SUPPORTING SCOTLAND'S STEM EDUCATION AND CULTURE

Science and Engineering Education Advisory Group (SEEAG)

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PART 1 INTRODUCTION AND CONTEXT

Scotland has a long, distinctive and distinguished record of discovery and innovation in science, engineering and technology through the industrial revolution and the 20th century, and is widely renowned for the quality and inclusiveness of its education system. Innovative science, engineering and technology are as fundamental to Scotland's future economic prosperity as they have been to its economic development over the past two centuries, driving growth in the fast-changing world of the 21st century. They are a major element of Scotland's heritage, culture and well-being, and our prospects as a successful nation in the 21st century will require new generations of ambitious young scientists and engineers to drive forward innovative technologies. Scotland also needs a scientifically-literate population of well-informed and responsible citizens to engage in driving forward not only our economic ambitions but also those of sustainability, the improvement of our natural and living environments, and the delivery of our climate change targets.

Young people grow up surrounded by technological innovation. Their lives are increasingly influenced and enriched by science and engineering in ways that they take for granted and of which they are perhaps largely unaware. Their lives will also be enriched by breakthroughs in medical science and technology, and by scientific advances as yet unimagined. Yet at the same time they worry about the impact that rapid scientific and technological progress will have on their future quality of life, on the local and global environment, and on the sustainability of the Earth's resources. They need to be persuaded of the capacity of science, engineering and technology to solve the many problems now facing societies around the world. In the present financial climate, they worry about their place in society, their future employment and career choices, and their capacity to cope with the many demands and uncertainties that they will encounter. They will need to be equipped above all with increasingly complex and sophisticated technical and cognitive skills in order to take advantage of the challenges and opportunities that will confront them throughout their working lives.

These many concerns and expectations are shared to varying degrees more widely across society. It is therefore of the greatest importance to Scotland's future that our young people experience science and technology both within the school environment and outside the classroom in ways that reflect its relevance to their lives, illuminate their understanding of the world around them, and inspire them to engage positively with science as a possible career choice. Just as importantly, science should challenge young people as responsible citizens able to make informed choices and decisions about the big social, moral, ethical and environmental issues of the day.

The economic importance of science, engineering and technology to Scotland

The importance of young people continuing with science subjects cannot be overestimated. Science, engineering, technology and mathematics (STEM)

underpin our economy. The Scottish Government has identified Energy and Life Sciences as two of its 'priority sectors' in its overall economic strategy, where Scotland already has leading expertise and the potential for growth. The facts are worth stating to give an indication of the importance of these sectors and to illustrate the relationship of science, engineering and technology to future economic activity and employment:

Energy[1]

- About 30% of the FTSE 100 is founded upon economic activity dependent on the Earth's resources, of which Scotland has an abundance. In 2012, about 60% of the UK's total energy needs are still met by oil and gas produced from UK reserves, ensuring continuing strong demand for scientists and engineers in the UK oil and gas sector.
- Renewable energy has the potential to support at least 16,000 new jobs over the period 2009-2019. Estimates of the job potential in clean fossil fuels and carbon capture and storage in Scotland, and through the export of technology and services, run to 10,000 jobs. In carbon capture and storage, a new technology involving the capture of CO_2 at major sources such as power stations and subsequent offshore subsurface disposal, Scotland is already a world-leader.
- The wider energy sector in Scotland contributed over £4.8 billion in GDP, around 5% of the Scottish total, in 2006, and employment in the energy sector stood at 40,700 in 2007, around 23% of the UK's total employment in the sector.

Life sciences[2]

- The life sciences cluster in Scotland in 2008 employed almost 31,500 people in 620 organisations. Turnover in 2006 was estimated as over £3 billion. Total value of the life sciences sector exports for 2007 stood at £675 million.

Other priority sectors

Within the Creative Industries[3], the most obviously technologically-based sub-sector also employs many in Scotland, with around 17,500 employees in the computer games, software and electronic publishing industries in 2007, while a further 8,000 people were employed in broadcasting, many of whom would be involved in the technical operations side.

Low Carbon Economic Strategy for Scotland[4]

The Scottish Government's *Low Carbon Economic Strategy*, published in November 2010, predicts that an estimated 60,000 new 'green jobs' could be created by 2020, in sectors across the economy, including ICT, tourism, transport, agriculture, forestry, chemical sciences, life sciences, food and drink, and environmental technologies. Most of these jobs would have a direct science, engineering or technology relevance.

The Scottish Government and major employers in STEM-based industries in Scotland have expressed widespread concern about the future supply of well-qualified, highly-skilled scientists and technicians to meet demand in the above sectors of industry and more widely across the economy.

Background to the SEEAG Report

'Plus ça change, plus c'est la même chose'

Scotland has many of the essential elements of a strong education system by international standards. It has an all-graduate teaching profession, structured induction of newly qualified teachers, a strong framework of standards and expectations, and professional learning and development offered by national organisations, education authorities and teacher associations. However, relative international performance indicators show that this potential is not yet being fulfilled.

In 2003, the Scottish Science Advisory Committee's (SSAC) report *Why Science Education Matters*[5] made a number of recommendations for the future improvement of science education in Scotland to meet perceived concerns and challenges. The report called for a programme of curriculum change that moved away from a cluttered, content-dominated and assessment-driven curriculum with little scope for teachers to include topical or innovative material to inspire learning.

It recognised that the lack of science specialists and the absence of science infrastructure and technical support in primary schools were major obstacles to sustaining the interest of young people in science across the transition into secondary education, and the need to improve the uptake of science and the standard of science educational attainment in secondary education. The report made several recommendations regarding primary school science facilities, teacher and technician support in primary schools, and continuing professional development (CPD) to tackle this problem. It recognised the deficiencies in school careers advice around pathways into science and career opportunities for science graduates, and recommended that CPD be provided to address these deficiencies. It recognised the need to reverse the decline in public confidence in science. It called for better co-ordination of science education activities and support across Scotland, and recommended the formation of local clusters of primary and secondary schools, industry, colleges, research institutes and universities to support and improve science education. Concern was expressed about the age structure of a science teaching cohort in which, in 2000, one-third of science teachers were over 50 years old, and a half over 45. ***These issues all remain priority concerns in 2011.***

On the positive side, there has been a slight decrease in the proportions of STEM teachers over 45 and over 50 – the reverse of the ongoing ageing trend of the wider Scottish secondary teacher cohort. But most importantly, the introduction of *Curriculum for Excellence* (CfE) as a radical and systemic educational reform addresses the SSAC call for radical curriculum change, opening up exciting new opportunities for bringing real-world relevance, wider contexts and interdisciplinary thinking to science learning, teaching and assessment.

It is against this background that the disappointing Scottish results of the *Trends in International Maths and Science Survey* (TIMSS) carried out in 2007[6] were published in December 2008. Fiona Hyslop, then Cabinet Secretary for Education and Lifelong Learning, said the TIMSS report "*painted a picture of Scotland standing still while other nations pushed by*"[7]. The survey compares the performance of Scottish pupils in science and mathematics at ages 9-10 (P5) and 13-14 (S2) every four years with those of 59 other OECD countries. Scotland's average scores in S2 mathematics, and P5 and S2 science in 2007 declined from 2003 levels back to 1995 levels, but remained similar to 1995 and 2003 levels in P5 mathematics. Scotland's best performing pupils in the survey showed a lowering in standards of attainment. These results demonstrated a need to review the extent to which science and its relevance to the skills, which children need for life and work in the 21st century, is embedded within school education.

The Scottish results in mathematics and science from the *Programme for International Student Assessment* (PISA) 2009[8], measuring performance by 15-year-old pupils (S4 level) every three years in 65 OECD countries, also left no room for complacency. In mathematics, Scotland's mean score was lower than in 2003, similar to 2006, and similar to the OECD average, while in science Scottish pupil performance was similar to 2006 but above the OECD average. While this reflects the relatively stronger performance in science by Scottish pupils at qualifications level than was demonstrated at P5 and S2 level, Scotland has not improved on its place as a mid-ranking performer[9]. The OECD report on Scotland[10] went on to warn that '*Scotland could slip through the ranks. It could be bypassed economically and become more divided socially*', noting the widening gap in achievement from about P5, marked social differences in basic achievement and in SQA qualifications attainment, declining student engagement and interest especially in early secondary, and comparatively high levels of young people not in education, employment or training.

Insofar as mathematics is the language of science, we should also be concerned that poor performance, and therefore low confidence, in mathematics is likely to have a negative impact on young people's performance and confidence in science and therefore on the uptake, enjoyment and performance in all sciences at secondary level and beyond.

The School Science Summit, Action Plan and SEEAG Remit

The TIMSS survey results prompted the Scottish Government to hold a *School Science Summit* in May 2009, whose main recommendations included:

- more collaboration across the profession
- seamless transition from primary to secondary education
- better and more creative use of ICT
- closer partnerships with industry/business and academia
- improved provision of CPD and initial teacher education (ITE)
- improvement in the image and status of science in schools
- greater relevance to the 'real world' in science education at all levels
- sharing of good practice via a 'one-stop shop' for initiatives and resources.

These strategic and system-wide recommendations underpin the *Action Plan on Science and Engineering for the 21st Century*[11], whose implementation has been progressed and monitored by the ***Science and Engineering Education Advisory Group*** (SEEAG).

The remit of SEEAG is to:

- Steer the programme of work outlined in *Science and Engineering 21 – An Action Plan for Education*. Communicate and share information with the work stream lead partners throughout the process on cross-cutting issues such as quality assurance and sustainability, and consider the impacts of activities across the work streams.

- Identify opportunities for collaboration and partnerships, alignment of activity and sharing of resources.

- Support young people to make informed choices about further learning and careers in science.

- Encourage good practice; support high achievement; value interdisciplinary learning; and acknowledge the need for a wider public appreciation of the value of science as a pillar of economic growth.

- Ensure that the programme of work outlined in the Action Plan is undertaken within the strategic context defined by the *Government Economic Strategy, Science for Scotland, Innovation Framework, Skills for Scotland, Curriculum for Excellence* and associated policies and that the action plan complements activities being progressed in these areas.

- Review the Action Plan as required and seek additional expert advice for example from HMIE, SQA and others as required.

- Agree appropriate monitoring and evaluation measures.

This remit requires a strategic framework and context within which work and actions of the Advisory Group and lead partners can be understood. This is defined by the specific strategies arising from the School Science Summit and developments defined above, in particular Curriculum for Excellence (CfE).

Much has happened in Scottish education since the School Science Summit in May 2009. CfE is being implemented in the broad general education phase *Experiences and Outcomes*, and new national qualifications are being developed in the senior phase. Additional frameworks and contexts are imposed by parallel work contained in recently-published reports that include:

The Donaldson Report on the future of teacher education in Scotland[12];

The Royal Society ‘State of the Nation’ report on Science and mathematics education, 5-14[13]; and

The Scottish Government report on delivering ambitions for post-16 education[14].

The current climate of spending cuts requires more to be achieved with less, and this requires ambitious educational reforms to be implemented in creative and strategic ways that make much better use of declining resources. The challenges of improving science education in Scotland must therefore be addressed within a dynamic and fast-changing situation that is in many respects unrecognisable from that of the Science Summit of 2009. The work of the SEEAG described in this first report has therefore evolved towards creating an evidence-based strategic plan within which STEM education can be strongly developed in Scotland.

The work and recommendations of SEEAG between April 2010 and December 2011 in supporting the implementation of the Action Plan, whilst recognising recent developments, is the subject of this report of SEEAG. The report considers a wide range of issues around science education and engagement, identifies the research evidence about what works in improving science education and engagement, and draws conclusions and makes recommendations about ways forward. The detailed work and actions of the SEEAG and of its lead partners contribute to the attainment of these strategic goals. Both are key elements of this report.

The SEEAG Workstreams

The Action Plan sets out a work programme containing five workstreams developed around key themes raised by delegates at the School Science Summit:

1. Building capacity and expertise of teachers
Lead partner: Schools Directorate, Scottish Government
(Remit: To provide teachers in all sectors with professional support and development opportunities…to enable them to become more confident and effective in delivering science and technology curricula and the mathematical skills to support these)

2. Practical support for teachers and learners
Lead partner: Learning and Teaching Scotland (LTS) - now Education Scotland
(Remit: To create a toolkit for teaching and learning that will exemplify CfE; provide practical guidance and support for teachers and learners including support for assessment and national qualifications; improve coherence and accessibility of high quality support material from partner organisations)

3. Increasing children and young people's engagement with, and understanding of, real life science, engineering and technology
Lead partner: Office of Chief Scientific Adviser (OCSA)
(Remit: To establish new/strengthen existing links between schools and external partners to increase children and young people's engagement with, and understanding of 'real life' science, engineering and technology)

4. Further learning, training and employment
Lead partner: Skills Development Scotland
(Remit: Further learning, training and employment in STEM)

5. Improving the public knowledge, understanding and perception of science
Lead partner: OCSA
(Remit: Improving the public knowledge, understanding and perception of science including through the media and improving the international perception of Scotland's Science and Technology)

Workstreams 1 and 2 were merged early in SEEAG's work to reflect the large overlap in their aims and a shared focus around the professional development of teachers.

The above themes implicitly recognise that artificial distinctions are commonly drawn in practice between the formal education of young people in the fundamentals of science and their relevance to the real world; the training of professional scientist and technicians in the world of further and higher education; the essential role of STEM in world of work; and an improved understanding of benefits, risks and impacts of science and technology amongst the citizens of Scotland. In reality these are seamlessly interconnected. Scientifically literate young people are powerful ambassadors for science and technology within their own communities. They learn about science in the classroom, the outdoors, in the media and at science centres, and in their everyday lives. Science is all around them – it is about how the world works, in principle and in practice.

The Action Plan is quite simply about engaging more people more deeply and more effectively in science at whatever level, wherever they are, and in whatever way is most appropriate and effective. Throughout this report we will strive to make evident the connections in principle and practice between the above workstreams, and the resulting potential for practitioners to share scientific ideas and educational initiatives through networks, learning communities and partnerships, and their co-ordination at local and national levels.

The SEEAG work and report

This report gathers, integrates and presents the main recommendations and conclusions of the work undertaken within the five workstreams by the lead partners and sponsors. The individual workstream reports, prepared and developed through 2011, take the form of evidence-based frameworks and strategies within which the actions and outputs of the lead partners and the outcomes of the 12 meetings of the SEEAG may be presented and evaluated. The recommendations and conclusions of the individual workstream reports are founded on research evidence gathered by report authors, the feedback from a large number of stakeholders to a set of questions, and the responses and views of delegates expressed at workshops held during the SEEAG Conference held at the Glasgow Science Centre in June 2011. The report has

also benefited from key work undertaken and reports contributed by the *Deans of Science and Engineering Committee* of the Scottish Universities, the Scottish Science Advisory Council (SSAC) on science education in schools, and by Professor Jack Jackson on the *Provision of support for Scottish teachers of STEM subjects*.

This report is written for a wide audience: Scottish and Local Government, educational agencies, teachers, educators, parents, schools, colleges, universities, business and industry, learned and professional societies, science engagement organisations and the public at large.

The work of SEEAG was undertaken during and in parallel with the preparation of other recently published major education reports to Government that have a bearing on this report, including:

Donaldson G (2011) *Teaching Scotland's Future*, Report of a review of teacher education in Scotland. Scottish Government, January 2011[12]

Science and mathematics education, 5-14: A 'state of the nation' report. The Royal Society, 2010[13]

Putting learners at the centre: delivering our ambitions for post-16 education. Scottish Government Paper, September 2011[14]

Cameron D (2011) *Devolved School Management*, Scottish Government, October 2011[15]

McCormac G (2011) *Advancing professionalism in teaching*, Report of the review of teacher employment in Scotland. Scottish Government, September 2011[16]

Science education: Enhancing Support for schools through collaboration. Scottish Science Advisory Council, January, 2012[17]

Scottish Science and Engineering Education Action Plan, Teaching Excellence Initiative: Input from Deans of Science & Engineering. 2010[18]

The work of the SEEAG builds on and often extends the outcomes and recommendations of these reports, and the SEEAG report interprets the recommendations and conclusions of these reports together with additional research evidence in a STEM context. Importantly, the SEEAG's work differs in having a specific STEM focus; this distinction is reflected in the report's recommendations.

Science and technology are in a constant state of change. Rapid progress in both fundamental principles and in practice leads to new insights and greater understanding, and new applications to – and impacts upon – the lives of people in Scotland. These advances affect they way we look at the world around us and the way we live. Many STEM teachers can become out of touch with these new advances and applications as they are immersed in the

day-to-day business of teaching. This has a direct bearing on the nature and extent of both initial and continuing professional development needed by STEM teachers. Furthermore, science and engineering are practical, hands-on subjects; learners and teachers alike need to engage in active, practical, hands-on learning. This in turn imposes further important requirements on the nature of the teacher learning and professional development that are needed.

