and professional tutors. During year 1, participants also have access to a range of development opportunities as part of the Leadership Development Programme. These are designed to develop their teaching practice, people management skills, understanding of fundamental business practices (and how they relate to a school context), and their ability to maximise their strengths for the benefit of their pupils and their own development. While we are a school-based route, we work closely with HEIs who provide a vital contribution to participants' training. Participants work with one of the university training providers towards achievement of a PGCE after 13 months and QTS. The recent Ofsted inspection report

described the network of partner schools, university training providers and Teach First employees that deliver the LDP as a powerful and successful partnership (Ofsted, 2011). While we support a shift to more school-based and school-led training, we find that most schools welcome the partnership and support we bring and would not want to or be able to do it alone. Teach First's rigorous recruitment process provides a crucial filtering system, ensuring that the participants are of a high enough quality to be able to benefit from learning on the job. This may not be a suitable training approach for all.

8. h) How much of this training should be spent gaining experience in the classroom?
Our participants work as a full time teacher from day 1 in September (although on a slightly reduced timetable). We believe that after thorough preparation, participants learn more from actually doing the job. With the support of mentors and tutors, participants continuously reflect on and evaluate their own practice in order to continuously improve.

9. i) How long should courses be for training (i) primary; and (ii) secondary science or mathematics teachers to become fully qualified?
The Teach First model allows participants who have a good degree to gain a PGCE in their first year as a teacher and then during year 2 they pass their NQT year at the same school. Participants continue to develop as teachers and leaders in year 2 as they continue on their Leadership Development Programme. In year 2 they also work alongside a Teach First Leadership Development Officer (LDO) to focus on maximising the progress of the young people they teach.

1. a) What are the benefits of subject-specific CPD for science and mathematics teachers?
Subject specific development is crucial in ensuring teachers remain up to date with new approaches and developments in their subject area, so they can pass this knowledge on to their pupils. Developments in the field of STEM move at such a pace that up to date subject knowledge is extremely important, more so than in some other subjects. Opportunities for teachers to share good practice and learn from each other are also vital. These can serve to re-inspire passion for the subject and remind teacher what got them into the subject in the first place. It also allows them to develop new ways of allowing students to learn and think about science and maths (which is as important as the knowledge itself) – some of the ways we think about science and maths can be unique to these subjects.

2. b) How should science and mathematics teachers best keep up with their subject and with new approaches to teaching, assessment and the curriculum?
All teachers should take on responsibility for their own professional development and acknowledge that they are constantly learning and developing. By: (i). Reading relevant updates from publications and organisations such as the ASE, watching the news, using YouTube, going to lectures, researching things themselves – there is an overwhelming range of media to keep up to date with new developments – mostly free. Also, building links and relationships with resources of knowledge in the locality is effective e.g. by approaching universities and inviting professional scientists/mathematicians/undergrads to come into the school on a regular basis to speak about their latest research, being part of or leading school and local networks of teachers (professional learning groups) and creating opportunities to see other teachers practice and work alongside others to mutually develop skills and

understanding. (ii). First and foremost by taking a scientific approach in their own teaching – try, reflect, conclude, iterate. These cycles of self-reflection and improvement are key to developing any skill. In addition, going to watch others do great things, attend lectures, get onto policy update distribution lists, blogs etc.

3. c) At what times throughout their teaching careers and with what regularity should teachers undertake subject-specific CPD?
Teachers should be continuously learning and undertake subject-specific CPD throughout their careers. This should begin right at the start of their careers to get a sound grounding in the key concepts and effective ways of undertaking this training. Throughout the first year, this training should continue at least on a monthly basis. General trends show teachers tend to improve over their first two years followed by quite a pronounced plateau, so looking to maintain development momentum after this time is key – three times a year is recommended as a minimum, with input from a practicing scientist or highly effective instructor.

4. d) Should CPD be voluntary or mandatory? Why?
Mandatory. It should be a commitment made at the start of a teacher's journey and maintained. It should be an expectation that all teachers are learners and that plateauing is not acceptable.

5. e) Are there key obstacles preventing science and mathematics teachers from accessing subject-specific CPD? If so, how can these be overcome them?
We have seen that a reluctance of a school to release teachers to undertake CPD is a genuine barrier. We believe there is a range of factors affecting this, including prohibitive cover costs and a lack of confidence and belief in the impact of the training itself. We also believe there may be mind sets in the leadership of some schools that don't see the value of CPD or have lost some faith in its effectiveness. They haven't fully bought into the value and may pay lip-service to the development rather than fully embracing its potential. Also, the choices of CPD are vast and the quality highly variable, therefore causing some distrust/confusion amongst teachers themselves and CPD-decision makers e.g. headteachers/authorising managers. CPD can be fractious, irregular and infrequent – there is rarely a joined-up narrative to the development and it is often left to the initiative and negotiating power of individual teachers. Some schools and academy chains have centralised development and suite of interventions for particular stages of development/needs. This approach avoids some of the pitfalls of more general/ad hoc courses selected by the teacher.

6. 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?
CPD should be planned at the start of a year to meet the range of development needs, so a planning conversation would be ideal.

7. g) Should CPD be accredited (eg through the awarding of Masters-level credits)?
Yes. This is helpful for three main reasons. Firstly it should provide a quality bar for the content within it and the process of reflection and independent study that surrounds a Masters. Secondly, it should help people select training as part of a coherent development

programme – i.e. people choosing topics relating to a central development theme e.g. leading learning through others. Lastly, accrediting development that people are doing is a well-recognised incentive for people to take up the training that we have seen in our teachers. We are frequently asked if our training is Masters accredited, which it is.