SEEAG stakeholder consultation analysis report

SEEAG and its workstream leaders undertook a stakeholder survey to establish a baseline of knowledge and gather sector-specific views on questions relating to the Science Action Plan. Forty-three out of over 200 stakeholders from a range of sectors responded. These sectors included further and higher education institutions, industry, local authorities, professional bodies, school support providers, Government and its agencies, science centres, museums and other public providers, research councils, science media and science engagement providers. The responses enabled the identification of five themes that ran across all workstreams to varying degrees. These were strategic overviews; linking academia and industry; supporting schools; guidance and career paths; and funding. Common and recurring messages and issues that emerged included:

- Co-ordination and awareness of supporting activities locally, regionally and nationally
- Resources and funding for more hands-on CPD, relevant to real-life and in support of new qualifications
- Raising awareness of CfE and appropriate CPD in industry and universities
- Facilities to support essential hands-on science learning
- Improved guidance and awareness of STEM sectors and careers
- Links between subject choices and career opportunities
- Enthusing young people in science learning and STEM careers
- Development of science skills and knowledge in the primary sector through review of initial teacher education
- Negative impacts of short-term funding and its knock-on effects on partnership development
- Ring-fencing of LA funding in relation to CPD, facilities and science engagement access.

These are all issues and themes that are addressed within the strategic framework and the workstream actions of the report. They ground both strategy and actions in the concerns of stakeholders captured in the survey, and help to define and reinforce the direction of the SEEAG's work through 2011 reported here. They also highlight the complex landscape of activity and support in science education and engagement as perceived by these stakeholders that is compounded by the ongoing process of radical educational reform and development of new national qualifications. A clear strategy and framework for development and delivery of a science action plan

is essential if stakeholders are to make sense of this complex landscape; this strategy and framework forms a core component of the report.

Details of the survey and respondent recommendations and suggestions under workstream headings may be found at: http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/ConsultationReport

Educational reform – why it matters

Many countries are undertaking reform of their public education systems in order to ensure that their young people are able to take their place in the economies of the 21st century and at the same time to ensure that they retain a sense of their cultural identity in a time of rapidly increasing globalisation. The current system of free public education we have inherited and experienced, modelled in the interests and image of the industrial societies and economies of the 19th and 20th centuries, has generated winners and losers based largely on the criteria of academic achievement, standardised testing and a standardised curriculum. Educational reform requires us to think differently and more flexibly about the ways we nurture and develop the innate human capacity for curiosity, creativity and critical thinking ('higher order skills') and to ask whether our current educational system stunts, stimulates – or at the very least sustains – these capacities that young people require and that employers seek.

Why is educational reform important? A commitment to improving educational quality through radical reform is the current goal of many Governments. Because the pay-back on investment now lies many years in the future, the investment and commitment of Governments for the longer term often falls short of what is required. However, ***even relatively small improvements in educational standards can have large impacts on the economic, social and cultural well-being of nations that may offset and perhaps exceed the cost of effective educational reform***. It is estimated that an increase of the average PISA scores of all OECD countries of 25 points over 20 years would increase OECD GDP by $115 trillion over the lifetime of the generation born in 2010[19]. The educational gap between children in the USA and their counterparts in other OECD countries was worth an estimated $2.3 trillion in economic output (including hundreds of billions of dollars in unrealised economic gains) in 2008[20]. This is why a commitment to educational and curricular reform in Scotland should be given the highest possible long-term priority by its Government. The long-term social and economic benefits of effective education reform are enormous. For this to be achieved, transformative change that is innovatively founded on successful models is particularly required in areas of economic and social exclusion. ***The benefits of tackling educational disadvantage and alienation, social division and exclusion and the resulting unrealised human and economic potential would be felt widely across society and at the same time lead to major longer-term savings.***

The ambition and attainment of Scotland's most talented and best-performing young people must also be developed and extended across all fields of study. They represent Scotland's innovators and leaders of tomorrow. This goal will require special provision and opportunity within the comprehensive system, through the development of innovative and imaginative projects and creative partnerships, based on researched evidence of successful models. ***Investment in support for the educationally disadvantaged should be coupled with stretching of the educationally gifted.***

Curriculum for Excellence – its wider impact on science education

Curriculum for Excellence (CfE) is more than a radical reform of curriculum and assessment. It is arguably not a curriculum at all in the normal sense. It is at least as much about skills, pedagogy and context as about content, and incorporates additional values and capacities. CfE also recognises schools and teachers as the interpreters and developers of the curriculum rather than simply the deliverers. Its implementation is a process and not an event, and as such it will take a number of years for measurable evidence of its increasing impact to be gathered and demonstrated.

CfE creates a framework for improving science teaching and learning and provides rich contexts and opportunities for interdisciplinary and cross-curricular learning across the sciences and engineering. In doing so it encourages teachers as subject specialists to teach beyond the confines of their specialist knowledge in order to point out the connections between the science disciplines and across into other curricular areas, highlighting the real world relevance of science. This in turn generates an expectation that teachers will work with colleagues in other subjects, and challenges the capacity of teachers to respond to these opportunities. ***These changes will require a cultural change in the profession, particularly in the secondary sector, that must be recognised, articulated and supported.***

This report addresses many of the challenges and opportunities arising in implementation of CfE as it affects the delivery of STEM education and engagement, and examines the ways in which STEM education may be supported and developed through initial teacher education, professional development and the development of new support structures and partnerships. The report also considers how young people's engagement with STEM may be increased, how the transitions to further learning, training and employment may be improved, and how the creative science culture of Scotland may be sustained and developed.

PART 2 INITIAL TEACHER EDUCATION (ITE)

Training STEM teachers

The Trends in International Maths and Science Survey (TIMSS)[6] and Programme for International Student Assessment (PISA)[8] studies have highlighted major concerns about the performance of Scottish pupils in science and mathematics at primary and on into lower secondary level. The limited knowledge and understanding in mathematics and science of primary teachers and the resulting lack of confidence are identified from data in the TIMSS 2007 report as a major cause for concern. The Donaldson Report[12] addresses wider issues of teacher quality, training and professional development across the Scottish education system. Here we examine the importance of teacher quality with specific focus on STEM subjects, in the process reaching broadly similar conclusions but with some important differences.

The importance of teacher quality

"The quality of an education system cannot exceed the quality of its teachers"[21]

Research on the relative international performance of education systems such as the PISA and TIMSS studies have become key drivers of educational reform. The research evidence[21,22] indicates that in many OECD countries including the UK, there has been little or no measurable increase in standards of literacy and numeracy over several decades, in spite of recurring educational and policy reform. The same countries (Canada, Finland, Japan, Singapore, South Korea) repeatedly top the PISA league tables. A McKinsey report (2007)[21] has found a positive association between high-performing systems and the level of teacher qualification. Another study (Goe, 2007)[23] indicates that a teacher's academic calibre impacts on pupil achievement.

The principal determining factor for the success of high-performing education systems is neither class sizes nor teacher salaries but rather the quality of the teachers. The best performing education systems attract the best teachers, recruited ***from amongst*** the best university graduates. Teaching is elevated to a high-status profession, requiring high grades and selective entry to graduate teacher training. However, a high class of degree is not a guarantee of aptitude for a career in teaching and rigorous selection criteria and processes should be applied to all applicants to ITE to ensure the best quality applicants are selected.

In the teaching of physics at GCSE and A-level, teacher qualifications on entering ITE are found to be the second most important explanatory variable influencing pupil performance after pupil ability[24]. Teachers are the most important factor in determining the quality of primary science and mathematics education[25]. Teaching specialisms in primary science and mathematics are not generally recorded across the UK[13,26], and data on the UK's teaching

workforce are not sufficiently detailed[13], so that the scale of the problem is uncertain. Nonetheless, primary teachers with a first degree and ITE training qualification in science and mathematics represent only 3% and 2% respectively of the total number of primary teachers in England[13]. These figures are likely to give a good measure of the scale and nature of the challenge confronting primary STEM teaching.

Recommendation 2.1
It is recommended that the Scottish Government ensures that a clear and detailed record of the qualifications and capacities of the STEM teacher workforce in Scotland, particularly in the primary sector, is developed and maintained to inform the reform of initial teacher education and to address the weaknesses in STEM teaching in primary education measured in the 2008 TIMSS report.

This recommendation is also consonant with Recommendation 6 of the Royal Society Report[13], and will assist with the development and delivery of CPD programmes.

Recruitment and retention of STEM teachers

While, in general, Scotland has not experienced problems met in England in recruitment into its one-year PGDE and four-year BEd degrees, across the UK there have been difficulties in attracting science and mathematics graduates into the teaching profession[12], which has been seen as a less desirable or less financially rewarding career path than business, industry and other employment sectors. Potential shortages in the number and quality of teachers in some STEM areas compared to other subject areas should be borne in mind in any wider strategies for raising the qualifications required for entry into the teaching profession in Scotland.

Universities have an important contribution to make in encouraging high-quality STEM graduates and those with high-level aptitudes and skills for teaching into careers in teaching. Science and engineering graduates are now expected as part of their training to be increasingly aware of the importance of communicating and explaining their subject knowledge and understanding and its wider relevance to society. Many students receive formal training and practice in science engagement work at some level, enabling young graduates to recognise and develop their own capacities for communicating their subjects in a range of contexts including school education. Programmes such as STEM Ambassadors greatly enhance both the awareness and capability of young science graduates for careers in teaching.

The Teach First Programme – a successful recruitment model?

Based on the successful *Teach for America* programme[27], the *Teach First* programme[28] in England selects exceptional graduates and aims to transform them into effective and inspirational teachers, focusing its efforts into areas of

educational disadvantage and social deprivation. Selected graduates are expected to commit a minimum of two years to teaching. An early OFSTED report on the programme commented "*a commitment to excellence is a significant feature of the programme, with over half of trainees demonstrating outstanding teaching capabilities and 83% being good or better*"[29]. In 2011, the programme accepted only 15% of applicants, compared to 39% of applicants for university-based teacher training in England in 2010[30]. About half of entrants to the programme now have postgraduate work experience prior to entry. Importantly, 65% of those who enrolled for the Teach First programme in 2003, its launch year, are still working in schools or other areas of education, whereas the Royal Society concluded that about half of mathematics and science teachers drop out of the profession within 5 years of starting their more traditional teacher training[30]. ***The implication of this comparison is that retention of teachers in the profession may also be directly related to the calibre of recruits to the profession***. The *Teach First* programme provides strong evidence and support for teacher quality as a major factor in transformational improvement and improved teacher retention, and may provide a route to improving the recruitment of talented and high-quality science graduates into the teaching profession in Scotland. Currently, graduates from Scottish universities are regularly recruited into the Teach First programme in England, demonstrating the interest that the programme already attracts in Scotland.

Recommendation 2.2
The Scottish Government should adapt a programme to Scotland with similar aims and aspirations to the Teach First Programme.

Initial teacher education: tackling the primary STEM challenge

The relatively poor performance of Scottish primary science and mathematics education in international performance surveys has been highlighted above. The 2003 SSAC report recognised that the lack of science specialists and the absence of science teaching facilities and technical support in primary schools were major obstacles to sustaining the interest of young people in science across the transition into secondary education, and to improving the uptake of science and the standard of science educational attainment in secondary education. This problem may in principle be addressed by strategies and interventions at several different points in the professional development of teachers, such as:

- the selection and selection criteria for initial teacher education (ITE)
- during ITE (PGDE and BEd)
- induction and post-induction STEM professional development
- introduction of secondary science specialists into primary schools.

The Donaldson Report[12] does not address the problems of primary ITE training and development with respect to any one subject area (other than literacy and numeracy). However, Donaldson observes that "*it is neither*

necessary nor feasible for a teacher to be a subject expert in all areas of the primary curriculum, but ….all teachers [have to] have sufficient understanding to stretch and progress children's learning and to diagnose and remedy any conceptual or other learning problems which may undermine their progress. Weakness in the performance of children, particularly in primary education, can stem from low levels of confidence amongst teachers about their own knowledge of what they are teaching. This…is particularly the case in literacy, mathematics, science and modern foreign languages." Thus the problem is not peculiar to science, even if research has shown its effects to be particularly acute in science.

In their seminal work from 1995 *Confidence and Understanding in Teaching Science and Technology in Primary Schools*, Harlen, Holroyd and Byrne[31] reported *"this research shows that in Scotland, primary teachers' confidence about teaching science and technology is less than for almost all other curriculum aspects'' and ''we have concluded that the proportion of primary teachers who do not themselves understand the concepts they have to teach must be seen as a problem''*. Little in the literature would suggest this situation has changed for the better in the subsequent 16 years. In 1997 Harlen and Holroyd[32] reported that teachers lacking confidence tended to rely on 'safe'' teaching methods such as work books, and underplaying questioning and discussion.

A recurrent finding of the Scottish Survey of Achievement is that teachers lack confidence in science, and systematically over-estimate pupils' attainment. In the 2007 survey[33] whereas teachers thought that only about 30% of P7 pupils were operating at 5-14 level C or below in science, the tests administered as part of the survey found that about 94% were operating at this level. The same survey found that the proportion of primary teachers who said they were 'very confident' in teaching a science lesson to P7 was 28% for biology, 11% for chemistry and 10% for physics.

From analysis of PISA data McKinsey[20] reported a relationship between system performance and selective entry requirements for ITE for primary teachers. If more trainee teachers with good science and mathematics qualifications up to and including degree level are to be attracted into primary teaching, then ***it would make sense if the recruitment and entry criteria reflect this by setting targets for selection of a larger proportion of trainee teachers with good science and mathematics qualifications to at least Scottish Credit Qualification Level 6 (Higher) or beyond***, while also attracting more science and mathematics graduates, as part of a wider drive to increase teacher quality to a level that matches the best standards set by the most successful education systems internationally.

In Scotland and across the UK, primary teacher training has been generalist, even although entrants may have studied specific subjects, and little attention appears to have been paid to the numbers and proportions of primary subject specialists. While risks are perceived in putting specialist science and mathematics teachers into primary schools, for example by causing demotivation and 'deskilling' of generalist teachers, it is both reasonable and arguably essential for them to have ready access to specialist advice to meet

the requirements of the curriculum. That specialist advice is currently very limited.

Primary ITE and training in Scotland is delivered in the four-year BEd degree and the one-year PGDE degree, the planning numbers for 2010-11 being 800 and 400 respectively. Recognising that the location of Scottish ITE within universities has yet to realise the full potential of their belonging to the wider academic community with its wider learning possibilities, and that the BEd degree can over-emphasise technical skills at the expense of broader and more academically challenging areas, Donaldson[12] (Recommendation 11) recommends that "*the traditional BEd degree should be phased out and replaced with degrees that combine in-depth academic study in areas beyond education with professional studies and development''*. If implemented, this recommendation opens up the possibility of introducing a greater degree of subject specialism into and across a primary teaching profession founded on the model of practitioners as generalists. Although it is not entirely clear the extent to which this outcome was intended, it would offer particular advantages in creating a primary teacher cohort with a STEM specialism, supporting and extending the existing professional subject knowledge of primary teachers. While there are evident dangers in any shift from generalist to specialist teaching in primary education, we believe that an increase in subject specialism in science and mathematics is necessary and best addresses the weaknesses identified in international studies. This is consonant with the wider and overarching recommendation in the Royal Society 'State of the Nation' Report[13] ***that specialist teachers and their subjects need to come to the fore in the delivery of STEM education***:

This strategy provides a better solution than deploying secondary science teachers in primary schools insofar as teachers would have developed their more specialist STEM teaching skills within a primary training context, although there remains some urgency in ensuring that young learners and their teachers are confident and knowledgeable about STEM subjects. As a short-term expedient, secondary STEM teachers could meet regularly with teachers in associated primary schools to discuss and negotiate the depth of learning required at various stages.

In summary, we recognise that while all primary teachers are expected to teach the STEM subjects, the research evidence and the Royal Society '*State of the Nation'* Report highlight that primary STEM teaching is currently a major weakness.

Recommendation 2.3
It is recommended that Scottish Government, Universities and the General Teaching Council for Scotland (GTCS) support and implement the following Donaldson Report recommendations in relation to STEM Primary ITE:

Recommendation 12 (Donaldson Report)
Increased emphasis should be given to ensuring that primary students have sufficient understanding of the areas they are expected to teach.

Recommendation 13 (Donaldson Report)
Clear expectations about necessary prior learning for teacher education courses should be developed together with diagnostic assessments and online resources to allow students to reach that baseline in advance of formally embarking on a course. This mechanism could also be used to support existing teachers.

Recommendation 14 (Donaldson Report)
The professional component in programmes of initial teacher education should address more directly areas where teachers experience greatest difficulty and where we know that Scottish education needs to improve. That will require a radical reappraisal of present courses and of the guidelines provided by GTCS.

There would be much less scope for introducing similar specialist education and training in STEM into the one-year postgraduate PGDE, unless it is extended to 18 months or two years as described on p40 of the Donaldson Report. The PGDE currently attracts very small numbers of graduates with a science degree***. A key question for implementation of the Donaldson Report recommendations for PGDE primary teacher education in Scotland is whether and to what extent all graduate PGDE primary students should undertake subject learning across the piece (including science) with no subject specific extension other than literacy, numeracy, health and well-being (generalists), or rather undertake subject extension and enrichment to match their degree subjects (specialists) – or both.***

Young teachers responding to a poll (Donaldson chart 4.1; p35)[12] on the most useful aspects of their initial teacher education identified a greater focus on subject content and knowledge as the third most useful aspect after classroom management and pedagogy. Donaldson identifies core elements of teacher learning (Standard for Initial Teacher Education) for every student, and encourages diversity of practice and the possibility of greater specialism. University ITE is likely to introduce a diversity of practice in PGDE education and training. Balance is important. It would be counter-productive if primary teachers have no science within their ITE training yet are still expected to deliver the full range of CfE experience and outcomes. ***Selection and selection criteria for primary ITE students across Scotland are crucial to***

achieving a balance of provision, specialism and qualification sufficient to ensure a major improvement in knowledge of STEM topics through recruitment of high quality STEM graduates. At the same time, the universities have a role to play in encouraging more graduates across a range of science disciplines into primary science teaching.

It is important that primary ITE students have an understanding that the STEM subjects are more than just a body of knowledge to be learned. This is best achieved by exposure to the study and practise of STEM subjects including the application of the scientific method, developing practical skills, data analysis and problem solving. Currently, there is no requirement for students entering Primary Teaching ITE to have studied science or technology subjects beyond that covered in the general education phase of secondary education or mathematics beyond SCQF level 5.

We note the establishment of the National Partnership Group (NPD) and the progress it has made (http://scotland.gov.uk/About/NationalPartnershipGroup/documents) and recommend that it gives consideration in its work to the particular needs of primary schools and their teachers.

Recommendation 2.4
It is recommended that in order to move the profession to a stronger base the Scottish Government in partnership with universities establishes targets for increasing the number of trainee teachers admitted to Primary Teaching ITE with enhanced STEM qualifications by:

- **admitting an increased number of students with STEM qualifications up to and including degree level**
- **raising now the qualification requirement for Primary Teaching students to include a minimum of SCQF level five or above in a science and mathematics, increasing to SCQF level 6 or above in a science and mathematics within five years**
- **acquiring and making available on an annual basis data on the STEM qualifications of ITE applicants and recruits.**

Recommendation 2.5
It is recommended that the National Partnership Group considers the particular needs of primary schools and their teachers.

Primary-secondary transition

Transitions in our education system are about ensuring smooth learning progression and cultural adjustments, clearly understood choices leading to appropriate qualifications and well signposted pathways.

An increased intake of trainee primary teachers with much stronger science and mathematics qualifications up to and including degree level, with additional subject extension and enrichment during ITE, would introduce the

necessary level of STEM knowledge and specialism at primary level. This in itself would ensure a much smoother learning progression and cultural adjustment across the primary-secondary transition by ‘blurring’ the transition. The resulting increase in learner knowledge, understanding and teacher confidence would benefit not only subject knowledge and understanding but also science subject enjoyment and uptake through the critical period of subject choice at CfE levels 3 and 4.

There are a number of STEM projects in place that work successfully across the primary-secondary transition using a cluster approach, typically involving a secondary school and its associated primary schools. These clusters constitute an increasingly common example of professional (teacher) learning communities, which are discussed in detail in part 5.

PART 3 PROFESSIONAL DEVELOPMENT

Continuing professional development for teachers

Background

The Teachers Agreement (McCrone, 2001)[34] created an career-long commitment by teachers to maintain and develop professional expertise beyond their initial teacher education through a programme of continuing professional development (CPD). It made provision for an additional contractual 35 hours of CPD per year in addition to that undertaken during the contractual 35 hours/week working agreement, to consist of a balance of personal professional development, attendance at nationally accredited courses, school-based activities and other CPD activity, taking account of individual needs, together with school, local and national priorities.

There are many forms and models for CPD. Within a school, it may include, for example, professional reading and research, lesson observation and analysis, subject-based activities and attendance at in-service days (Donaldson, p63)[12]. Within a subject context, it may serve many purposes, supporting subject knowledge and understanding, context, content, skills, pedagogy and assessment. A survey of CPD accessed by teachers in 2009-10 reported by Donaldson (p65)[12] shows an emphasis on internal personal or group development and local authority (LA) courses, whereas current teacher priorities (Donaldson, p67)[12] emphasises improvement in (72%), sharing of (69%) and learning about (52%) new teaching practice, and increasing subject area knowledge (50%). This disparity may raise doubts about the perceived quality, relevance and balance of currently available professional development accessed by teachers. With respect to LA CPD provision, a significant number of newly qualified teachers reported that the quality of some CPD was low and did not always develop knowledge and understanding in subjects across the primary curriculum. Most teachers sought more subject-specific CPD.

Many practical challenges surround the development and delivery of relevant, high quality CPD that has a positive impact on learner achievement. These relate to the time allocated to and available for CPD; CPD provision and cost; additional professional development demands arising from implementation of CfE; engaging teachers who do not currently participate in externally provided CPD; the balance between different types of CPD; the role of LAs in CPD provision and co-ordination; the roles of local and national provision, the quality assurance of CPD and its impact on improving outcomes for learners; the role of ICT in professional development; the overall co-ordination of access to external CPD.

Research evidence

Teachers in successful education systems[21] are well supported in their ongoing professional development (e.g.100 hours/year in Singapore; one afternoon per week in Finland). Significant effects of professional development programmes for STEM teachers are seen when the programmes include a

focus on content knowledge together with follow-up pedagogical training for total times of *at least* 50 hours/year[35]. One-off CPD sessions and programmes of less than 14 hours in total have no measurable effect on student learning, but programmes of between 30 and 100 hours over 6-12 months have a measurable positive impact on student outcomes[36], indicating that 'sustained and intensive professional learning for teachers is related to student-achievement gains'. At the same time, 75% of Scottish teachers who responded to a survey for the Donaldson Review[12] reported that they were unable to undertake all their CPD and collegiate activities within the allotted time.

It is vital for STEM teacher development and stimulation that they are provided with, and enabled to access, opportunities for CPD throughout their careers. These opportunities should enable them to refresh and update their subject knowledge and pedagogical skills and thereby re-invigorate their teaching[25].

Four factors are particularly important for effective CPD[37]:

- Teachers have some control over their professional development, so that it meets their changing needs as their experience develops
- Effective CPD requires the support of senior leaders and managers
- Professional development must focus on learner needs and achievement
- CPD is enhanced by external support and by networking with other schools, education authorities and universities

The content of CPD that improves student achievement is characterised by common features[38]:

- CPD builds on, and from, what teachers already know
- Teachers are encouraged to support each other
- There is external input by sharing experience with other schools/teachers
- There is a shift in 'ownership' from providers to teachers

The research evidence above sets high standards and criteria for STEM teacher support and professional development that exceed those currently widely practised in Scotland.

We note that the McCormac Review[16] recommended that the 35-hour CPD allowance should "not be viewed as a time limit" (recommendation 8) and strongly endorse that, but on the basis of the evidence above we consider that it is essential for science teachers to be formally committed to 50 hours per annum.

Recommendation 3.1
It is recommended that the Scottish Government ensures effective implementation of CfE by providing funding to support an increase in the time provision for CPD to 50 hours per year for all STEM teachers, and that primary teachers devote at least 15 hours per year to STEM CPD.

Appropriate CPD models for science and engineering

The Donaldson Report[12], drawing on research by Kelly[39], finds that CPD is most effective when it is 'site-based', fits within an existing school structure and ethos, addresses the needs of different groups of teachers, is peer-led, collaborative and sustained, and notes that such forms of CPD offer a richer learning experience than is usually offered in short courses. While noting that conclusions about effectiveness cannot easily be detached from the quality and availability of CPD, the type of CPD offered also needs to reflect and respond to the 50% of secondary teachers (and perhaps an equal or greater proportion of primary teachers) who call for CPD to improve their subject area knowledge and understanding. In addition, without external stimulus, the horizons of teachers will be far too narrow and diminished.

The Donaldson Report[12] does not make specific recommendations about subject-specific CPD, other than to identify science, languages and areas of mathematics as having a particular and priority need for improvement in teaching, learning and attainment in relation to national and international benchmarking. However, we believe that subject-based CPD is critical to professional development for teachers in the STEM area. STEM subjects have quite distinctive additional professional development needs from those of many other subject areas because:

- Science and technology are in a constant state of rapid progress in their principles and practice, creating new applications and impacts in the real world.
- A graduate STEM teacher cohort may become quickly out of touch with these new contexts and applications, which are encouraged by CfE.
- Teachers in STEM subjects need to access opportunities to keep pace with recent major STEM developments – new 'big ideas', new thinking, new applications and new technologies.
- Science and technology are practical disciplines that demand active, hands-on teaching and learning to communicate both subject knowledge and its applications in the workplace.
- The CfE experiences and outcomes, and new STEM qualifications will reflect and contain much new content and rich new contexts for STEM learning and teaching.
- The introduction of CfE brings with it a new focus on interdisciplinary learning and teaching, which will have particular relevance to STEM subjects.

These factors set particular demands on the nature and amount of professional development for science teachers that is required if young learners are to be enabled to grasp the principles, opportunities and relevance of science and technology in their lives. The *balance* of internal (peer-supported) and external CPD undertaken by science teachers should reflect these demands.

STEM CPD can be seen as simply about updating knowledge. CPD about pedagogy and subject knowledge are often seen as separate forms of provision. We disagree. STEM CPD should concern knowledge and understanding, pedagogy, skills, contexts and assessment in an integrated way, as well as enhancing (where possible) understanding of STEM careers in the form of real world exemplification. CPD is found to be most effective when its context, content and skills are delivered together with pedagogical development and training. The need for high quality science CPD to support implementation of CfE is widely recognised by teachers, learned and professional societies, industry, universities, education authorities and a wide range of stakeholders and organisations. ***This CPD should address the needs of the different sectors, for example the need to improve the competence and confidence in basic numeracy, mathematics and science of many primary teachers, issues of topical science and interdisciplinarity for secondary teachers, and assessment literacy for all teachers.***

Recommendation 3.2
It is recommended that STEM CPD providers ensure CPD quality by embedding new relevant content and knowledge within appropriate contexts and with effective pedagogy and delivery, and engage teachers and pupils in active, hands-on investigative learning.

The CfE context

Previous educational initiatives and reforms such as Standard Grade and Higher Still were supported by centrally and co-operatively produced support packs for use by teachers. CfE endeavours to offer a more flexible, less prescriptive and more creative approach to teaching and learning by restoring teacher autonomy and creativity, and providing teachers with the freedom to deploy their professional skills more effectively. However, Scotland is rightly being very ambitious by international standards in developing CfE, and this ambition must be balanced against risk. ***Scotland does not yet have a teaching profession that is fully trained to deliver CfE, insofar as it has not been trained fully in curriculum design and assessment and also requires updating and extension in STEM subject knowledge and contexts. Therefore, the freedom and autonomy that is inherent in CfE must be supported in the long term by CPD that meets a wide spectrum of pedagogical and subject needs.*** The CfE outcomes and experiences and new science qualifications will contain much new content and new contexts;

with these will come increasing and ongoing demands for subject support if CfE is to be creatively and successfully implemented.

Teachers are concerned about how they will access the new curriculum, who will take responsibility in helping them interpret what is expected, and where they will find the time to prepare new resources or modify existing resources. Teachers are also concerned about the pedagogical implications – the 'how' rather than simply the 'what'.

There is a balance to be struck between providing science teachers with sufficient resources to prevent them from having to 'reinvent the wheel' while allowing flexibility to adapt to local needs and building teacher capacity and skills. CfE has provided teachers with flexibility. This balance will change as teachers become more confident in interpreting and implementing CfE and in curriculum development.

CfE also provides increased autonomy for schools and teachers, within which both will have much greater ownership of the direction of teaching and learning. The implication of this is that ***schools and teachers will have an increasing influence on CPD strategy and development***. Increased decentralisation and teacher autonomy have to be balanced against a need for some level of common experience and understanding, and the resources available to support that need. If widely available, CPD has the capacity to provide that continuity, common experience and understanding without requiring central control of the curriculum that would previously have been expected.

Within the context of increased decentralisation and autonomy, there is a critical need to articulate the ways in which teachers can become empowered to influence and drive change in a system that has been historically strongly centralised. In this respect, the need for good, clear leadership and articulation of strategy at all levels to communicate this message becomes paramount if schools and teachers are to have more direct influence on CPD strategy and content, and to ensure some level of common experience for learners.

A wider evaluation is required by teachers and CPD providers about the merits and limitations of different forms of CPD (e.g. in-house, whole-school, hubs/cluster, transition, residential, teacher-pupil (classroom), twilight, teacher learning communities) in delivering positive impacts on learners and teachers, cost effectiveness, and the continuity and common experience and understanding, whilst retaining scope for diversity and innovation.

Web-based support

A lot of attention and resource has been focused on virtual support environments for teacher support and professional development, yet there is a widely articulated plea from teachers for more good quality face-to-face CPD

from across the teacher/provider spectrum for the practical reasons listed above. A teacher questionnaire (Donaldson, chart 5.4, p73[12]) identifies online provision as the least effective form of CPD, reflecting problems of quality, relevance and access.

More informal web-based resource-sharing mechanisms have suffered from issues including copyright, intellectual property rights and encouraging sufficient people to contribute. Whilst excellent in principle, many teachers feel that Glow suffers from having a user-unfriendly interface and poor internal structure that makes it difficult to find and share content. Glow is also not freely accessible to all involved in Scottish education. The cancellation of the Glow Futures procurement has been announced by the Scottish Government, and while Glow continues to play a part in Scottish education there are many cheaper ways of delivering online services to learners and teachers, linked to the rapidly falling price of educational hardware. ***Ultimately, it is the quality of teaching that determines what pupils learn, not the quality or availability of technology.***

A rebalancing of effort and resource should therefore be given high priority. New web-based methods may have a particularly powerful capacity to support the evaluation of other forms of teacher CPD and provide ongoing feedback and support, promoting self-supported study, and thus ensuring the continuing use and impact of the material and resources. They also enable teachers in remote areas to access CPD and peer support that would otherwise not be readily available.

Recommendation 3.3
It is recommended that virtual learning environments are recognised as a <u>support</u> – and not as a <u>substitute</u> – for interactive, hands-on CPD.

Hands-on STEM CPD

There is little doubt that residential CPD and teacher CPD followed by classroom engagement with teachers and pupils are both extremely effective. In recent years high quality, two-part residential science CPD courses, some of which also involve additional activities between the residential elements, have been offered by SSERC, working in partnership with other organisations, to around 540 teachers and technicians annually. This CPD has been very well received by participants and external evaluators[40]. Other high quality CPD has been delivered from a wide range of providers but is often limited by issues such as lack of funding, long-term sustainability, reliance on volunteers or the lack of effective co-ordination.

School-delivered STEM CPD offers several potential advantages. It reaches the many hard-working and hard-pressed teachers who seldom, if ever, go to external courses in their own time, but who respond positively to quality CPD in their place of work and will ultimately make a telling contribution to the

successful implementation of CfE. It provides the necessary external stimulus in introducing new ideas. Generic principles may be illustrated with subject-based or cross-disciplinary examples. It offers value for money insofar as it requires no cover cost for teacher time out of school, and no time or cost in travelling. Participating staff hear the same message, circumventing potential limitations of cascade models and enabling peer-support in its implementation. However, fewer teachers are reached in one CPD workshop.

Cascade models for delivery of external teacher CPD are widely criticised as being less effective than in-house and peer-led models. *The impact of one-off courses or events, however stimulating, tends to dissipate on return to the realities of the classroom and cascading of guidance in contexts … do not allow real and sustained engagement on tasks which lead to impact on learners* (Donaldson, p9[12]), because effective cascading depends on effective onward transmission of knowledge and understanding to local peers. Donaldson[12] asserts that the most powerful forms of development are local, collegiate, relevant and sustained but recognises that without some form of external stimulus, the horizons of groups of teachers may be too narrow. High quality STEM teachers are a key multiplier of good practice.

How can this circle be squared and the right balance achieved? How can the initial impacts of CPD be sustained, implemented and developed? The various different forms of CPD are not mutually exclusive; all may be used in their appropriate contexts and locations, providing a rich variety of support for teachers in collaboration with the essential national role of SSERC (see recommendation 5.4). ***We believe that high quality STEM professional development delivered within the context of locally or regionally-based support structures such as professional learning communities (PLCs), additional and complementary to that available nationally through SSERC, has the capacity to deliver the necessary balance of external stimulus and peer-support.*** Support structures for CPD delivery including PLCs will be considered below in Part 5.

CPD quality and evaluation

There are large inequalities in CPD provision and quality, geographically, across subject disciplines, and between primary and secondary sectors across Scotland. A large number of teachers do not participate in externally provided and externally delivered CPD. The quality of CPD experienced by teachers can be very variable, and many teachers are unconvinced of much of its value. CPD is only effective if it meets the needs of teachers **and** learners.

There is a lack of research evaluation about CPD provision, quality and impact on teachers and most importantly on learner achievement. CPD is usually evaluated (if at all) in terms of the quality of the provision (content, delivery and impact on teachers) rather than actual impact on the progress and achievement of learners (Donaldson, p70[12]). CPD providers will usually obtain participant evaluations of the effectiveness of their workshops in order both to guide their further development and improvement, and to address

weaknesses. These evaluations help to justify the support of funders. However, only 29% of teachers responding to a survey (Donaldson, p70[12]) said that they try to monitor the impact of CPD, and only 22% said that their schools did this. 49% of teachers reported that they monitored impact infrequently or never, and 52% reported that their schools did this infrequently or never (Donaldson, p70[12]). It is essential to evaluate and quality-assure CPD in order to ensure that it is aligned with the outcomes and values of CfE and meets the needs of learners. Teachers and schools are best placed to undertake such monitoring and evaluation in partnership with CPD providers.

Recommendations 3.4
It is recommended that teachers and schools, in partnership with CPD providers and local authorities, should plan and evaluate CPD, taking into account its impact on young people's longer term progress and achievements.
This is consonant with recommendations 34 and 37 in the Donaldson Report.