The Science Council

Background

The Science Council is an umbrella organisation of over 35 learned societies and professional bodies in the UK drawn from across science and its applications: a list of member organisations is attached. In addition to providing a mechanism for the sector to work collectively, the Science Council develops and leads collaborative projects working with member bodies and the wider community, including the Future Morph web site that is designed to provide information for young people, their parents and teachers about careers from studying science and mathematics. The Science Council awards the professional qualification of Chartered Scientist (CSci) and is now leading an initiative which aims to raise the profile and aspirations of technician and graduate scientists by developing new professional registers at these levels. Collectively our member bodies represent more than 350,000 individual members, including scientists, teachers and senior executives in industry, academia and the public sector.

Introduction

The Science Council welcomes the opportunity to input to the Royal Society's Vision project and acknowledges its ambitious scope. Our member bodies consistently identify education as one of their key areas of interest, with many members undertaking their own work to support 5-19 education. Over time we have produced a number of statements and consultation responses which, taken together, describe the Science Council's views on science and mathematics education. A number of themes and key issues emerge from these documents, each of these cuts across a number of the Vision areas of focus and are listed below with reference to the most relevant documents.

Key themes

Practical Skills

The Science Council member bodies are very clear on the importance of practical skills which are central to science and also provide an opportunity to develop knowledge and understanding of key concepts. Our input to the 2011 House of Commons Science and Technology Committee Inquiry on the subject provides detail on this topic in relation to 5-19 education.

Importance of Mathematics

All Science Council member bodies emphasise the importance of mathematical skills to their discipline. As stated in our response to the recent National Curriculum review, science and mathematics are intrinsically inter-linked. In 5-19 education it is essential that the two strands of science and mathematics work effectively alongside each other achieving coherence in the sequencing of topics.

Careers Awareness
Science is now ubiquitous in modern life and young people need to understand the relevance of science and mathematics to their lives and their future careers, whether or not they go on to further study in these subjects. Various research1 2 has also shown that whilst many young people enjoy science they cannot visualise themselves working in science. Raising awareness of the variety of career opportunities available from studying science is part of the solution to increasing the numbers choosing science subjects and the Science Council has been very active on this issue, including running the Careers from Science project and the Future Morph website. Teachers and the school environment have a key part to play in raising careers awareness as testified by research by the Secondary National Strategy and the University of Warwick4 for the Department of Education. There are many careers focused enhancement and enrichment activities available and in addition to this the Science Council and others have produced resources to illustrate how examples from the world of work can easily be incorporated into everyday delivery of the curriculum.

1 ASPIRES King's College London
http://www.kcl.ac.uk/sspp/departments/education/research/aspires/index.aspx
2 Important but not for me, Jenkins and Nelson 2005
http://dx.doi.org/10.1080/02635140500068435
3 Progression to post-16 science, Secondary National Strategy 2009
http://dera.ioe.ac.uk/2509/1/sci_post16_rept_0046109.pdf
4 Good Timing, Centre for Education and Industry, University of Warwick 2011
5 Girls in the Physics Classroom: An action guide for teachers, Institute of Physics Dec 2006
The People and Skills section of our *Priorities for Science and Innovation Policy 2010-2015* paper, *Science and mathematics education for 5-19 year olds* position paper and submission to the Royal Society of Edinburgh's inquiry into barriers to women in STEM provide brief pointers on this topic.

Diversity
The Science Council believes that access to science education should be available for all those with talent and commitment to ensure that the science workforce reflects society's diversity.

The Royal Society will be very aware of the gender disparity in many science subjects, particularly the physical sciences. The Institute of Physics, in particular, has undertaken research in this area5 and advises teachers to work to highlight the links between topic areas, to avoid fragmenting the curriculum and to show the progression of ideas. The vision for a high-performing 5-19 education system should incorporate such measures to address gender imbalance and other aspects of diversity.

Chartered Science Teacher
The Chartered Science Teacher (CSciTeach) designation forms part of the Science Council's professional registers and was designed to embrace teachers as an important part of the professional science community. The Masters level designation combines requirements for pedagogy and knowledge of specialist subject. It recognises and rewards the high quality expertise and commitment to continual professional development of high

performing science teachers. The designation recognises teachers who can demonstrate professional autonomy through self-evaluation, collegial activity, personal responsibility and leadership.

This professional designation is of relevance to your questions on both teachers and the workforce but also leadership and ethos.

Understanding of the Science Workforce

In September 2011 the Science Council published research undertaken by TBR which examined the nature of the UK science workforce. The report showed that science has become increasingly important across all sectors of the UK economy and society with 5.8 million people now employed in science-based roles. The report takes account of the complexities of the economy, examining the science workforce across the whole economy rather than a narrow band of so-called science sectors. Through this and other work we are developing a more detailed understanding of the different roles and skills for scientists that are required now and will be required in the future in the various employment sectors. Research from the UKCES shows that the expansion in demand for associated professional and technical staff will be over 2.2 million up to 2017. The report TBR produced for the Science Council shows that the science workforce is made up of roughly equal proportions of workers with non-graduate, graduate and postgraduate qualifications. To satisfy demand we will need to broaden the cohort choosing to study science by developing alternative routes to GCSEs and A levels drawing on practical and applied learning methods. The addition of Registered Science Technician and Registered Scientist to the Science Council's professional registers will help to give focus to these qualification pathways and support the progression opportunities and transferability they must offer.

Multidisciplinarity

Our member bodies represent a wide range of subject disciplines and employment sectors: from across this broad spectrum there is a very clear message that modern science is a multidisciplinary activity built on a foundation of knowledge of the core sciences. The major challenges facing the world, for example, food security, climate change and water scarcity will demand a multidisciplinary approach to seek solutions. In addition, a host of new areas promising future innovation, such as bioengineering or biophysical chemistry, require a multidisciplinary approach. As such it is important that young people understand how biology, chemistry and physics interact, the connection to other sciences and the multidisciplinary nature of science. Sir Harry Kroto recently echoed this view when expressing concerns that nanoscience's potential to drive epochal advances in engineering, physics and biology was being hampered by the traditional academic boundaries dividing the subjects.6 It is clear that there is a need for multidisciplinary skills which will continue; education must respond to this.