Recommendation 3.5
It is recommended that the following should be subject to ongoing evaluation and feedback by Education Scotland in partnership with local authorities:

- **The strengths, weaknesses, impacts and costs of various models.**
- **The quality and impact of externally provided CPD.**
- **The role and impact of CPD in improving and updating pedagogy, improving assessment literacy, developing subject knowledge, increasing teacher confidence and its effect on pupil learning environment and experience.**
- **How teachers themselves best respond to professional development (what works best for them, how they can best be supported, how they can contribute to the development of their colleagues).**
- **How teachers can influence and engage with CPD development and strategy.**

One existing route whereby teachers throughout the UK are required to maintain a significant CPD commitment with some requirement to evaluate its impact on their work is through Chartered status. This is currently available for science, mathematics and geography teachers through schemes operated by the appropriate professional bodies such as the Association of Science Education, the Association of Teachers of Mathematics and the Royal Geographical Society. Currently, Chartered status has a low uptake within the Scottish teacher workforce as there is little incentive or direct benefit to gaining Chartered status. Nonetheless, 39% of teachers responding to a survey for the Donaldson review said they would undertake more CPD if it was accredited. Accreditation through whatever route (e.g. universities, GTCS, professional associations, Quality Awards) would help to ensure CPD standards and quality. In 2000, the McCrone Report[34] called for teacher CPD to be

accredited. The Donaldson Report[12] recommendation 44 recommends that a greater range of CPD undertaken by teachers should be formally accredited.

Recommendation 3.6
It is recommended that a greater range of CPD undertaken by teachers should be formally accredited.

Co-ordination of CPD

An over-riding impression of science CPD provision in Scotland that was widely recognised and discussed at the SEEAG Conference and at many meetings with stakeholder is one of lack of coherence and co-ordination in many areas, with resulting inefficiencies, duplication of effort and waste of scarce resources and goodwill. This is the complex landscape of activity and support in science education and engagement that is perceived by a wide range of stakeholders, particularly by teachers and providers. A clear strategy for development and delivery of CPD is essential if stakeholders are to make sense of this complex landscape. For a small country such as Scotland whose strength should be in co-ordination and working partnerships at local, regional and national level, this complexity is unnecessary and unacceptable.

The first step in co-ordinating STEM CPD nationally is to map ***current CPD provision and other forms of professional support, including contributions from industry, as a starting point to ensuring a more coherent, relevant and appropriate CPD provision and quality across all areas of science that provides common experience and understanding***.

Local authorities and university education faculties now have fewer staff available for co-ordination, development and delivery of subject-based CPD than for previous education reforms. In most local authorities in Scotland there is no longer an Adviser specifically for the sciences or for technology, but there may be a Quality Improvement Officer (QIO) with some responsibility for the sciences and/or technology. Much local authority and school-based CPD, whilst large in scale, can often be generic rather than subject-specific, addressing learning and teaching approaches, assessment strategies and quality assurance, and often fails to meet the needs of subject teachers. However, some authorities also sustain subject networks for teachers that increasingly include clusters comprising secondary schools and their associated primary schools working in partnership to develop coherent approaches to transition over the P6 to S2 stage range. In addition, SSERC offers a range of high quality ‘hands on’ practical CPD in partnership with local authorities and other bodies. Furthermore, STEM specialists in mainstream science and engineering departments in universities play an increasing role in supporting, developing and delivering CPD, encouraged by the increased recognition and funding given by research councils (through research grants) and universities to STEM education and engagement.

There is much good, innovative professional development going on that is by nature opportunistic, and dependent on enthusiasm, creativity and small

amounts of funding. This is to be encouraged, but needs to be recognised, co-ordinated, mapped and sustained to clarify the landscape. This is more likely to happen where for example professional societies, educators and industry are able to provide funding and expertise, especially where they work together. By contrast there are many areas of STEM where support is particularly needed to develop and update teacher knowledge, skills and confidence, but where support is inadequate or lacking. This is more likely to be the case in interdisciplinary areas where knowledge is commonly developing rapidly. ***Interdisciplinary science teaching and its links to other curriculum areas will require particular support to ensure changes in classroom culture and practice and to provide the additional subject knowledge and skills necessary to build the bridges between the traditional STEM subjects and other curriculum areas. University science and engineering departments together with industry may be able to provide effective support to achieve this goal*.**

With the reduction in local authority capacity and the development of a more autonomous system, there are opportunities for teachers to create or further develop their own support and co-ordination networks. ***The opportunity for network building is a key strength and capacity of hands-on face-to-face CPD.*** Effective network-building across groups of schools may be extended by local or regional alliances involving schools, colleges, Initial Teacher Education faculties, universities, professional bodies and education authorities. This is one of several capacities that may be built or formalised to good effect around existing links and programmes (support structures are discussed in detail in Part 5).

Scottish Education has no single representative body responsible for co-ordination, provision, quality, evaluation and funding of CPD. Teachers require easily accessible, user-friendly ways of being made aware of available, relevant and quality-assured CPD, and of ways of sharing resources. *STEM-Central*[41] and *CPDFind*[42] are welcome developments providing additional information and resources for teachers; however, STEM-Central is currently very engineering focused. The following additional recommendations about CPD arising from the work of the Scottish Science Advisory Council (SSAC) reported to SEEAG[17] resonate well with the work and conclusions of SEEAG:

Recommendation 3.7
It is recommended that Education Scotland continues to expand the focus of STEM-Central and for STEM-Central to become the entry portal for teachers to Education Scotland STEM materials.

This is in agreement with the SSAC Report Recommendation 7[17] (see also recommendation 6.1 of this report).

SSAC (recommendation 3)[17] consider that CPDFind should be developed further to include the full range of science-related CPD opportunities available (including those available via industry) and more actively promoted to teachers as the one-stop shop to find CPD. There is currently a function to 'endorse' certain courses and consideration could

be given to expanding this function to provide 'quality marking' for others considering undertaking the CPD.

Recommendation 3.8
It is recommended that Education Scotland should develop CPDFind to make it more user friendly for both CPD providers and for teachers. It should be easy to post and retrieve information about CPD events.

The role of industry

Industry plays an important role in supporting the professional development of teachers in STEM subjects, committing funding, ideas and materials. Industry is rightly concerned about the longer-term supply of skilled and well qualified graduates to meet its recruitment needs (see part 7). The range and variety of ways that industry engages with schools in relation to subject breadth, level, geographical coverage and methods of delivery further contributes to an apparently complex, crowded and uncoordinated landscape for teachers and schools. Some support and materials are delivered directly into the classroom, while some industries work in partnership with educators and schools to support delivery of CPD to teachers or work in classrooms. This lack of co-ordination has been highlighted above in the context of STEM CPD provision. There is no readily accessible central recording of the breadth of existing industry support activity and no evaluation of what constitutes good practice in school/industry/academia liaison and support.

SSAC consider that there should be a greater role for industry and academia in developing and contributing to science-specific CPD for science teachers. It is as vital to industry as to STEM education to ensure that the resources, goodwill and expertise of industry are used to maximum effect in supporting the implementation of CfE.

Recommendation 3.9
It is recommended that industry, universities and colleges work collaboratively with CPD providers and other partners to ensure the evaluated quality, relevance, appropriateness and longer term impact on learners of the support they provide. Partnership working between industry and CPD providers should be strongly encouraged rather than directly with schools.

The SSAC consider that it would be valuable to capture and map the breadth of existing schools engagement with industry, colleges, universities and other STEM providers now and on an ongoing basis.

SSAC co-ordinators

STEM CPD provision in Scotland requires some level of overall direction and co-ordination within the new decentralised system that is evolving through current educational reform, at least to the extent of establishing strategic

priorities, ensuring quality and breadth of provision, and delivering some level of common and widely available experience and understanding.

To achieve these aims, the SSAC has worked with the Deans of Science and Engineering in Scotland, Scottish Government, SSERC, STEM-Ed Scotland, CBI Scotland and SEMTA to address this co-ordination challenge. ***They strongly recommend the creation of Industry/Academia Schools Liaison Co-ordinator for Sciences posts***, whose role they propose should be:

- To act as central co-ordinators for science-related schools activities, including CPD for science teachers and schools science engagement activity, which provide support for science teachers and schools as they implement new science courses under the CfE.

  To act as a central liaison to facilitate good practice engagement between schools, universities and industry to widen pupil experience and teaching in support of the new CfE.

Funding is being made available to implement this plan.

Whilst welcoming this initiative in principle, SEEAG has some comments and constructive proposals regarding the location (hosting), duration, tasks and scope of the co-ordinator post(s) if the required impact is to be achieved:

The specified range of tasks involves mapping, evaluating and co-ordinating current activities, developing and disseminating a range of exemplar materials using a variety of resources for use by teachers, creating interdisciplinary linkages across the life, physical and engineering sciences. The varied practical experience of SEEAG members leads the group to consider this range of tasks to be over-ambitious relative to the funded time available, and some prioritisation is likely to be necessary. For instance, while exemplification is an important deliverable, it is in itself very time consuming and requires particular subject expertise. The tasks of the co-ordinator should be carefully prioritised on realistically attainable goals.

To function effectively, the co-ordinators need to develop a strategic overview of a wide range of CPD and science engagement activities and organisations across Scotland, to be recognised and included yet remain independent. Whilst the
co-ordinators might be based in a key stakeholder organisation engaged in CPD development and delivery in order to function effectively, the location should be chosen with particular care to ensure the capacity to operate independently of any one organisation and engage widely.

Unless the appointee(s) have broad and deep knowledge of the complex CPD and science engagement landscape, they will take a period of months to become sufficiently familiar with this complex landscape to make an impact. Yet this landscape is constantly evolving and is poorly mapped. The work will require ongoing and long-term engagement.

The co-ordinators should not duplicate but rather empower and enhance the work of existing providers and organisations also working to achieve better co-ordination of their STEM support work. The establishment of effective working partnerships will itself help to achieve shared goals more effectively.

In order to maximise impact and ensure independence and impartiality, it would make sense for the co-ordinators to work and liaise with a support group of providers and stakeholders, with broad representation from industry, higher education and a range of support organisation across CPD and schools engagement, especially including SSERC, local authorities, relevant professional associations, and CPD providers.

Cost of CPD

The cost of CPD is a major issue. School CPD budgets are very limited and teacher attendance at externally delivered CPD is often low. Universities and science centres have suitable venues but without external funding they cannot deliver CPD that schools or individual teachers can easily afford. Professional bodies have co-ordinated appropriate low-cost subject-specific CPD but this has relied on these bodies obtaining venues for little or no cost (which is becoming more difficult) and on the time and effort of volunteers.

Not all subjects are supported by well-resourced professional societies. CPD in cross-curricular and interdisciplinary areas of science encouraged in CfE tends to be less well supported and developed than that in the basic sciences where the resources of large professional associations and industry may be brought to bear. CPD providers should be encouraged to co-operate to find ways to deliver effective subject and cross-curricular CPD at a cost affordable by schools and teachers.

Financial and material support from Government, local authorities and non-governmental sources such as industry, universities and learned societies for development and delivery should be better co-ordinated to ensure quality, transparency and cost effectiveness. It should be established on a long term basis so that teachers and schools can confidently engage in a reliable and sustained manner.

For the effective implementation of CfE and future educational developments a significant upscaling of the quantity of the best STEM CPD is required in Scotland. This will require additional resource and co-ordinated CPD delivery through SSERC and other providers to deliver on the scale required. Without such investment Scotland's STEM education will certainly not improve and may well deteriorate.

PART 4 THE NEW CURRICULUM: ADDITIONAL CHALLENGES

In the rapidly evolving landscape of CfE implementation and the development of new qualifications, a number of additional challenges and opportunities are emerging.

Interdisciplinary learning and teaching in Curriculum for Excellence

A widely-welcomed feature of the aims and values of Curriculum for Excellence, particularly in the context of science, engineering and technology, is the intention to develop cross-cutting interdisciplinary themes drawing together outcomes from one STEM area with another, with attention being given to the applications of science and real-world relevance. This has provided rich opportunities for active learning in open-ended investigations leading to critical thinking, discussion and debate. Interdisciplinary science learning fosters an awareness of the relevance of science to the real world and contemporary issues that is fundamental to the CfE capacity of responsible citizens.

Science is by nature 'interdisciplinary', with an overlapping core of knowledge and skills for each science area. While there is great value in the different views that emerge from the study of particular disciplines, a level of common understanding is an important part of a holistic or 'systems' approach to real-world problem solving that is fundamental to CfE[43]. 'Pure' science (including mathematics) provides a foundation of knowledge and understanding to the more applied science disciplines, but these latter also have their own core principles and paradigms that should be articulated coherently. ***Interdisciplinary working requires that all science subjects should continue to be founded on deep and coherent pillars of knowledge and understanding. Interdisciplinary understanding will lack rigour and utility if it is not part of a structure in which the disciplines are pillars with interdisciplinary work as lintels.*** Without the pillars the lintels will fall. In STEM subjects, this is one of the grand challenges of CfE.

To address this challenge, SEEAG asked the Deans of Science and Engineering to organise a workshop in February 2011 to discuss the ways and means of encouraging, promoting and delivering interdisciplinary and cross-curricular STEM teaching, learning and assessment within Curriculum for Excellence and the new National Qualifications. Some key issues, outcomes and recommendations arising from these responses are summarised here and were incorporated into the SEEAG report on ***Excellence in Science Education*** in its capacity as the Government's ***Science Excellence Group***. The report arising from the meeting is available at: http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/DeansofScienceInterdisciplinaryLearning. Practical steps were identified to support and develop interdisciplinary teaching and learning.

Working across the disciplines

Major scientific advances and insights at the research frontiers of science occur at interfaces between science disciplines, where progress depends on making interdisciplinary connections and gaining new interdisciplinary insights. They depend upon teamwork and cross-disciplinary collaborations. A powerful approach is to bring together a group of people from different disciplines to work towards a common aim. This approach to problem-solving is particularly beneficial in industry and increasingly in higher education, and should be rehearsed in a school environment to prepare young people for situations they will meet beyond school. Universities and employers increasingly seek students with interdisciplinary awareness as well as the substantive STEM subject knowledge on which it is founded. Both are essential.

STEM education should reflect these contemporary developments, engaging both pupils and teachers. Interdisciplinary working offers opportunities for developing teamwork and problem-solving skills, essential features of CfE. The real world provides excellent contexts for teaching STEM subjects that arouse the curiosity of young learners so that they will want to study STEM not just for its own sake but because of its relevance. If young people are interested in a problem or issue, they will become interested in the underlying science.

Practical promotion of interdisciplinary and cross-curricular learning

Subject specialist teachers often venture reluctantly outside the comfort of their disciplines. CPD is required that encourages teachers to communicate and collaborate on teaching across discipline and curriculum boundaries. This will require a major culture change within the teaching profession.

Exemplification of interdisciplinary topics should build on work such as the Connecting It Up project[44] and include good teaching materials and associated equipment to promote practical skills development and associated CPD on its implementation, with national coverage and access for all appropriate STEM teaching staff.

Interdisciplinary science teaching and its cross-curricular links to other curricular areas will require particular support to ensure changes in classroom culture and practice and to provide the additional subject knowledge and skills necessary to build the bridges between the traditional STEM subjects and other subject areas.

Exemplification and associated CPD are needed to encourage changes of practice in schools.

Recommendation 4.1
It is recommended that SEEAG and the Deans of Science and Engineering Group working with STEM-Ed Scotland and teachers from all STEM subjects lead and organize a project to exemplify good interdisciplinary and cross-curricular teaching and learning, emphasising its foundation on sound subject knowledge, and to make these examples and associated CPD widely available to teachers.

SQA science qualifications

Until recently, insufficient attention has been paid by SQA to the exploration and development of explicit interdisciplinary and cross-curricular links between the sciences consistent with the broadening of contexts for science learning and teaching. We welcome SQA's establishment of cross-disciplinary subject working groups to develop these links. However, such links (Figure 1) are only the first step in a wider process. Such links need to be identified and developed much more broadly rather than simply linearly between the science disciplines (in other words ***inter****disciplinary* rather than ***cross****-disciplinary*) in order to ensure that the broad real-world contexts are evident that enable learners to recognise the practical relevance and connectivity and wider relationships of the STEM disciplines.

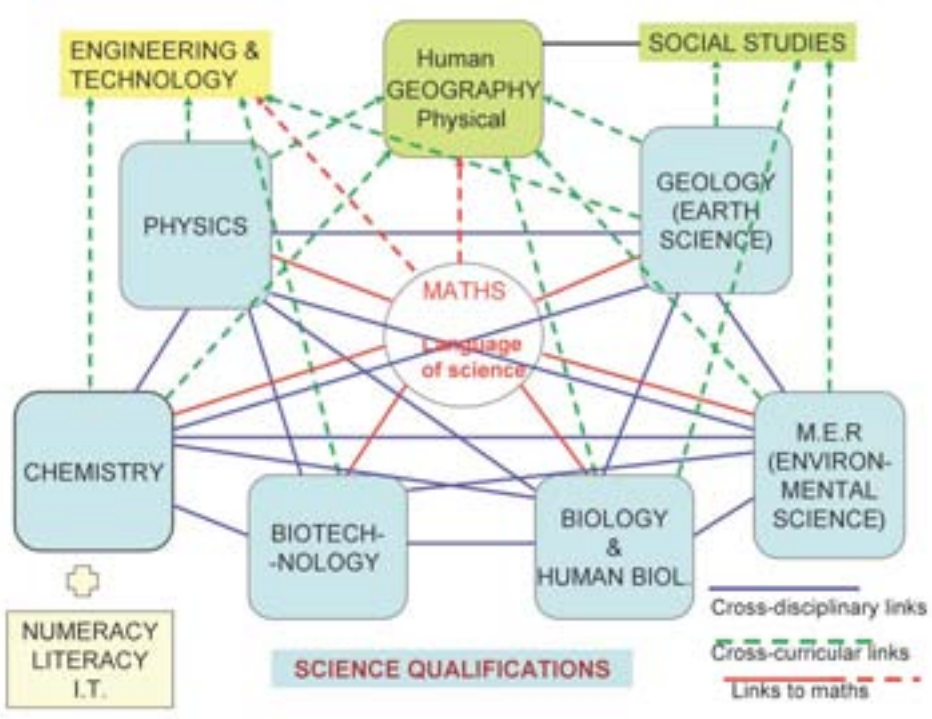

Figure 1

An obstacle to interdisciplinary and cross-curricular science teaching and learning has been a either a lack of subject knowledge beyond their own subjects or a lack of pedagogical experience that results in discipline-based science teachers, who are dominantly physicists, chemists and biologists, experiencing a lack of confidence in teaching beyond their own subjects. ***The***

challenge should be addressed through enhanced professional development for teachers and a new culture of teachers working together to explore new interdisciplinary areas.

Recommendation 4.2
It is recommended to universities that more graduates in, for example, engineering, electronics, Earth and environmental science disciplines should be encouraged and recruited into teaching in order to broaden and enrich the discipline knowledge base of the profession and to contribute to developing and enhancing interdisciplinary approaches to science learning and teaching.

The recent introduction of the Science Baccalaureate provides a new opportunity for S6 pupils taking Advanced Highers to explore science within the context of an industry or academic setting. An interdisciplinary project on real life science applications is a key feature of this new qualification, awarded since 2010.

Recommendation 4.3
It is recommended that Scottish universities give much greater recognition to the Advanced Higher and Science Baccalaureate qualifications in order to promote a higher level of uptake across Scottish schools and colleges, and to encourage more flexible pathways to college and university entry.

Interdisciplinary science teaching and its cross-curricular links to other areas of the curriculum will require particular support and professional development to ensure changes in classroom culture and practice and to provide the additional subject knowledge and skills necessary to build the bridges between the traditional STEM subjects and other curriculum areas.

The ways and means of ensuring the delivery of interdisciplinary and cross-curricular STEM at various levels require careful consideration and implementation. The cognitive and transferable skills developed by deep learning together with an understanding of interdisciplinary STEM subjects and topics are particularly valued by employers. These will only be achieved if sufficient curriculum time is devoted to allow deep learning of both the key pillars of knowledge and skills of science as well as the awareness of the interdisciplinary nature of much of modern science and technology.

Recommendation 4.4
It is recommended that Education Scotland provides national guidance to schools to ensure that schools devote sufficient curriculum time to the study of STEM subjects to allow pupils to develop a deep learning of the pillars of knowledge and skills of STEM as well as an understanding of the practical and interdisciplinary nature of STEM.

Subject choice

One of the principles of curriculum design for the Curriculum for Excellence is that of personalisation and choice:

''The curriculum should respond to individual needs and support particular aptitudes and talents. It should give each child and young person increasing opportunities for exercising responsible personal choice as they move through their school career. Once they have achieved suitable levels of attainment across a wide range of areas of learning, the choice should become as open as possible. There should be safeguards to ensure that choices are soundly based and lead to successful outcomes.''

In interdisciplinary and cross-curricular science, units and courses that broaden understanding of the application of science have struggled to find space in the curriculum, with teachers and/or curriculum managers unwilling to stray far from familiar basic science[45,46]. Well-designed applied science qualifications such as Biotechnology, Electronics, Geology ('Earth science') and Managing Environmental Resources ('Environmental science') have struggled to increase uptake but are considered to be of wide interest to young people if the courses were more widely available; in other words these are essentially low access – not low uptake – subjects. Only Human Biology and Psychology have been successful at Higher in attracting an increased uptake, mainly because of their vocational link with medicine and allied professions and their perceived relevance to the human condition.

The development by SQA of new suites of courses in Environmental Science, Engineering Science, Computing and Information Science is welcomed. However, at qualifications level, the six science qualifications offered to Higher level (Figure 1) will shortly be reduced to four following the removal of Biotechnology and Geology from the science qualifications portfolio. The loss of subjects with central relevance to the economy of Scotland in the 21st century reflects a lack of the vision and support necessary to ensure their continuing and wider accessibility to learners across Scotland, particularly through the failure to attract and train teachers from a wider range of science disciplines in sufficient numbers over the past two decades. The problem is also a reflection of the narrowness of the science base in Scottish primary and secondary education that is indicated by research evidence, but has neither been recognised nor addressed.

The 2007 TIMSS report[6] recognised that Scottish STEM education has remained rooted in the three 'big sciences' at the expense of other sciences. At eighth grade (S2) level, Scotland's pupils spend a very much lower amount of time on 'earth science' (6%) and 'other' sciences (1%) than the OECD average, but higher amounts of time on the traditional sciences (chemistry, physics and biology; 30-32% each) than the average. ***Scotland ranks 39th of 41 OECD countries in the percentage of all 'other science' taught, i.e. science that is not classified as physics, chemistry or biology (7%). This is less than one-third of the OECD average (22%).***

Only the three traditional basic sciences are offered at Advanced Higher Grade. While a strong grounding in the basic sciences in the Senior Phase is of great value, the school world is an unreal representation of how knowledge is structured and used. There are more than just three science disciplines in the real world, and indeed much (perhaps most) major progress in STEM takes place at and across discipline boundaries or in interdisciplinary areas. Science disciplines are no longer confined within well-defined walls. ***The narrowness of the science base in Scottish secondary education is a poor foundation for the support and development of interdisciplinary science learning. In a small country rich in natural resources and dependent on the scientific and technological skills of its population, this very narrow STEM discipline base in its secondary education system and the resulting failure to engage with the increasing diversity of STEM subjects is ill-judged and ill-timed, and poorly serves a small country that aspires to be and to remain at the forefront of STEM research and STEM-based scientific and technological innovation.***

Rather than reducing science subject choice, SQA should work with universities and colleges to seek new ways of regenerating, sustaining and increasing choice, in order that young learners have a much better understanding of the options and pathways available to them in further and higher education and in the workplace. An alternative means of delivering this provision is to make additional relevant, economically important STEM subjects available at for example Higher level through web-supported distance learning, with provision being made available locally or regionally for practical aspects to be taught centrally at key (hub) schools, colleges or universities; the latter approach of central provision is already being adopted in some local areas for delivery of Advanced Higher courses. The above points are addressed further at Part 7 in considering more effective learning pathways through the transition from secondary to further and higher education.

The responsibility for subject choice and availability does not rest solely with SQA. Subjects introduced over recent decades such as Biotechnology, Electronics and Managing Environmental Resources, together with Geology, have not been made widely accessible by curriculum managers. A shortage of suitably trained teachers with relevant qualifications and subject knowledge, the failure to attract suitably qualified graduates from across the wider STEM disciplines into the profession, and a failure to provide additional CPD and qualifications for existing teachers of physics, chemistry and biology, have been contributory factors. The implementation of the Donaldson Report[12] is likely to require ITE students in Scottish universities undertaking in-depth academic study in areas beyond education. The extension of this principle to secondary PGDE training, and to new four-year degrees to replace the B Ed, provides another means of enabling and supporting access to currently low-access STEM subjects. The problem may be further addressed through CPD and additional teaching qualifications as part of a wider professional accreditation system.

Recommendation 4.5
It is recommended that SQA develop mechanisms for increasing the breadth of CfE STEM subject qualifications provision, and that Education Scotland and universities provide the necessary support for the redevelopment and delivery of these qualifications nationally.

The development of the senior phase in schools is intended to provide increased flexibility and a more individualised approach to learning for pupils, supported and enabled by new and updated qualifications. However, concerns have been widely expressed that under the new arrangements some pupils will have to make subject choices too early in their academic development, and also about the possible restriction of choice and loss of opportunity for scientifically-minded pupils to study two or three sciences at Higher or Advanced Higher. This decision will be up to individual schools and a 'postcode lottery' may prevail, which will be a particular disadvantage for the many children who, for reasons outside their control, have to move between secondary schools during their education. In its State of the Nation report *Preparing for the transfer from school and college science and mathematics education to UK STEM higher education*[47] the Royal Society highlights the relative success of the existing Scottish curriculum in allowing pupils to study STEM subjects and recommends that in moving to a Curriculum for Excellence equally successful options are provided.

Recommendation 4.6
SEEAG supports the SSAC Recommendation 9[17] that there should be close monitoring by Education Scotland of the curriculum models introduced across Scotland to ensure that a sufficient breadth of opportunity to study the full range of sciences is available to all pupils across Scotland.

Modularisation of teaching, learning and assessment

Throughout the formal stages of education, in the Senior Phase of secondary education, further and higher education, there has been a growing tendency in recent decades to package knowledge into modules that are taught, assessed and attract 'points' as disconnected packets of knowledge in which progression and inter-connection have been diluted or even lost (the 'education supermarket'). ***Modularisation of learning and teaching is inimical to strong interdisciplinary working.*** It is little wonder that ***students and graduates are rather poor at making connections between learning modules, both within and between disciplines (systems thinking)***, a point that is commonly made by employers and universities. The introduction of CfE introduces a greater focus on inter-disciplinary teaching of STEM subjects.

SQA qualifications in science are split into Units, and Units further split into Outcomes, and in many Courses separate assessment instruments are used for each separate Outcome. Such an atomistic structure of assessment tends to encourage an atomistic or modular approach to teaching and learning, and discourages making connections within and across disciplines ('systems thinking').

Assessment

SQA examinations in the sciences, compared to those from many other countries, are complex instruments of assessment which assess both the basic knowledge of a candidate but also more complex skills such as problem-solving of different forms, data handling and analysis, evaluation and the drawing of conclusions usually set in a real-world context. Such assessments benefit from being undertaken by candidates under controlled examination conditions and therefore provide a reliable and standardised assessment of the work of the candidate. However, over the last few decades there has been a gradual trend to more structures, short answer questions and a move away from more extended responses, at least until the introduction of more Open-ended Questions in courses such as the recently introduced Revised Higher Physics and Chemistry.

The assessment of scientific practical, research and investigative skills in Scotland has had a somewhat chequered history, apart from the CSYS and Advanced Higher Projects and Investigations which are often seen as the 'jewel in the crown' of Scottish school science education. Over the years various approaches to practical abilities assessment have been attempted including Practical Investigations and Practical Techniques at Standard Grade, the individual assessment of an experiment by SCOTVEC and Practical Activity Reports in many of the current NQ units. These are competence-based and also require candidates to understand theories behind practical techniques.

There are a number of pressures which have resulted in a reduction in the validity in much of the practical assessment of science in Scottish schools. These have included:

- a desire to ensure the assessments are reliable across centres
- concerns amongst the teaching profession that standards may not be applied equally across centres
- inflexible verification procedures
- the requirement of an assessment procedure that can be managed by teachers in classes of 20 pupils.

Aspects of investigative work obviously lend themselves to coursework assessment rather than assessment in an examination. However, the assessment of coursework across all subjects in Scotland, and in other countries, has suffered from problems such as bias where students from poorer socio-economic backgrounds have been at a significant disadvantage.

Recommendation 4.7
It is recommended that SQA ensure that assessment instruments build on the strengths of the current procedures and are more holistic in nature. Innovative methods should be employed for the assessment of practical, research and investigative skills. These could involve the use of pre-release resources, synoptic questions and open-ended questions, and should be designed to avoid the pitfalls of previous assessments, including undue bias due to the background of candidates.

Assessment of interdisciplinary learning

Interdisciplinary learning and teaching in senior phase STEM is a key challenge. At qualifications level, science knowledge and skills are assessed in a subject context, and this substantive knowledge is important. Interdisciplinary teaching opportunities are limited and secondary teachers value subject identity. In an assessment-driven system, we need to identify new ways of assessing interdisciplinary thinking and common skills sets, for example in project work and by setting problems and the application of knowledge in unfamiliar contexts. If a desired learning outcome is an interdisciplinary approach, then assessment should reflect that.

Recommendation 4.8
It is recommended that SQA develop exemplars of interdisciplinary questions, together with assessments that measure the different inputs from the different sciences.

Recommendation 4.9
It is recommended that SQA assessments should use a broader range of interdisciplinary contexts within which to locate examination questions, and explore innovative courses (perhaps units within courses) which deliberately blur traditional subject boundaries. These courses should include innovative assessment methods (synoptic questions, extended assignments and collaborative project work)[43].

Skills development

''Curriculum for Excellence is as much about improving skills and methodology as it is about updating subject knowledge.''

The case for higher order thinking skills (HOTS) development through science education

To meet the social and economic realities of the 21st century, young people will need to acquire more sophisticated high-level skills and ways of thinking. The promotion of skills is a central function of the new curriculum at all levels. The shift from a curriculum based primarily on knowledge and 'content' to one in which knowledge and higher order thinking skills are interwoven is a

substantial shift in emphasis. Such a shift will serve learners well through their lives, when much of the detailed subject knowledge they have learned is long superseded. Here we draw on key points from the *Higher Order Skills Excellence Group* Report[48] that are particularly relevant to STEM learning and teaching.

Development of thinking skills: research evidence

Research evidence indicates that the reasoning ability of British children has declined over the past 30 years[49,50,51]. If this is so, grade inflation may have masqueraded as genuine educational gains. One reason for this apparent decline may be the increasing importance attached to assessment that largely tests factual knowledge rather than skills and understanding, synthesis, analysis, evaluation and creativity. A shift from the acquisition of knowledge towards one with a stronger emphasis on skills therefore has implications for the process of assessment.

Recent research[52] has also demonstrated the effectiveness of including the teaching of thinking and problem solving skills within the curriculum on raising academic achievement. Children who spend time thinking about, and working on improving, their general thinking skills show consistent gains in reasoning powers and academic outcome measures such as Standardised Assessment Tests (SATs) and examination grades. The implementation of thinking programmes in schools is rare.

Examples of successful effective thinking skills programmes include *Cognitive Acceleration through Science Education* (CASE), *Activating Children's Thinking Skills* (ACTS), *Philosophy for Children, Guided Socratic Dialogue* and *Klauer's Inductive Reasoning*[48]*.* All have positive impacts on reasoning and mathematical skills. All have common elements. They encourage discussion, constructive argument, exploration and skilful questioning. The thinking skills classroom is characterised by high quality dialogue, metacognition (pupils thinking about their thinking) and cognitive challenge (stretching the minds of pupils). Learners take ownership of their learning and teachers mediate, encourage, challenge and support. In science, learning will typically be collaborative, problem-based, interdisciplinary and multi-context, and involve systems thinking, high level discussion, interactive questioning, peer reflection and challenge.

Many of these skills are fostered and strongly developed in STEM learning. Research[53] has demonstrated that skills of high value to non-STEM employers were found to be unique to STEM graduates, such as a logical approach to problem solving, enabling some STEM graduates to progress faster in their careers than non-STEM graduate colleagues. This link is discussed more fully in Part 7.

The Higher Order Skills Group[48] has constructed a modified Bloom's cognitive taxonomy of skills, which helps organise thinking about practical skills development in a scientific context. This cognitive taxonomy (Figure 2) may be linked directly to the process of cognitive enquiry, which is familiar to scientists

as the ‘scientific method’. Knowledge and understanding are pre-requisites to skills development, and within the taxonomy knowledge and skills become inseparable.