6 Times Higher Education 24 February 2011
http://www.timeshighereducation.co.uk/story.asp?storycode=415261

We hope that our input will be of use to the project committee; we would be happy to meet to discuss the issues that we have raised or to provide further assistance.

Diana Garnham 13th March 2012 Chief Executive

Enclosed Science Council Statements and Reports
1. Science and mathematics education for 5-19 year olds – Position Statement, June 2007
2. Priorities for Science and Innovation Policy 2010-2015, March 2010
3. The current and future UK science workforce, TBR for the Science Council, September 2011

Submissions to:
4. Department for Education Review of 14-19 Vocational Education, October 2010
5. Department for Education Review of National Curriculum, April 2011
6. House of Commons Science and Technology Committee Inquiry: Practical experiments in school science lessons and science field trips, May 2011
7. Royal Society of Edinburgh Inquiry: Barriers to Women in STEM, August 2011
8. House of Lords Science and Technology Sub-Committee 1: Higher Education in STEM Subjects Inquiry, December 2011

UK Deans of Science

Background

1. UK Deans of Science (UKDS, www.deansofscience.ac.uk) is a national body that seeks to represent the individuals, usually formally designated as Deans, who are responsible for science in HEIs across the UK and who generally hold the budgets for science including any research budgets. Its primary aim is to ensure the health of the science base through the promotion of science and scientists and of scientific research and science teaching in the UK. This response has been agreed by the UKDS Executive Committee.

2. We believe that those with the most knowledge of many of the matters raised are teachers and others who are most directly involved in 5 – 19 education. However, their views and any solutions they propose will need to be robustly tested against the opinions of others and evaluated against all available evidence. We have tried to limit this response to questions where our members' knowledge is relevant as receivers of the 5-19 education system or through their contact with science and mathematics education in schools and the FE sector.

General questions

1) Science and mathematics education in the UK

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

UK science and mathematics education:

- has had the vocal, and sometimes active, support of successive Governments for a number of years
- is compulsory in Key Stages 1 to 4 of the National Curriculum
- is based on key concepts, processes and understanding evidence
- attempts to relate the science learned to real life issues
- is delivered by many committed and inspiring teachers.

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?

i. Political dogma must eventually be removed from education planning, development and delivery. Please note that this is not intended to be a negative political point about the current or other recent Ministers of Education. There has been too much political involvement over many years. The Royal Society’s ultimate aim should be to ensure that science and mathematics education is removed completely from the political arena and given to independent experts in schools, universities and appropriate professional, statutory and regulatory bodies.

ii. Action is needed on the curriculum and its delivery that ensures an emphasis on acquisition and retention of an appropriate knowledge base.

iii. Assessment needs to be robust and rigorous.

iv. All pupils who can benefit, and wish to do so, should have the right to study the three separate sciences at GCSE.

v. Science education must have within it more opportunity to engage in challenging and interesting practical work.

vi. Assessment should be more rigorous. We strongly support the move to decrease the contribution of coursework to the assessment of qualifications.

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

i. The effects of league tables on the various Awarding Bodies and the behaviour of many schools and on classroom teaching are sufficiently well known that we will not repeat them here. It is almost impossible to find any possible justification for having several Awarding Bodies (whether they are for profit or not-for-profit companies) competing for ‘business’.

ii. Changes in the curriculum are far too frequent. A significant period of stability is needed during which some small evolutionary changes might be made in the present system. This period of relative calm should be used to develop a proper landscape for education that is: thoroughly thought out; based on as much evidence as possible and on the knowledge and understanding of experts from the UK and elsewhere; and leads to the development in every subject of an agreed way forward that is devoid of political bias and produces thoughtful, useful citizens by giving each and every pupil appropriate opportunities to develop their full potential. Although this may well be what every change in education and education policy is intended to deliver, the continual curriculum churn never appears to take account of the whole picture or recognise the individual needs of each pupil.

iii. Discipline is an issue for all school activities, particularly in science subjects.

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

i. The science and mathematics education needs of employers and higher education are frequently different. Because science and mathematics are linear, hierarchical subjects, for those who study them in higher education there is a need to possess a certain quantity of subject specific knowledge and skill.

ii. UKDS are not best placed to comment on the needs of employers, except to note that we hope that the Royal Society will be able to engage in such a way with employers during this exercise that it finds employers who will go beyond the usual generalities and be willing to engage in understanding the content, teaching, learning and assessment in 5 to 19 education and the context within which they are delivered in both the state and private systems, so that they can make constructive suggestions as to how 5-19 education can deliver what they need.

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?

We suggest Korea and two related administrations that have developed under very different circumstances: China and its Special Administrative Region, Hong Kong. We are less familiar with China but believe that the success of all three countries is built less on 'high quality' education (though there is evidence of extremely high levels of teacher commitment) than other social factors. These include total commitment and belief in the importance of education and academic success across the whole population, a 'can do' attitude in business, the encouragement of competitiveness (to be the best) in schools, the high level of parental involvement in children's educational development and the willingness of families of even limited resources to pay for coaching outside school.

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

It is not obvious *per se* that the curriculum, teachers, teaching and assessment methods make the education systems in China, Hong Kong and Korea so successful, but the aspects noted in (a) above.

Teachers (and the wider workforce)

1) Teaching as a career

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

A way must be found to give such individuals the kind of freedom, within sensible constraints, that allows them to have the same level of self management of their work and career as they would have in almost any other profession that they might choose to follow.

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?