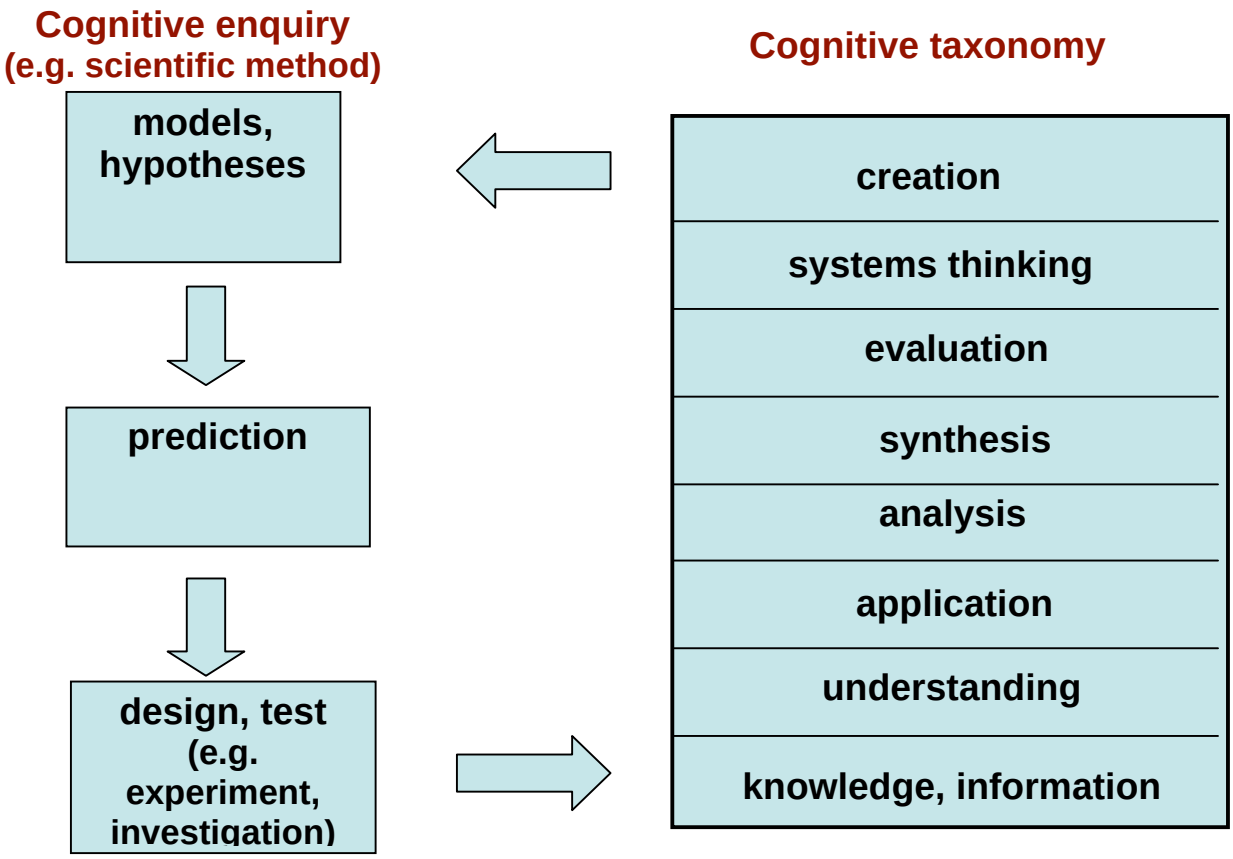

Figure 2

The shift from a curriculum based primarily on knowledge and ‘content’ to one in which knowledge and higher order thinking skills are interwoven should not be underestimated. This will be a particular challenge in science, requiring a major shift in teaching culture and styles of assessment. The above analysis indicates that such a shift may need to be supported by professional development around the teaching of critical thinking and problem-solving skills, and changes in classroom practice. Realistically, such changes will take many years to achieve and will be most readily achieved if there is a strong foundation of peer support.

Recommendation 4.10
It is recommended that Education Scotland initiates and supports a programme to implement the teaching of thinking and problem-solving skills within the STEM curriculum in order to raise academic achievement.

Development of practical skills – promoting and supporting practical work in schools

Science, engineering and technology have practical work at their core. If young people are to learn the investigative skills of science or the practical craft and problem solving skills of engineering and technology it is important that they are able to practise these practical skills in schools. This requires both specialist accommodation of laboratories and workshops and the equipment to allow quality practical activities to be undertaken on a regular and frequent basis. Whilst watching a good teacher demonstration has its place, hands-on doing in the classroom by all pupils is the best means for developing their skills and understanding.

Generally, Scottish secondary schools have satisfactory accommodation. HMIE reported in 2001[54] that science accommodation was good or very good in 65% of schools although they also reported that ‘‘*many laboratories presented a dull and depressing learning environment, ill-suited to the needs of new science and technology courses in the 21st century*.’’ Since then a significant number of schools have been rebuilt or refurbished which may have improved the quality of accommodation for many.

In the same report HMIE reported that *‘‘Even where there appeared to be sufficient scientific equipment, some of it was out-dated and some did not meet the needs of new units and courses, particularly those which involved developing technologies such as biotechnology and microelectronics. Most science departments were poorly supplied with modern equipment for information and communications technology.’’*

There has been concern about the supply and maintenance of up-to-date equipment in Scottish secondary school science departments for many years. The Royal Society[55] and SSERC[56] produced estimates of the cost of equipment required to adequately deliver the curriculum based on reasonable assumptions of both consumable use and the writing-off the cost of capital items over sensible life times. Using this information as a benchmark Farmer[57,58,59] collected funding data from 30% of Scottish secondary school physics departments between 2001 and 2003. With the aim of determining the total funding resource allocated to Scottish secondary school physics departments, this was based not only on physics and science department per capita allocations but also bids for additional funding such as for curriculum development and central supplied ICT resources. It was determined that Scottish secondary school physics departments received on average 16.5% of the funding SSERC recommended for replacing, maintaining and updating equipment. In 2003 physics departments spent over 50% of their budget on photocopying and other non-equipment costs. It is likely that in recent times, with the tightening of school budgets, the funding science departments are able spend on equipment will have come under even greater pressures. The very positive feedback received from teachers attending SSERC, Optoelectronics College and other CPD where modern equipment is supplied as part of the workshops illustrates the demand there is from teachers for quality, modern science equipment in Scottish schools.

Recommendation 4.11
It is recommended that SSERC build on its previous work and that of The Royal Society to research the cost of adequately delivering the STEM curriculum at all stages in Scottish schools. Budget recommendations should be based on reasonable assumptions for use of consumable materials by pupils and the writing off costs of equipment over sensible lifetimes. These figures should be widely circulated and regularly updated.

Recommendation 4.12
It is recommended that schools and their local authorities ensure pupils are provided with quality learning experiences where they can develop the skills of practical investigation and problem solving. This can only be done when there is sufficient equipment for hands-on pupil practical work in small groups or individually. Schools must be provided with adequate funds to provide and maintain sufficient equipment for effective hands-on experiences for all pupils based on the figures provided in SSERC's recommendations in 4.11 above.

Recommendation 4.13
It is recommended that Education Scotland in carrying out their inspection of schools should review and comment on the school's allocation of resources against SSERC's recommendations in 4.11 above.

STEM equipment is specialist in nature and good quality technician support is required in schools for effective delivery of practical STEM subjects. In 2002, based on survey information from across the UK, The Royal Society[60] came to the following conclusions regarding school science technicians:

- The number of technicians per science lesson was found to be lowest in comprehensive schools compared to other types of schools. In grammar and independent schools, technicians worked with fewer pupils while servicing comparable numbers of laboratories to colleagues in comprehensive schools. The number of technicians per science lesson was lower in Scotland, Wales and Northern Ireland than in England.

- Technicians in schools and colleges have a vital role to play in the provision of high quality science education and, if they are to play this role to the full, all technicians must be supported in their work and accorded the professional status they deserve. Clear job descriptions for all technicians, linked to a national career structure and pay scale, are required, as is substantial investment in technician continuing professional development.

- Science is a practical subject, and good quality 'hands-on' activities which involve students undertaking experimentation and investigative work add hugely to the experience of learning science. A well-trained, professional

technician support service is essential if students are to experience such work.

- Up to 4,000 additional science technicians need to be recruited into schools in England in order to provide adequate technical support to all school science departments. A precise figure for the number of science technicians currently working in schools is not available.

- The profession of science technician is not attracting young recruits; this is perhaps unsurprising considering technicians' pay and conditions. If young people do not see the profession as an attractive and viable career option it seems unlikely that it will be possible to recruit several thousand more science technicians into the school system.

- Without adequate numbers of science technicians in schools and colleges the learning experiences of students will be impaired, raising levels of achievement will be made much more difficult, and safety in school and college laboratories will be compromised.

Recommendation 4.14
It is recommended that local authorities and schools ensure that STEM departments and faculties have sufficient well trained, specialist technicians to ensure delivery of practical STEM work within CfE, and that in parallel with recommendation 2.1 the Scottish Government ensures that a clear and detailed record of the number, qualifications and capacities of the STEM technician force in Scotland is collected and maintained.

Numeracy and mathematics

Numeracy and mathematics are fundamental interdisciplinary skills that have attracted the attention of educational policy makers, prompted in particular by wide concerns about numeracy teaching in Scottish primary schools that followed publication of the TIMSS 2007 report[6]. This report highlighted the disparity between primary pupil confidence and teacher preparedness in numeracy on the one hand and pupil performance on the other. The solution lies in improving the professional capacities and qualifications of primary teachers, as discussed above and addressed extensively elsewhere.

Good creative numeracy teaching in primary schools critically underpins mathematics teaching and learning in secondary (and higher) education, and mathematics is the language of science. ***Primary-level numeracy is therefore of such fundamental importance to science education that it merits particular attention, through a numeracy action plan***. Numeracy need not take more space and time within the curriculum. What is needed is better rather than more numeracy teaching, coupled with the embedding of numeracy skills more widely into the curriculum in real-world contexts to ensure relevance, and to raise challenge, expectation and confidence amongst learners and teachers.

A national action plan on numeracy has been commissioned by the Scottish Government to report in February 2012, to be informed by the Scottish Survey of Literacy and Numeracy (SSLN). However, the SSLN will only offer an insight into numeracy levels at stages P4, P7 and S2 within the broad general education. The action plan will aim to strengthen numeracy levels within the CfE. Specific proposals to improve numeracy levels will be in place by June 2012 and Education Scotland will have a role in informing the proposals. ***This is very welcome as the critical importance of numeracy as a foundation to mathematics and science cannot be underestimated.***

Numeracy is an important part of mathematical capability, but mathematics is more than just becoming familiar and fluent with numbers[61]. Mathematical capability includes:

- Using and applying skills in the real world, including the appropriate use of information and communications technology.
- Being open to new ideas and alternatives, and appreciative of the importance of evidence, and critical reasoning.
- Being curious, imaginative and diligent.

These are capacities that apply equally to the other STEM subjects.

Universities and employers increasingly seek STEM students who are both numerate and mathematically literate. The *application* of mathematics is fundamental to the practice of science, and in this context it is an example of interdisciplinary practice and as such must be founded upon a pillar of deep understanding of applicable mathematics. The application of mathematics should include a basic understanding of statistics as a foundation for a deeper understanding of the nature of risk, and of uncertainty in scientific measurement and prediction.

Recommendation 4.15
It is recommended that the Scottish Government should implement a numeracy and mathematics action plan based on the findings of the national survey, that this implementation recognises the fundamental role of numeracy and mathematics plays as a foundation to science, and ensures that these are more widely used in an interdisciplinary way in the teaching of science, engineering and technology.

Computer Science

Widespread concern has been expressed about the way that computing is taught in schools. At the McTaggart Lecture (August 2010) the chairman of Google (Dr Eric Schmidt) expressed disappointment that the UK's ICT curriculum focuses on teaching how to use software but not how it is developed. The Royal Society is undertaking an investigation into the teaching of computing against a backdrop of plummeting levels of applications to study

computing at UK universities and concerns about the economic impact of this decline in the digital age, and its impact on the supply of specialist teachers necessary to equip young people with the skills and understanding they will need to prosper. Issues concern whether computing is a discipline in its own right, whether it is best taught in the classroom, and the distinction between computer science and ICT.

Scotland has not experienced the dramatic fall in numbers studying computing that England has experienced at GCSE and A-level, with over 4,000 Higher entries versus 4,000 A-level Computing entries in England. The SEEAG welcomes the new Computing and Information Science Course being developed by SQA to articulate with the CfE Experiences and Outcomes, which will include a Software Development and Design unit and required learning in current and emergent technologies. The Royal Society of Edinburgh and BCS Academy of Computing are preparing CfE exemplification materials for teaching of computer science with an introduction to computing science and computation; completed materials will be made available on the Education Scotland website.

Early years STEM

''Real science incorporates many things to which young children are particularly open - creative thinking and problem solving and experimentation and invention.''

The early years have been widely recognised to be highly influential in a child's subsequent educational development and outcomes[62]. Early years or 'emergent' science is an important foundation for all later development. There is a growing national and international interest in pre-school science education. An *Emergent Science Network* was formed in 2007 (now involving nearly 300 professionals internationally) to facilitate communication between people interested in emergent science, to develop an understanding of young children's scientific development, to support professionals working with young children and to evaluate the impact of emergent science research on pedagogical practice[62]. In exploring the world around them, ***children are intuitive scientists from the earliest age***, developing scientific (including basic numeracy) skills, attitudes, understanding and language in a holistic way. Development of young children's scientific skills is thought to depend on dialogical social interaction in play, in which peers and adults have an important role to play[62].

The term 'scientist in waiting' expresses the recognition that pre-school children are not engaging in authentic scientific activities but rather are learning how their everyday activities of exploration and discovery - measuring, predicting, questioning and explaining - all connect to scientific practices and attitudes in a socially based enquiry process[63]. Scientific practices, especially experimentation skills, were found to be stronger amongst those who experienced the *Pre-school Pathways to Science*

curriculum[63] than those who did not, and stronger among children after experiencing the *Pre-School Pathways to Science* curriculum than before[64].

The above research evidence stresses the exploration and enquiry processes of young learners as scientists in waiting; however, measurement and numeracy (the basis of mathematics) form an essential part of the development language of science. It is extremely important that children obtain a good grounding in mathematical thinking from a very early age to enhance the effective development of science learning at later stages in their education. Effort and resources invested in secondary school science may be wasted if similar effort and resources are not invested in early years and primary.

Recommendation 4.16
It is recommended that the Scottish Government and Education Scotland support and ensure the wider development of skills and expertise in the teaching of early years (emergent) science by identifying and building upon existing expertise in Scotland, and through teacher education and professional development.

PART 5 SUPPORT STRUCTURES FOR TEACHERS AND LEARNERS OF STEM SUBJECTS

Background

CfE offers a more flexible, less prescriptive and more creative approach to teaching and learning by restoring teacher autonomy and creativity, and providing teachers with the freedom to deploy their professional skills more effectively. It encourages teachers as subject specialists to teach beyond the confines of their specialist knowledge in order to point out the connections between the STEM disciplines and to highlight the real world relevance of STEM. This in turn generates an expectation that teachers will work with colleagues in other subjects, within and amongst schools. This cultural change within the profession requires the development of peer-led and collaborative support structures that will enable new knowledge understanding and skills to be acquired in a sustainable way. These support mechanisms should also support the development, delivery and implementation of high quality professional development. ***High quality STEM teachers within such support structures are the key multipliers of good practice.***

SEEAG has gathered evidence of a widespread perception amongst key stakeholders of a complex landscape of support activities for STEM teachers and learners and of STEM engagement in general. The development of stronger teacher support structures is a key element in communicating a clearer view of the range of available support and the structures within which such support can be readily accessed and delivered.

With the development of a more autonomous system, there are opportunities for teachers to create or further develop their own support and co-ordination networks. Effective network-building across groups of schools may be extended by local or regional alliances involving schools, colleges, universities (including both their mainstream science departments and ITE faculties), professional bodies and local authorities. Many such support structures and arrangements already exist, and others have been proposed in recent reports, so that there is an opportunity to highlight and extend models of good practice and to propose new or modified support mechanisms. These typically fall into two broad types - hubs and networks. The former imply some form of centralised support or distribution such as a school or other science-focused centre, and the latter imply a more distributed arrangement for support, for example clusters involving secondary schools and their associated primary schools and other subject-based teacher learning communities. Here we outline and review different types of support structures, drawing on both research evidence and relevant recommendations in the Donaldson Report[12].

Changing contexts

The adoption and implementation of CfE across all stages and subjects in Scotland takes place against a changing context and pattern of support for STEM teaching in Scottish schools. These changes include[45,46]:

- Loss of initial teacher education staff
- Loss of local authority subject advisers and subject networks
- Loss of subject Principal/Assistant Principal Teachers and move to faculty structures
- Loss of specialist subject staff in Education Scotland and SQA
- Donaldson Review of teacher education

In addition, the age structure of the STEM teaching cohort (half of STEM teachers are over 45 and a third over 50), their typically short career paths into teaching and the long subsequent teaching career can introduce an element of inertia into the profession. The scale of rapid and radical change associated with CfE implementation, the lack of vocational emphasis in the current qualifications, the need for greatly improved contextualisation of STEM teaching, the recruitment needs of STEM-related industries both at graduate and technical level all bring additional pressures and uncertainties into the profession and underline the particular need for putting in place robust and widely accessible support structures. Clear, co-ordinated, reliable and readily accessible external support structures will be essential for STEM teachers and schools to empower them to implement CfE, update their skills and subject knowledge, and extend their working to address wider contexts and interdisciplinary opportunities.

Here we examine several potentially competing models that are currently proposed, implemented or deployed, and examine models that might be best suited and/or adapted to support STEM teaching and learning in Scotland. These all involve partnership working with other teachers both in schools and between schools, and encompass external support, for example from universities, colleges, CPD providers and other organisations.

Local authorities (LAs)

Most CPD has previously been provided by LAs, including central training and supporting school or community based professional development. CPD is now increasingly devolved from LAs to schools, who are encouraged to work in networks, clusters and teacher learning communities. The provision of centrally-delivered CPD is decreasing. In some authorities the central programme for newly qualified teachers is generic, and participants from all sectors and subjects often take part in the same CPD sessions. A significant number of newly-qualified teachers reported that the quality of some sessions was low, particularly when LA officers spent time explaining corporate policy[12].

SEEAG commissioned a survey questionnaire sent to Directors of Education of all local authorities to gauge the current level of provision and support for school education in STEM subjects, and to inform progress with the Science and Engineering 21 Action Plan. Responses were received from 24 authorities. Responses are not always easy to interpret. The results of the SEEAG survey[65] give a picture of patchy and variable provision of support for STEM subjects by LAs, although this may in part reflect the variable

interpretation of questions and nature of response to the survey. Subject development officer posts have largely disappeared, and in most authorities Quality Improvement Officers/Managers (QIOs/QIMs) have a remit that is far broader than the STEM subjects. On the positive side, recruitment to STEM teaching posts is not considered to be a significant problem, and there is evidence of increased work in STEM across the secondary-primary transition. Nonetheless, the survey confirms a decline in the level and quality of specific and high-level support for STEM, with a much higher level of responsibility and autonomy being assumed by schools. This marks a very substantial shift in the role of LAs in STEM support in schools. ***Nonetheless, it is also important to recognise that the Scottish Schools Equipment Research Centre (SSERC), as the major provider of high quality STEM CPD in Scotland, is a local authority shared service*****.** The central role of SSERC in supporting STEM education and technician training across Scotland is considered below.

LAs have often helped to co-ordinate centrally the delivery of CPD to teachers and schools by external providers. However, recent evidence shows that teachers and schools no longer always look to LAs in the first instance for this co-ordination and for information about available external provision, but they obtain this information from a wider range of sources; practice varies across LAs. This is consistent with the conclusion from the Directors of Education survey that ‘‘*There is no uniform approach to how local authorities and schools engage with external delivery partners, but decision making on involvement most often takes place at school level*’’. Schools may already have taken over much of the responsibility from LAs for establishing availability of external (usually subject-based) CPD through alternative routes, and CPD providers are modifying their marketing strategies accordingly. This situation reinforces the need to establish robust, reliable and widely-recognised central sources of information about external STEM CPD provision, to which LAs will continue to contribute.

The degree of additional autonomy implicitly adopted by schools is consistent not only with a shift in the level and nature of LA support, but also with the decentralisation of decision-making and empowerment of teachers and schools envisaged in the CfE. The merit of such autonomy is supported by research evidence published by McKinsey in 2010 showing that *the best education systems in the world are those in which schools enjoy autonomy*[66,67]. A recent OECD report[68] argues for greater diversity and autonomy within the Scottish educational system. Improvement in educational standards and quality is more likely to come where those delivering change can take responsibility to determine the nature of that change.

The review of Devolved School Management (DSM)[15] identifies a strong political consensus for the need to enhance devolution of responsibility, giving teachers and schools greater control over provision of learning in order to tailor the curriculum to the needs of learners. To achieve this, schools must acquire the capacity to make relevant decisions, and to exercise that capacity to implement CfE and make decisions about curriculum content, resources and teaching. The DSM Review[15] advocates a model of schools working in partnership through learning communities that include all schools serving the

same catchment in order to ensure the most effective and efficient delivery of learning choices for pupils. Recognising that learning goes beyond the confines of the school, there are opportunities to share placements of pupils to support the breadth and depth of provision needed for the senior phase of CfE, for example at Advanced Higher level and for so-called 'low uptake' STEM subjects. This partnership approach is consonant with the model of professional learning communities encouraged below.

Hub schools

Within the context of reform of teacher education and professional development, the Donaldson Report[12] proposes the creation of a network of hub school partnerships across all local authorities. These hub schools would develop close working relationships between a university and schools locally or regionally to support and deliver the practical training of student teachers in placements. ***The university involvement should also encompass mainstream university departments other than education*.** Additionally, this working relationship would extend to ongoing professional and leadership development, drawing upon the professional support of local and national organisations. Their remit would extend to interacting with and supporting neighbouring schools and their teachers to enable the wider development of effective practice. Donaldson[12] recommends that "*New and strengthened models of partnership among universities, local authorities, schools and individual teachers need to be developed. These partnerships should be based on jointly agreed principles and involve shared responsibility for key areas of teacher education''*. While rooted in the reform of initial teacher education and continuing professional development, the report's proposal recognises the important relationship of hub schools to the wider concept of teacher or professional learning communities that would be essential to their success if implemented.

The Scottish Government's response to the hub schools proposal[69] notes unspecified concerns. The hub school proposal raises several questions. Would hub schools provide support for initial and professional teacher development across all subject areas or only in the more generic aspects of teacher training placements?; and if across all subjects, how would it develop the capacity and infrastructure to function in this way? For science and technology, the adequacy of facilities would be a major concern. Would the establishment of hub schools drain funds from other schools in a local authority area? Nonetheless, ***the place of hub schools at the interface between wider teacher learning communities and universities and their teacher education colleges has merit if these concerns are satisfactorily addressed. Their potential role as centres of subject excellence is considered below***.

Specialist schools (centres of subject excellence)

A number of countries have recognized the need to focus on key areas of strength in schools in order to improve achievement, extend opportunities for

young people and build capacity both within and across schools. The evidence[45,46] is reviewed here.

Evidence in Scotland

In Scotland, there are secondary schools with nationally-funded specialist units with selective entry (centres of excellence) focusing on music, performing arts and sport, but none in science or engineering. In 2004, more than 50 (mostly secondary) schools were involved in the nationally-funded *Schools of Ambition* programme, which aimed to create "*a radical step change in the approach to transforming educational outcomes in Scotland*". Most programmes focused on broad aspects such as creativity, health and well-being, enterprise, information and communications technology and vocational education. Only one school declared a clear curricular focus (modern languages) with the intention that developments in this curriculum area would have a positive impact across the whole school. No school included science as a focus for development and improvement.

Evidence from other systems

In England, more than 350 science specialist schools (of a total of around 2200 specialist schools) have been formed from existing state schools for pupils aged 11-16 or 11-19. Their major aim is to encourage young people to study science and to increase the numbers of students choosing to pursue science both at A-level and at university. They work in close partnership with university science departments, science industries and major UK science bodies. The intention is that they become centres of excellence through developing innovative teaching and learning practices that draw young people of all levels into biology, chemistry and physics, acting as a resource for neighbouring schools. They are also encouraged to teach other science subjects such as astronomy, electronics, psychology and geology. They must collaborate with partner schools, usually associated primary schools and any special schools.

In the USA virtually all states have developed special programmes to promote science education at elementary, middle and high school level, with a diversity of structures and links to local business, industry and higher education. In Texas, very large high schools (~3000 students) are divided into smaller learning communities around a variety of career themes, supported by a high level of guidance and career advice at key stages to ensure that students are in the most appropriate learning community.

Establishing Centres of Excellence in Science in schools in Scotland?

There is a widely-recognised need to improve the status and performance of STEM education in Scottish schools. There are examples of good practice in Scotland and also many initiatives elsewhere where centres of excellence in STEM have been created from which Scotland can learn. However, it is always dangerous to simply transfer initiatives across geographical boundaries without recognising the context and culture in which another country's schools

work. This is certainly true in Scotland where the comprehensive education system is widely supported and where selection of pupils across schools based on academic ability or prior attainment is not a widely accepted option.

Hub schools as centres of excellence in STEM

The hub schools model proposed by Donaldson[12] centres around their role in ITE. As such, they have merit. If they are to be implemented as such, they would also function in part as centres of excellence. While good STEM teaching should be available in all schools, key features of hub schools as centres of excellence in STEM teaching would be their place within wider professional learning communities, their links with universities (including both ITE faculties and mainstream STEM departments) and perhaps with local industries, and their capacity to make available an enhanced level of provision of science, particularly at qualifications level, that might not be available in practice in all schools. For example, they might provide the capacity to broaden the science subject base (see Part 4A and recommendation 4.2 above) by delivering so-called 'low uptake' sciences (e.g. Environmental science, earth science, engineering, biotechnology) and in so doing building expertise in interdisciplinary science learning within and across wider learning communities that would otherwise not be widely accessible, thus ensuring greater equality of access.

Recommendation 5.1
It is recommended that the Scottish Government considers the development of hub schools as proposed in the Donaldson Report[12] and that hub schools with a STEM specialism fulfil the additional role of centres of excellence in STEM, with strong links to professional learning communities, universities (including ITE faculties and STEM departments) and industry, and with the capacity to make available a broad provision in science subjects and interdisciplinary science teaching.

Professional Learning Communities (PLCs)

"Great teaching is a team sport."

Background and research evidence

A recurring theme in this report is the need for teachers, educators, colleges and universities, business and industry, CPD providers, professional and learned societies, local authorities and other organisations and stakeholders to work together in partnerships. This may occur in virtual groupings or through face-to-face collaborations. Some partnerships (clusters and networks) already exist, providing working models. The concept of educational partnerships has been formalised under the heading of *Professional Learning Communities*[70].

A two-year study by the US National Science Foundation[71] has confirmed teacher effectiveness research showing that STEM teaching is more effective and student achievement increases when teachers join forces to develop strong professional learning communities (PLCs) in their schools[70]. One of the major advantages of PLCs is the clear, consistent and coherent support provided to teachers from training through to practice. Teachers who work in strong learning communities are more satisfied with their careers and more likely to stay in teaching. Performance appraisal, compensation and incentive systems that focus on individual teacher performance at the expense of collaborative professional capacity building and teamwork undermine the capacity to prepare today's students for 21st-century success.

Six principles that make learning communities effective are[70]:

shared values and goals
collective responsibility
authentic assessment
self-directed reflection
stable settings
strong leadership support.

Participants in PLCs[70]:

- engaged more openly in discussions about the mathematics and science they teach
- understood mathematics and science better
- felt more prepared to teach mathematics and science
- used more research-based teaching methods
- paid more attention to students' reasoning and understanding
- used more diverse modes of engaging students in problem-solving.

McKinsey[66] found that teachers work together in PLCs to:

- research, try and share best practice
- analyse and constantly aim for high, internationally benchmarked standards
- analyse student data and plan tailored instruction
- map and articulate curriculum
- observe and coach each other.

In STEM, PLCs may take many forms. The typical PLC is a group of teachers working in the same school. Other PLCs may function across districts (meeting after school, at weekend workshops or during vacations) or as virtual groups. STEM PLCs typically develop and are built around common visions and strategies or around specific STEM challenges.

Models of PLCs in a Scottish context

There are several models of PLCs already in operation in Scotland. Examples include:

1. The Institute of Physics (IOP) Teacher Network (established in 2002) in which seven Local Physics Teacher Network Co-ordinators provide support to teachers and schools within a geographical area and collaborating beyond. The Network also maintains the SPUTNIK email group to which over two-thirds of all Scottish physics teachers belong and which allows the mutual support of the physics teaching profession and sharing of good practice. Scottish Government funding enhanced the establishment of the Network, which has since been maintained by the IOP.

Recognising the success of the Physics Teacher Network, The Royal Academy of Engineering, with the support of BG Group from the energy sector, set up a similar network across the UK in the autumn of 2011.

2. Aberdeen City Council and The Association for Science Education, with support from BP, are creating a support network for the teaching of science in a cluster of primary schools working towards the Primary Science Quality Mark in Scotland. This is building on the sort of support structures many local authorities already have in place, but adding additional co-operation with professional bodies, industry and the local science centre.

3. Dundee Science Centre, the University of Dundee, Dundee College and SSERC have set up the Dundee Science Centre Science Learning Institute with the aim of sharing resources for the mutual enhancement of provision for science learning students and professionals on Tayside. This initiative has harnessed the capacity and expertise of four sectors (science centre, education, FE and HE) and has established close relationships with LAs and individual schools in order to:

- enable teachers to benefit from knowledge exchange with researchers
- enable science access students in FE to engage in dialogue about science in society and science communication
- enable HE science education specialists to engage a wider teacher audience
- enable ITE students to access Dundee Science Centre resources to enhance BEd and PGDE courses enable researchers to carry out science communication training and practice
- enable science undergraduates and Science Baccalaureate students to carry out science communication and science in society placements in the science centre
- enable SSERC courses to be extended more sustainably to Tayside.

4. A number of Scottish Local Authorities have entered into a partnership with Tapestry which focuses on Professor Dylan Wiliam's model of Teacher Learning Communities (TLC). This model allows schools to establish TLCs to support teachers in improving their pedagogy or assessment practices, providing an opportunity for clusters (typically a secondary school and its associated primary schools) to work in partnership. Each TLC would be facilitated by a trained Leader of Learning. The professional development programme will support and prepare staff well to deliver the school's own improvement plan.

Conclusions

PLCs offer a very effective way of developing and supporting interdisciplinary STEM teaching, learning and assessment, particularly in a climate of limited resources. They offer the flexibility to adapt to local institutions, local strengths and local needs, which will themselves evolve with time, and articulate well with the new CfE landscape of enhanced school and teacher autonomy. They may nucleate and grow around existing partnerships and should include hub schools[12].They could proactively engage with CPD providers and organisations. PLCs provide key components of local and regional cross-sector collaborations or centres of excellence, interfacing groups of schools with local universities, colleges, science centres, science learning centres and industries. ***PLCs have the capacity to balance the provision of subject-based and/or skills-based external professional development with the strengths of peer-support to ensure the sustainability and wider delivery of professional development initiatives, ensuring the most effective use of scarce resources.***

Recommendation 5.2
It is recommended that Education Scotland and local authorities ensure that support and resources are made available to stimulate the development and growth of Professional Learning Communities in STEM learning and teaching, with strong links to universities and/or colleges where possible.

Recommendation 5.3
It is recommended that the Scottish Government ensures that support and resources are made available to professional societies, colleges, universities, science centres and other stakeholders to support and extend Professional Learning Community networks.

Recommendation 5.4
It is recommended that LAs establish and maintain a record of professional (teacher) learning communities in their authorities, and Education Scotland develops and maintains a profile of learning communities across Scotland, as a basis for stimulating their wider establishment and development, and to document examples of good practice.

A truly ambitious education system should also explore other innovative and imaginative new ideas within the framework of PLCs and comprehensive education system to develop and extend the most talented and best-performing young people in STEM (and across all subject areas) by raising expectations and opportunities. They represent Scotland's innovators and leaders of tomorrow. Initiatives based on researched evidence of successful models might take the form of summer schools, school master-classes, and creative local 'partnerships of excellence' amongst schools across the education spectrum. Such partnerships embedded within professional learning

communities might attract the intellectual and financial support of universities, colleges, business and industry.

Support from industry

Scottish Science Advisory Council (SSAC) work

The Scottish Science Advisory Council (SSAC) organised a series of meeting and workshops in 2010 and 2011, and met with a range of organisations and individuals to identify key issues, gather evidence, make recommendations and take actions to enhance the links between schools, colleges, universities and industry in supporting STEM education within the CfE. Some of their arguments, conclusions and recommendations[17] have been incorporated in this report and are in excellent agreement with the work and recommendations of the SEEAG.

The SSAC report[17] identified four key themes that present opportunities for better engagement with partners in industry, colleges and universities to support teaching outcomes in STEM and beyond into science and engineering careers. These are:

- co-ordination of STEM activities
- importance of science-specific CPD for science teachers
- support for curriculum development and support for teachers in implementing the new curriculum
- career advice for pupils.

The SSAC report[17] focuses on the roles of industry in supporting STEM in schools in a variety of ways. There is an evident appetite from industry to work with schools to promote and encourage the uptake of STEM subjects amongst pupils, reflecting the vital importance of STEM skills to industry and the concerns across the major industrial sectors in Scotland and more widely about where their skilled employees will come from over the next decades. A recent report by the Science Council[72] estimates that about 5.8 million people (20% of the UK workforce) are employed in science-based roles, a figure predicted to rise to 7.1 million by 2030, further increasing the demand for skilled STEM graduates and technicians. Declining school rolls present a further challenge.

Forms of engagement by industry with STEM education

Engagement with and by industry works in several ways and can take different forms. Visits by pupils to industry and vice-versa provide important and immediate understanding about STEM careers and the workplace, making apparent the relevance and links to young people’s formal STEM education. This work contributes strongly to the range, richness and breadth of activity supporting STEM in schools. Engagement also occurs through the STEM Ambassadors programmes and Skills Development Scotland (SDS) has paid careers advisors in every school.

Some types of engagement by industry with schools may have longer-term benefits for pupils than others. A large amount (probably the majority) of the resources and materials prepared and distributed by industry to schools in previous decades remained unused as they were incompatible with the curriculum, articulated poorly with the timetable and were largely aimed at promoting rather specific niches of STEM that related to the interests of a particular industry. The support and resources of industry should be more broadly aimed at attracting more young learners into STEM at school and thence into career pathways across industry sectors and raising awareness of STEM in the workplace. More recently, industries have worked much more effectively in partnerships with professional educators, CPD providers and schools in a range of ways to ensure that a wide range of learners are attracted into STEM.

Recommendation 5.5
In order to ensure that industry input into the curriculum and CPD is aligned with students and teachers needs and CfE in future it is recommended that Education Scotland ensure that all industry engagement is developed and delivered in partnership with appropriate pedagogical partners (see also recommendation 6.6).

There are many examples of such working. This partnership approach articulates well with the concept of professional learning communities.

Careers

An important role of industry in STEM education is to educate pupils and their parents about the diverse range of career opportunities that are available through STEM and to emphasise the number of different routes into STEM-based careers beyond the traditional academic route. The recent Scottish Government report[14] on the reform of post-16 education in Scotland highlights its support for developing a wider range of progression and articulation opportunities, including higher level technical and graduate opportunities. ***SSAC considers that there should be a greater role for industry in educating teachers, particularly career advisers and guidance teachers and parents/carers, about the wealth and diversity of STEM-related careers.*** Pathways from school to colleges, universities and the workplace are considered in Part 7.

A Scottish Science Learning Centre?