The minimum entry requirement should be the same as is required for entry to an honours degree (including the equivalent of at least a grade C GCSE in English and mathematics) together with evidence of a real interest in, and commitment to, a career in teaching. To guard against the problem of the 'shelf-life' of previous qualifications or experience a diagnostic test should be used to ensure that at the point of embarking on the course, the candidate still has the abilities that would be expected of a holder of GCSE English and mathematics and her/his other higher qualifications.

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?

While there may be some benefit in having a form of inducement to enter teacher training, the main emphasis should be the creation of inducements that encourage good science and mathematics teachers to remain in teaching.

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

Full-time, part-time, mixed mode and distance learning programmes should all be available to ensure the widest possible participation by all who might wish to become teachers.

3) Continuing Professional Development (CPD) for teachers

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

Its most important benefit is to ensure that teachers are able to keep up to date with the latest discoveries and applications so that they maintain the relevance of their teaching.

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

It should not be assumed that they will only keep updated through completion of formal CPD. They should be expected to maintain their personal development by a mixture of formal CPD, attendance at conferences and other relevant events and by personal study.

c) *At what times throughout their teaching careers and with what regularity should teachers undertake subject-specific CPD?*
CPD should be practised in some form within each year of a teacher's career.

d) *Should CPD be voluntary or mandatory? Why?*
CPD should be mandatory for teachers as it should in every profession in the UK.

e) *Are there key obstacles preventing science and mathematics teachers from accessing subject-specific CPD? If so, how can these be overcome them?*
There is frequently too little resource available for CPD and its use is not necessarily directed to outcomes that will support the teaching of science and mathematics. Significant funding allocations must be guaranteed and ring-fenced for all science and mathematics teachers.

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?
It is better to separate subject related CPD from other professional development.

g) Should CPD be accredited (eg through the awarding of Masters-level credits)?
CPD should be accredited and its satisfactory completion - properly monitored and robustly assessed - should be a requirement for maintaining Qualified (Science) Teacher status.

4) The wider workforce

a) *How and where should we be training laboratory technicians?*
Laboratory technicians deserve to receive appropriate training – they should all complete 'initial technician training' which is as well developed and delivered as initial teacher training. Such an approach could create a workforce that is able to act in a similar, but probably more effective way, as standard classroom assistants. Some of the training should take place in a higher education environment and should include work experience in schools.

b) *What CPD needs will laboratory technicians have and how will these best be accommodated?*
They have a need for updating of a similar nature to that of teachers and we would expect it to be acquired in similar ways.

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?*
Apart from the possible use of teaching assistants in support of early learning of mathematics we do not think that it would be possible to recruit sufficient numbers of people with the right skills to support higher level mathematics education. For science classes, please see the response in question 4(a) above.

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?)*

Proper advice on careers in STEM is a continuing problem despite the efforts of professional and other bodies to create excellent informative websites. The suggestion of a national network of careers advisers with specialist knowledge and understanding of careers in STEM is an excellent one. Such a group would need to include in their advice the importance of knowledge of science and mathematics to careers that do not fall directly in the STEM part of the economy.

Skills, Curriculum and Assessment

We have no comments to make directly on the questions in this section but offer some general points under 'Other comments'.

Other comments:

UKDS is not an expert on the design of curriculum, assessment and skills development in schools. However, in respect of these issues we would make the following general points.

i. It is essential that 5-19 education delivers a *knowledge and understanding* of the basic aspects of the sciences including: the basic building blocks such as the cell, atom, molecule; multicellular organisms and compounds; how to carry out scientific observations and make conclusions based upon them; how to solve problems in science; knowing, appreciating and understanding how science can explain aspects of nature, man and man's interaction with, and effect on, the environment; how science can be applied to develop solutions to challenges including human health and sustainability (including food, water, energy); a comprehension of aspects of modern technology; aspects of manufacturing industry.

ii. For mathematics, it is essential that 5-19 education develops as a minimum an understanding of numbers and sufficient mathematical skills to comprehend the meaning of risk.

iii. The aim must be to ensure that, within the ability of each individual, all pupils achieve some ability in the above elements of the curriculum so that the vast majority understand the scientific method and recognise the opportunities and limitations of science and mathematics and are able to make some judgments about the sciences and their application. Beyond this, and for those with an aptitude and interest, the curriculum needs to stretch their ability to know in detail and understand in some depth one or more scientific disciplines and be able to make a smooth transition to their study in higher education.

Infrastructure

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

Science classes, in particular, should normally take place in modern and well equipped laboratories/workshops. As pupils progress, there should be increasing use of external visits where pupils can relate the science to issues of health, manufacturing industry and the world about them.

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

Please see the comment on external visits in (a) above.

Accountability

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?*

We do not believe that science and mathematics education should be differently accountable from any other subject.

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

They should each be regulated by a single body with representation from professional, statutory and regulatory bodies, and employers (including employers whose main business is not directly focussed on science or mathematics). Please also see the comment on Awarding Bodies above (General Question (c)).

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

No comment

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

We take this question to relate to performance targets for schools. We are deeply concerned that the nature of measurement of 'success' of schools and teachers (including the publication of league tables) that relate almost solely to the numbers/proportions of candidates obtaining passes, high grades or GCSE *equivalents* have led to several well publicised unintended consequences.

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

No comment

UK Mathematics Trust

Dear Martin,

I am attaching a brief response from the UK Mathematics Trust (whose Council I chair) to your call for views on the Royal Society's project on science and mathematics education 5-19.

I apologise that this comes to you after the deadline of last Friday: I am afraid that I did not know about the project until receiving the President's message below earlier this week. I apologise too that the UKMT response does not directly answer any of your questions, but it describes briefly what UKMT does (and some things we would like to do more of if the funding were available), most, if not all, of which is relevant to the Royal Society's project.

I am copying this to Rachel Greenhalgh who is the UKMT Director. If there is any more information or other help we can provide, please let us know.

With best wishes
Frances

About the UK Mathematics Trust
The UK Mathematics Trust is a charity established in 1996 to advance the education of young people in mathematics, primarily through running of mathematics competitions (the Maths Challenges and Team Challenges), and also by developing, selecting and training the most able pupils to represent the UK at the International Mathematical Olympiad (IMO) and other international mathematics competitions.

The UKMT also runs teacher training CPD events throughout the UK in the form of its teacher meetings, organises and runs the National Mathematics Summer Schools, and administers mentoring schemes for high achieving pupils. This year, the UKMT is running a new international event, the European Girls' Mathematical Olympiad with the aim of increasing UK female participation at the highest level and particularly in international competitions. We have also recently developed new Mathematical Circles to provide a stimulating environment for bright mathematicians from various geographical locations to come together for two or three days and follow a mathematically demanding programme.

Over 600,000 pupils from over 4,000 secondary schools and colleges participate annually in the Junior, Intermediate and Senior "Maths Challenges", mass entry multiple choice maths competitions. These questions are accessible but require problem solving ability, and are designed to stretch able pupils beyond the school curriculum.

High scoring pupils from the challenges are invited to participate in follow-on rounds, the "Olympiads". Around 800 top scoring UK pupils from the Senior Maths Challenge are invited to participate in the British Mathematical Olympiad Round 1 (BMO1), and based on these results, the top 100 or so invited to take BMO Round 2. After BMO2, a group of 20 students is invited to an intensive week long training camp at Trinity College, Cambridge, where a group of around 8 students is selected to attend a further training camp at Oundle School before the final UK IMO squad is named.

The two highly regarded National Mathematics Summer Schools (NMSS) run by the UKMT provide an intensive week-long camp for talented mathematicians aged 15 and 16. The 84 students who participate in the summer schools are selected from all over the UK and the demanding academic programme introduces students to a number of mathematical topics that they may not have met before, and allows them to develop important mathematical skills such as problem solving and proof.

The UKMT Mentoring Schemes are aimed at the very brightest mathematicians in schools, normally those who are at Olympiad level. We provide free resources for schools and external mentors (normally Oxbridge undergraduates) to assist in stretching and developing the most able students beyond the school curriculum.

The UKMT Team Challenges promote mathematical dexterity, team working and communication skills, whilst giving pupils the opportunity to compete against pupils from other schools in their region.

The UKMT works closely with other mathematical bodies, in particular, organising and running the Senior Team Maths Challenge (for pupils in Years 11-13) in partnership with the Further Maths Support Programme. Teams from over 1025 schools competed in regional events this academic year, with 63 teams competing in the National Final held in London in early February. The UKMT also partners the Royal Institution in running a series of “Best in School” celebration masterclasses for Year 9 and Year 12 students.

All our activities are run at low cost aided by a huge network of committed volunteers (mainly school maths teachers and academics) throughout the UK. Currently the UKMT receives no financial support from the Government.

The value of the UKMT’s activities has been recognised in white papers. Professor Adrian Smith’s Inquiry into post-14 mathematics education “Making Maths Count” reported about more support being needed for the sorts of activities that we and other groups do. More recently, the report “A world-class mathematics education for all our young people” by the mathematics taskforce chaired by Carol Vorderman said about the UKMT and our activities “...These events provide a mechanism to give students real mathematical challenge outside the actual curriculum. They should, therefore, be supported and promoted to those who could benefit from the opportunity to participate in them”.
For more details of our activities, please see our website: www.ukmt.org.uk

How the UK Mathematics Trust can provide additional support for talented young mathematicians
The UK Mathematics Trust (UKMT) is very active and successful at promoting mathematics within schools and helping students develop a broader and deeper understanding of the subject. Through the Maths Challenges we reach hundreds of thousands of students each year. We are able to target the most able students and develop them through our mentoring

and summer school programmes and encourage them to study mathematics at a top university.

Our summer schools in particular have over the years brought together some of the country's most able young mathematicians and inspired these youngsters to study mathematics at a leading university, though unfortunately at the moment there are only two summer schools each year, attended by 84 students in total. We currently charge £150 for attendance at these summer schools. This fee, which is remitted in the case of financial hardship, covers about one-third of the total cost. We believe that there are hundreds more pupils who would benefit from attending such summer schools if they had the opportunity. We could expand the summer schools if we had sufficient financial support.

University of York Science Education Group

The members of the Science Education Group at York have met to discuss your call for views on science and mathematics education 5-19 and decide how to respond. Many of the questions you are asking are very large ones, to which a considered reply would require several pages, in some cases a short monograph. Indeed, many would make good PhD projects. We simply do not have the time to address these in the kind of depth and detail they require. We would also question whether views and opinions on many of them are useful; a thoughtful review of the research literature would potentially be more valuable. In other words, evidence might be a more reliable guide than opinion in trying to take matters forward productively.

This response is therefore limited to a few relatively brief observations on some of the questions you ask:

1a A higher proportion of UK school science lessons are taught by science graduates, and in laboratories, than is the case in most other countries. Provision of school laboratory assistants in UK schools is the envy of teachers and science educators in most other countries. We also have a particularly strong and respected professional organisation for science teachers (the Association for Science Education, ASE) which has always done a much better job than the corresponding organisations in many other countries in creating a productive meeting ground for practitioners, researchers, academics, and policymakers/shapers. Its role and contribution to creating a professional environment for science education is underestimated.

1b Too high a proportion of starting undergraduates in science in UK universities come from the independent school sector. Put the other way round, children with an interest and ability in science, who happen to live in certain areas and attend certain schools, have a much reduced chance of taking the study of science beyond GCSE level. In international comparisons like PISA, our average national performance is good (when compared to other comparable countries, very good), but we have a much broader range of performance within the national sample than many other countries, including the most successful ones. The performance at the 'lower end' is often a consequence of provision and resourcing in the schools these students attend, which may not have a specialist teacher in the physical sciences. The unevenness of the 'playing field' is not far short of a national disgrace – and is the thing we should be most concerned to alter (over time, as there is no quick fix here). How might it be done? Paying beginning science teachers salaries similar to those of beginning lawyers and accountants might make a difference over a five year span. This might also be seen as an answer to question 1(c).

Approaching this question from a different angle, it could greatly benefit the planning and organisation of science education at school level if the professional science community made a clear and succinct statement that it is concerned both about the educational pathway for future scientists and about the general level of understanding of science in the population (i.e. in the education of both future scientists and non-scientists). If this could then lead to a serious and thoughtful discussion about how best to achieve both of these goals (rather than focusing on one at the expense of the other), and to support for efforts to test possible ways of achieving this, that would be a real step forward that could lead to significant improvement in curriculum structure and content which could reap rewards within a 5-10 year time span. This would also be the core of our answer to your question 1(d).

Robin Millar 9 March 2012

Wellcome Trust

Response by the Wellcome Trust
22 March 2012

Key Points:

1. The 'Vision' exercise is an opportunity for the Royal Society to assert high level principles to underlie its position on science and mathematics education. The Wellcome Trust is committed to making inspiring, high-quality science education available to all young people. We are therefore pleased to respond to this call for evidence. We would be happy to expand upon evidence provided in this response and contribute further to the development of the Royal Society's vision.

2. Our main response focuses on some of the key areas requested in the consultation document, namely the need for high quality teaching, curriculum and assessment, and governance and accountability. In moving towards a vision for science and mathematics education, these aspects of the current system must be improved.

3. We also provide the following thoughts that you may wish to consider as you develop the overall vision.

At the highest levels, achievement in science and mathematics education are already excellent in the UK. The challenge is to close the very wide gap between the best and the average and below average, without losing the high level of excellence that currently exists. The highest priority should be given to improving the scientific and mathematical literacy of the future citizen – while at the same time ensuring that the new generation of scientists and technologists are inspired and well prepared.

To achieve the principles above, it will be vital to ensure that teaching of science and mathematics is of the highest quality. Teaching in these subjects should be situated within rich real-life contexts, and ensure that students understand the methods of science as well as the facts and theories.

Practical work is essential to any science education setting, providing young people with hands on experience of how science works. In an increasingly technological world, virtual platforms for science learning are likely to become more commonplace. While these will have their place, those that mimic the “practical experience” of science must not detract from the importance of real life physical learning. This is particularly important if we are going to equip the scientists of tomorrow.

There are many cultures where vocational learning is more highly valued than it is in the UK, with little disparity between academic and vocational routes. The UK would only benefit from greater recognition of vocational routes to science learning. Vocational education will become more important as the age of compulsory education and training is extended to 18.

Any future education system will require appropriate means of assessment and accountability. The current accountability framework has a distorting influence on how young people are taught in schools. Work is needed to create an accountability framework to measure the performance of the education system that is separate from, and is not solely driven by, pupil assessment. Similarly, an assessment system must be created that tests deep learning of science, and is relevant to how skills will be used in work and life.
4. Depending on the timeframe of the vision for the future, it will need to consider how the currently somewhat turbulent expansion of the diversity in education for both teachers and students will settle, as well as advances in educational technologies.

TEACHERS (AND THE WIDER WORKFORCE)
5. No education system can be better than the quality of its teachers. The quality of teaching has been shown to be a major determinant of young people’s interest and achievement in science1. High quality and inspiring teaching from well-trained teachers is vital to ensure effective student engagement and therefore improve science and mathematics education going forward.

Recruitment and retention of high quality teachers
6. Recruiting and retaining the best science and mathematics teachers is vital. As mentioned in the call for evidence, there remains a shortage of science specialist teachers at primary and secondary level, particularly in the physical sciences. We support the move to increase the number of high quality teachers in the system through incentivising excellent science and mathematics graduates2,3. By steadily raising the bar, we are optimistic that the status of the profession will be enhanced, which, over time, will help to attract better qualified applicants.

7. One area of current concern regards bursaries to incentivise high quality graduates into primary teaching. A very low proportion of science and mathematics graduates enter primary training4. In maintained primary schools in England, only 3 per cent and 2 per cent of

teachers are science and mathematics specialists respectively5. Those entering training for shortage subjects in secondary will receive £20,000. However, prospective primary teachers – even with qualifications in mathematics, chemistry and physics - will receive a maximum of £9,000. This disparity potentially acts as a disincentive for science and mathematics graduates to enter primary teaching. We believe it is important to bring the bursaries available to primary trainees up to the level for secondary trainees.

Worrying data show that, of teachers receiving Qualified Teacher Status (QTS) in 1999, just fewer than 60 per cent of new recruits were still teachers after 5 years6. Providing interactions with Higher Education Institutions and employers, are important factors in improving retention. As is providing all teachers with access to high-quality continuing professional development7, which is why Wellcome is strongly committed to the Science Learning Centres (see paragraphs 15 to 17).

Initial Teacher Training (ITT) and continuity with continuing professional development (CPD)

9. Those in the teaching profession must get the best possible training, in their early years as well as through the rest of their careers.

10. ITT is the first step to a successful career in teaching and therefore must be fit for purpose. It is a particular feature of science that teachers are often required to teach outside their first subject specialism: for example a biology specialist may well have to teach chemistry and physics up to GCSE level. An appropriate level of basic subject knowledge is therefore essential. The Trust recently commissioned a study from the University of Birmingham into the subject knowledge content of different ITT courses8. This study shows much variation across different institutions, particularly in the subject knowledge content of the school-based component of ITT. Steps must be taken to assure that trainees emerge with a minimum level of subject knowledge across all three sciences.

11. ITT and CPD should not be separate processes, but too often they are. Initial training is only the start of what should be a career-long process of professional development. Newly-qualified teachers (NQTs) still have much to learn, and although the best schools have excellent induction programmes at the beginning of the NQT year, the process is far from complete at the end of the year.

12. Teachers realise the need for CPD in the early stages of their career. However, steered by their schools' management, they are more likely to take up opportunities for generic CPD rather than science specific courses9. We would like to see a more proactive strategy for systematically developing the skills and knowledge of science teachers, especially in the early years of their careers, to build on knowledge gained in ITT and link with CPD.

Continuing Professional Development

13. Good subject specific CPD should be a regular part of good teaching practice and is vital for increasing the quality of teaching in schools. It is particularly important for science teachers: to keep them up-to-date with scientific developments; to equip them with skills to deal with changes to the curricula; and to learn innovative techniques to explain

contemporary science in the classroom. The availability of opportunities for teachers to undertake CPD should be monitored by Ofsted to ensure that each school places this as a priority for improving teaching.

14. The National Science Learning Centre (NSLC) and network of regional Science Learning Centres, funded in partnership by the Wellcome Trust and DfE, were established as a resource providing high quality subject-specific CPD to science teachers and technicians across the UK. By July 2011, 98 per cent of schools had used the National network of Science Learning Centres including over 50 per cent working with the NSLC at least once.

15. In addition, DfE, industry11 and the Wellcome Trust joined forces in Project ENTHUSE. This initiative aims to address a continuing problem for teachers and schools to find the time and money to cover teachers attending CPD courses. ENTHUSE provides funding for CPD courses, travel and teaching cover for teachers from across the country to upgrade their subject knowledge and teaching skills at the NSLC in York. Similarly, DfE funds the Impact Awards for teachers attending courses at their regional Science Learning Centre.

16. Evaluations of the Science Learning Centres and Project ENTHUSE showed their significant impact on the quality of science teaching and attainment in UK schools12,13. The National Audit Office recognise in its 2010 report14 the impact that training courses supplied by the National Network of Science Learning Centres have had in improving teaching and increasing take-up of science and mathematics in schools. It is imperative that ongoing support for these initiatives is maintained.

Science expertise in primary schools

17. Young people's interest in science is often sparked in primary schools, yet a survey by the Wellcome Trust and the National Science Learning Centre (NSLC) suggests that many primary schools have experienced a decline in the status of science in recent years15. This follows the removal of science tests at age 11, and is linked to the long-term weakness of primary teachers' knowledge and confidence in science, as observed in our 2005 report '*Primary Horizons: starting out in science*'16.

18. As mentioned above, there is a need to provide the appropriate incentives to recruit high quality science and mathematics graduates into primary teaching in the long term. However, a more immediate problem is the lack of scientific expertise currently available in primary schools. We believe that increasing the level of science expertise in primary schools is therefore a priority.

19. To address this, the Trust is developing a programme of CPD to train a primary science specialist in 50 schools. The programme will be aimed at teachers who are acting as primary science coordinator but do not have a background in science. Should the scheme prove a success after piloting and independent evaluation, we believe that it should be rolled out nationally with support from the Department for Education.

School laboratory technicians
20. Recent studies have shown that laboratory technicians provide invaluable support to teachers in schools and colleges in preparing and managing practical work and demonstrations17. Heavy workload has been cited as one of the main reasons for teachers leaving the profession18 and the work of technicians also reduces the burden on the teacher. The challenges around the future supply of school technicians is of particular concern and must be addressed19. The profile of technicians, including pathways to become a technician and career prospects20, must be raised along with good incentives to attract and retain them in schools, including CPD.

Careers advice
21. Careers advice and guidance in schools regarding all STEM (science, technology, engineering and mathematics) qualifications and their intended routes is critical and must be improved to ensure that students are aware of the different career opportunities and appropriate progression routes. The National Audit Office21 listed careers information and guidance as one of five critical success factors in improving take-up and achievement in science.

22. The range of careers available to people with STEM qualifications is so large that it is difficult even for professional advisers to give fully informed advice. At present, young people depend on their families22 (78 per cent), teachers (48 per cent) and careers advisers (20 per cent) for guidance. Following the removal of a ring-fenced budget for careers advice in schools, it is imperative that young people, parents and teachers are able to access good, clear information on career pathways and subject choices.

23. One way to help achieve this would be to expand and augment the existing Labour Force Survey and Annual Survey of Hours and Earnings to create a new, online and accessible resource on labour market information (LMI) to inform learners and their parents about the earnings and opportunities in different occupations, and the qualifications needed to enter them.

CURRICULUM AND ASSESSMENT
24. Our points in this section refer mainly to the National Curriculum, assessment mechanisms, and the need to increase the mathematics content of science qualifications.

National Curriculum
25. Over many years the existing National Curriculum has been subjected to multiple piecemeal changes that have contributed to it being over-prescriptive and inflexible. Although there is currently a review of the National Curriculum, we would like to see a commitment to an agreed long-term (at least 10 years) vision for the National Curriculum that policy makers, teachers and other stakeholders could work towards.

26. In July 2010 the Wellcome Trust convened a seminar to reflect on 21 years of the national curriculum for science. The report from the seminar provided five key messages which are designed to aid policy makers and curriculum reformers23. This is particularly

pertinent with the current review of the National Curriculum, but the principles remain relevant for the future.
i. The aims and purpose of the national curriculum for science must be clearly articulated and adhered to.
ii. The body of core knowledge should be clearly defined but not over prescribed.
careful attention must be given to how subject content is presented so that the context of what is taught is not lost in place of facts alone. Each subject should display an appropriate balance between information (what we know), skills (how we do things) and concepts (what we understand).
iii. Assessment should be designed as an integral part of national curriculum development. National Curriculum should be intrinsically linked to assessment. Appropriate means of assessing young people's progress and achievement must be developed to follow, not drive, what is taught in schools.
iv. New developments should be carefully piloted and rigorously evaluated before being refined and rolled-out nationally.
v. The implementation of a new curriculum must be carefully planned to ensure that all parties involved understand how it should be applied.
When introducing new curricula, it is crucial to encourage and support teachers through guidance, teacher training and ongoing CPD. This will promote confidence and understanding of how best to apply the curriculum, and provide ongoing stability for the teaching profession.

Assessment

27. Assessment should be intrinsically linked with the curriculum. Appropriate assessment should be designed to support learning, improve achievement and promote progression. The danger with any assessment system is that learning becomes directed towards achieving the best examination results rather than giving students a broad understanding of a subject - "the tail that wags the dog"24.

28. We support assessment that enables a good balance between formative and summative outcomes. It will need to inform students, parents and teachers of young people's attainment and progress, as well as assist children to chart their own learning, build their confidence and offer a constructive critique on their progress25. It should not be used as an overall measure of system performance due to the distorting influence on learning outcomes (see paragraph 37).

Examination system and supporting materials

29. An appropriately run examination system in England is vital for qualifications across the breadth of education. The examination system must be fit for purpose and ensure that young people are taught deep knowledge of science and mathematics subjects rather than being "taught to the test". This is currently being investigated by the Education Select Committee and Ofqual, but any reforms will need close monitoring over the coming years to assess if improvements have been made.

30. There are significant problems arising from the current model of multiple awarding bodies for academic qualifications for 15-19 year olds. If we were establishing the

examination system from scratch, a single awarding body would be most favourable and would be that envisaged in an ideal vision for the future. If the current model persists, it needs substantial improvements, specifically:

- There needs to be greater consistency across awarding bodies in the process of awarding grades, and much more openness about how it works.
- Awarding bodies must communicate better with each other, especially in sharing best practice and introducing innovations.
- National subject committees should be established to oversee the standard of examinations of major subjects across all awarding bodies.
- The changes to specifications every five years should be discontinued and awarding bodies given the ability to make incremental changes to examinations as and when needed, under the guidance of national subject committees.

31. In addition to this, we also believe more should be done to promote the value of STEM subjects to Higher Education Institutions and employers, to ensure that pupils are not put off taking them due to perceived difficultly in achieving higher grades as compared to other subjects. A recent report by the Russell Group provides a useful starting point26.
32. Textbooks should be effective tools to aid deep and lasting learning. We are concerned that linking textbooks solely with awarding body examination specifications encourages "teaching to the test". Ofqual should use its Codes of Practice to stop awarding bodies endorsing textbooks wherever this carries a risk that the quality of the textbook and/or the associated examination will be compromised as a result of the association.

Increasing mathematics content and uptake
33. A specific area of concern is the low mathematical content of science specifications and examinations at GCSE and A level, highlighted by the report of the Science and Learning Expert Group27. Mathematical content should be strengthened within the science specifications and, most importantly, required in the actual examination questions. This is something that Ofqual can and should demand as a matter of urgency.

34. People need fluency, confidence and the ability to apply mathematics in study, in the workplace and in their personal lives. These qualities come from learning and using mathematics regularly over a sustained period. England (with Wales and Northern Ireland) has an exceptionally low rate of participation in post-16 mathematics (under 20 per cent28), and Michael Gove has set a new goal for the education system so that 'within a decade the vast majority of pupils are studying maths right through to the age of 18'29.

35. With this level of concern, there is a singular opportunity to make progress towards the goal of continuing mathematics education for all young people until 18. Actions are needed on both the supply side (ensuring there are the right high-quality post-16 qualifications in mathematics to meet the needs of all people, whether or not they are university bound) and the demand side (making sure that universities and employers speak loudly and clearly of their preference for mathematical qualifications). The Advisory Committee on Mathematics Education (ACME) can and should be the lead body to take this work forward, but it needs strong support from all stakeholders and may need additional resources.

GOVERNANCE AND ACCOUNTABILITY

36. It is important not to confuse the role and purpose of national accountability with assessment information for parents, teachers and pupils to guide and measure a pupil's personal progress. It is clear that that current system of school accountability, for example league tables based on pupil achievement in examinations, have a distorting influence that drive learning outcomes based on test results rather than deep knowledge of a subject. Further work is needed to create a framework to measure system performance separately from pupil assessment.

37. We believe that one element of performance improvement and accountability of schools should include robust local governance of schools30. As part of this, careful thought must go into the training and recruitment to governing bodies to ensure appropriate experience and full understanding of the role of governing body members. The Wellcome Trust is investigating a number of initiatives in this area, such as producing something equivalent to a Statement of Recommended Practice31 applicable to governing bodies, and would be happy to share the findings and developments as they emerge.

38. Overall, we believe that effective assessment and accountability can only be realised if there is additional work to:

- strengthen formative assessment within schools to guide and develop pupils;
- identify a suitable range of indicators of school performance;
- strengthen accountability through effective school governance and appropriate patterns and criteria for school inspection.

Appendix.

Vision for science and mathematics education 5–19

Call for Views

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?

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?

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

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

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?

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?

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?

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

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

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

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?

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

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

Other comments:

3) Continuing Professional Development (CPD) for teachers

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

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

d) Should CPD be voluntary or mandatory? Why?

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

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?

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

Other comments

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?

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?)

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?

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?

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

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

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?

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?

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?

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

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

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?

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

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

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

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

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?

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

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

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?

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

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

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

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 ☐ No ☐

b) Would you like to be kept in touch with the project? If 'yes' please provide a contact email address. Yes ☐ No ☐ email address: ______________________________________