Scottish Schools Education Research Centre (SSERC)

SSERC is a Local Authority shared service providing a comprehensive CPD programme, supported by the Scottish Government, in practical hands-on science. In providing this CPD, they collaborate with a wide range of organisations including SQA, Education Scotland, the National Science Learning Centre (NSLC) in York, the Institute of Physics (IOP), the Royal

Society of Chemistry (RSC), the Association of Science Education (ASE), the Scottish Earth Science Education Forum (SESEF), the Royal Zoological Society of Scotland, the Royal Observatory Edinburgh, the Science Centres, the Scottish universities and many other providers. SSERC's support is holistic, encompassing professional development in a variety of formats (in-house, outreach, twilight and residential), and extending to an advisory service which also provides guidance on health and safety appropriate to school science, an invaluable resource for local authorities. It offers professional development to classroom teachers, student teachers, technicians and curriculum leaders in science with a view to supporting the best possible environment for learning in schools.

CPD delivered by SSERC with support from the Scottish Government has recently been evaluated by The University of Glasgow[40]. The evaluation reports extremely positive feedback from teachers, technicians and PGDE students on their training, resources, confidence and enthusiasm, with positive impact on teaching practice and enhanced pupil engagement and performance.

On an annual basis, some 1700 teachers and technicians experience face-to-face professional development provided through SSERC. The subject matter covered ranges from health and safety through specialist science and/or technology areas. SSERC's audiences are chiefly secondary science and technology teachers, technicians and primary teachers and the professional development may be tailored for a single or mixed group. SSERC provides bespoke courses for LA partners in their own area. In addition to using its own training facilities, SSERC also delivers courses in Science Centres and other venues across Scotland.

On an annual basis, some two-thirds of Scottish secondary schools have representation at face-to-face SSERC-led courses; over the two-year period from 2009-2011, SSERC had face-to-face contact with delegates (teachers and technicians) from over 90% of Scottish secondary schools. In addition, more than 95% of each cohort of student secondary teachers has attended the Scottish Universities Science School which SSERC runs each year in collaboration with the seven Scottish universities that offer initial teacher education. In total, SSERC's contribution to supporting STEM teacher and technician engagement through residential courses, workshops, summer schools and conferences is immense, amounting in 2010-11 to some 3000 training days. ***This figure compares strongly with wider UK figures.***

SSERC has a strong funded partnership with the National Science Learning Centre (NSLC) in York, achieving a percentage of engagement in Scotland which compares favourably with most other regions of the UK. SSERC/NSLC courses are funded by the ENTHUSE and Research Councils UK awards schemes. In most respects, SSERC already acts as a national STEM learning centre for Scotland, with the potential and scope to develop further and play an enhanced role in supporting the additional and ongoing demands that are arising during the implementation of CfE, supporting primary science,

interdisciplinary science and the increased demands of teachers that will arise during introduction of the new qualifications.

In November 2011, the Scottish Government, NSLC and SSERC held discussions around the need for a continuing, extensive long-term programme of professional development in science and technology for primary teachers. Instigated by these initial discussions, SSERC and NSLC have drawn up initial plans. With some resource provided via NSLC and collaborating with Local Authorities, SSERC will in 2012/13 design and pilot a programme of structured professional development that focuses on working with teachers in school clusters. The aim of the programme is to raise the level of confidence in the teaching of science of all the primary teachers in the clusters. In carrying out this pilot, SSERC will build on the successes of its programme of professional development in science and technology for primary teachers, which has run since 2007.

Recommendation 5.6
Building on the proven success and large scale of SSERC's work, delivered with support from Local Authorities and the Scottish Government, it is recommended to the Scottish Government that SSERC, working with partner organisations and linked to the NSLC in York, becomes Scotland's national science learning centre, with enhanced provision to deliver a wider range of support for STEM teaching and learning.

National Science Learning Centre (NSLC)

The National Science Learning Centre in York was established with funding from the Government and Wellcome Trust. *Project Enthuse*, launched in 2008 with funding (£30m for four years from 2009) from the Wellcome Trust (£10m), UK Government (£10m) and nine industry partners (£10m), provides generous bursaries to science teachers and school technicians to attend residential professional development courses at the NSLC. By late 2009, almost 1400 teachers had benefited from the scheme, which provides bursaries of £1800 to meet the cost of fees, travel and accommodation for individual teachers plus the cost of teacher cover. Over 90% of participating teachers reported significant positive impacts on themselves, their schools and their teachers, with two thirds reporting development of new skills in teaching methods.

Cross-cutting issues: educational leadership

The Donaldson Report[12] recognises that leadership is central to educational quality. The most effective educational systems are characterised by the development of future leaders in a progressive manner. A report by McKinsey & Co[73] reported that *"Apart from classroom teaching, nothing influences improvements in school standards more than the quality of head teachers. Wherever they are in the world, good headteachers share many common attributes and approach the role in similar ways. They spend more time*

coaching and developing their teaching staff, and interacting with students and pupils. They help each other and establish networks and clusters, which they then use for learning and development, and providing support for weaker schools." Thus, Donaldson[12] recommends that *"a greater range of CPD opportunities should be provided for experienced headteachers…"* and that *"A scheme for national leaders should be developed to enable experienced, high-performing headteachers to contribute to system-level leadership of education in Scotland".*

However, ***for there to be effective learning and teaching, appropriate distributed leadership must be developed and demonstrated at all levels from the classroom teacher through school management to local and national Government, educational support agencies and professional associations***. Accordingly, Woods *et al*[74] found that *"experienced headteachers value professional development focused on building leadership capacity at all levels."* Effective leadership relies on the participants taking ownership of issues within their sphere of influence. Top-down approaches are less likely to work well[75].

Some make a clear distinction between leadership and management, but Bush and Coleman[76] make the case that for school improvement effective leadership and management are **both** required. Similarly Boleman and Deal[77] state: *"Organisations which are over-managed but under-led eventually lose any sense of spirit and purpose. Poorly managed organisations with strong charismatic leaders may soar temporarily only to crash shortly thereafter."*

Research has shown that effective leaders can make a difference in school and student performance if they are granted autonomy to make important decisions. However, autonomy alone does not automatically lead to improvements unless it is well supported and demonstrates a level of accountability. School leaders need time, capacity and support to focus on the practices most likely to improve learning. Policy makers and practitioners need to ensure that the roles and responsibilities associated with improved learning outcomes and pupil experiences are at the core of school leadership practice[75].

Too often those delivering education to learners lack appropriate support. This support takes many forms including: financial; suitable resources; time; quality CPD and even just the encouragement and enthusiasm from those in leadership positions to make the most of opportunities. Often teachers are restricted in their opportunities to promote STEM education due to perceived factors such as the need to be seen to be equitable in the promotion of different curricular areas, health and safety issues, or concerns about how they might be judged in school inspections or other quality assurance procedures. However, mostly these are pseudo-restrictions. At times teachers and others involved in promoting STEM education feel that those in leadership positions far from facilitating and supporting rather thwart or confound their ability to deliver quality STEM education.

In secondary schools the leadership of STEM subjects has been the remit of suitably qualified and experienced specialist principal teachers. Historically, these teachers acted as champions for their subjects. In 2001 HMIE[54] reported: *"Most principal teachers of the sciences were good teachers and fulfilled their remits effectively. They were typically experienced, conscientious and well organised individuals. They devoted considerable energy and expertise to the management of a wide range of resources and to the smooth running and development of courses. They communicated effectively and promoted teamwork, especially within their discrete subject departments."* Effective principal teachers:

- had a clear vision for their subject and its benefit for pupils
- were outward-looking, professionally up-to-date with good subject knowledge, including awareness of national and local developments in their specialist areas and in science teaching as a whole
- promoted teamwork, including strong working relationships with staff and pupils and had high expectations of them
- involved teachers and ancillary staff fully in development tasks in order to promote ownership of provision and develop professional expertise
- provided guidance and support for staff to ensure a consistently high quality of pupil experience across the department as a whole
- employed a systematic and rigorous approach to departmental self-evaluation and monitoring in which strengths and areas for improvement of the department were acknowledged and where necessary improvements were planned
- successfully introduced initiatives which improved learning and teaching, motivated pupils and raised their attainment through time.

In recent years the flattening of management structures in many secondary schools has decreased the leadership in specialist subject areas. It is now less likely that schools will have experienced staff in promoted posts in all STEM areas who are able to provide subject support for newly-qualified and student teachers, subject specific health and safety advice and sound knowledge of practical work and assessment procedures. Earley[78] states that middle managers have long been recognised as crucial to an organisation's success and based on National Foundation for Educational Research (NFER) research states they are the key to improving the quality of learning and teaching. Those organisations that define strategy predominantly in terms of senior management responsibilities are unlikely to make the best use of the resources at their disposal. With flattening management structures it is essential that leadership is delegated and distributed appropriately. Donaldson[12] recommends that *"a clear and progressive educational leadership pathway should be developed, which embodies the responsibility of all leaders to build the professional capacity of staff and ensure a positive impact on young people's learning."*

In primary schools it is rare for teachers to have a STEM subject background and even if they do they are not always able to act as subject champions. In 2010 the Royal Society[25] reported: *"Historically, recognition of the value of science or mathematics 'coordinators' or 'leaders' has fluctuated over time in*

accordance with transient funding initiatives, and the people fulfilling these roles have often not had strong educational backgrounds in these subjects. A rigorous approach to improving the quality of science and mathematics teaching and learning is needed across primary and early secondary education."

Jackson[45,46] has identified that over the last two decades or so the structures providing support and leadership for school STEM subjects have been significantly reduced in capacity. This has included:

- a reduction in the number of teacher education institute staff
- a reduction in the number local authority subject advisers
- a reduction in the number of local authority subject networks
- a reduction in the number of subject staff in Education Scotland and SQA
- the move from subject Principal Teachers/Assistant Principal Teachers to flatter faculty structures.

The implementation of Curriculum for Excellence and of the recommendations of the Donaldson Report should provide catalysts for the emergence and development of educational leadership.

We note also the McCormac Review's recommendations[16] in respect of Career Structures (Section 5) and support their implementation.

Recommendation 5.7
It is recommended that local authorities and headteachers ensure a supportive framework is in place to allow senior and middle managers and leaders to support and facilitate all those delivering STEM education to our young people. The leadership provided previously by those in the roles such as LA subject advisers and subject principal teachers is still required. LAs and head teachers should ensure that sufficient staff with the range of expertise required across the whole STEM spectrum be employed to provide leadership for STEM education in schools.

PART 6 REAL LIFE SCIENCE, ENGINEERING AND TECHNOLOGY: INCREASING YOUNG PEOPLE'S ENGAGEMENT AND UNDERSTANDING

Real life science and technology and the Curriculum for Excellence

The introduction of *Curriculum for Excellence* provides an opportunity to increase the 'topical' aspects of science in the classroom to allow young people to make their learning more relevant. Knowledge of new developments in science is vital for those young people thinking about a career in science, technology, engineering and mathematics (STEM). However, it is equally important that *all* our young people have an opportunity to learn about and understand topical issues in STEM, to allow them subsequently to make informed life choices with confidence on a range of issues, whatever their destination after school. Increasing young people's engagement with practical or 'real life' STEM therefore contributes more widely to Scotland as a 'science nation', not just as an investment in their future but by providing them with the tools to influence their own families and communities today.

In the classroom, increasing young people's engagement and understanding of practical STEM has the potential to make a marked difference in their enjoyment of science lessons. Being able to see the relevance of STEM appears to be a key factor in young people's enjoyment of science lessons, particularly at secondary level. Focus group research with secondary pupils carried out as part of the Scottish Government's 'Do something creative. Do science' campaign found that even pupils who had enjoyed science at the primary level look for more engaging and challenging secondary lessons that make STEM relevant to their own lives. Furthermore, research published by the Wellcome Trust in September 2011 suggests that around 40% of young people struggle to see the real life relevance of their science lessons. Stimulating activities, projects and practical work that bring to life the theory learned in the classroom can make a significant difference in reinforcing and strengthening learning, and help to ensure that young people have a positive experience of secondary school science lessons and Curriculum for Excellence.

At the same time, the fundamental pillars of knowledge and understanding must be sustained. This is a hard challenge. However, teachers need not work in isolation. There is a strong 'science engagement' sector in Scotland, with many organisations delivering a range of initiatives and activities that complement and strengthen formal science learning and provide young people with opportunities to experience at first hand the practical relevance of science, technology, engineering and mathematics.

Real life STEM outside the classroom

There is no formal requirement within Curriculum for Excellence for 'engagement with real life science', nor any benchmark of what is expected, though the development of interdisciplinary teaching will encourage such engagement. There are a range of methods of engagement, but no 'one size fits all' solution. What inspires some young people may not work for others, or even be available to them.

Further, many young people will already be exposed to opportunities to make sense of STEM outside the classroom. This could include visits to science centres, museums, zoos, botanic gardens or science festivals with their families, or involvement in club or group activities with their peers. Websites, broadcast and print media are other avenues that allow young people to find about STEM, particularly around new developments and the ethical issues involved. In addition, today's young people are familiar with STEM applications (particularly ICT-related products) to an extent that was not the case with previous generations. This should provide more opportunities for the link between theory and practical application to be made clear in a way that is engaging and relevant to young people.

Research evidence

A Wellcome Trust research report[79] suggested that young people feel more engaged with science and wider STEM subjects when they can see the relevance to themselves. This includes STEM's impact and applications in their current everyday lives as well as whether they have a bearing on future study, training and career opportunities. Furthermore, young people value and enjoy opportunities for learning outside the classroom and tend to feel more engaged with science as a result of undertaking such activities.

There is a broad range of opportunities for young people – and the wider public – to engage with STEM, and many of these are listed in the Workstream 3 report published on the Scottish Government we bsite[80]. They include science centres and festivals, touring outreach programmes for schools and community audiences, botanic gardens and wildlife parks/zoos, aquaria, museums and observatories. There are also a number of programmes involving STEM club activities and project work that may lead to a badge or award under a recognised competition or scheme. The wider science engagement and scientific communities appear to be committed to assisting schools to deliver STEM learning. This is particularly the case with the scientists and researchers signed up to the STEM Ambassador scheme, run across the UK by STEMNET, and involves STEM professionals from industry, colleges, universities, research institutes and other employers assisting schools with STEM learning and teaching, e.g. assisting with practical lessons, running STEM clubs, talking at careers events, developing new practical activities and judging STEM challenges. National Foundation for Educational Research (NFER) research on the STEM Ambassadors programme found that *"Six out of ten pupils (61%) felt that taking part in activities with a STEM*

Ambassador had made a 'great difference' or 'some difference' to their enjoyment of, and interest in, science."

While this range of support and resources is to be welcomed, there appears to be a lack of co-ordination between practitioners, leading to schools and teachers being targeted by multiple marketing materials and initiatives in a way that could be, at best, confusing and, at worst, off-putting, according to the SEEAG stakeholder consultation responses[81] and evidence submitted as part of the Science and Technology Select Committee's recent investigation into practical lessons and field trips[82]. Several respondents to the SEEAG stakeholder consultation felt that better co-ordination of STEM activities, particularly around geographically-based hubs, could be a way forward to assist teachers and prevent duplication.

At the same time, school uptake of opportunities appears to be dependent on the interplay of a number of factors, including quality of 'the product', its availability (from both a geographical and cost/resources point of view) and teachers' awareness of what is being offered. Add on timetabling issues and the need for individual teachers to recognise the value of such initiatives and it is clear that there are likely to be many pupils who will have limited access to science engagement opportunities that bring practical experience to their science learning.

Many respondents supported the development of a 'one stop shop' resource that could help teachers, with ideas around how particular aspects of STEM within the curriculum could be 'brought to life' by particular activities, initiatives or visits.

The SEEAG consultation responses from industry organisations[81] in particular suggested that there was strong support for industry to be more involved with schools. This could have a number of benefits, including introducing STEM 'role models' to the classroom, and giving teachers an opportunity to increase their knowledge and skills related to current practical STEM applications. However, several non-industry respondents felt that not enough industry partners are aware of existing schemes (such as STEM Ambassadors), and that some companies prefer to initiate their own activities, particularly with schools local to their premises. As highlighted above, this latter approach risks adding to confusion around what is available for schools.

Another key issue from the consultation was around funding of science engagement initiatives. There was a recognition that a number of possible funding streams, including charitable trusts, industry sponsorship and local and Scottish Government (particularly from the Office of the Chief Scientific Adviser), are currently available and appreciated by those delivering practical STEM projects. However, there was a feeling that there were opportunities to set a more strategic direction for projects that were funded in future, particularly by Scottish Government. In addition it was felt that funding could be used as a driver for partnership working across a number of organisations, involving Government and Industry's monies, to help improve co-ordination of activities.

Discussion and recommendations

Schools need to be aware of the opportunities open to them for their pupils to engage with practical STEM. There appears to be no single Scottish paper directory or website where teachers can find advice and information on relevant activities. Instead schools are sent numerous programmes, brochures and leaflets for a multitude of initiatives. The recently-established 'STEM Central' website (www.ltscotland.org.uk/stemcentral) developed by Education Scotland has the potential to develop into a key resource for teachers and young people, particularly in highlighting aspects of practical STEM and their relevance to class work. It is currently engineering led but if widened it could serve the whole community.

Recommendation 6.1
It is recommended that STEM Central be extended and supported by Education Scotland so as to develop it into a useful 'one stop shop' for teachers, learners and parents in terms of practical STEM and science engagement ideas, activities and providers. This support should include encouraging STEM engagement providers to contribute information and links to/from STEM Central.

Awareness is only one factor in the take-up rates of practical STEM activities and initiatives. Quality and availability, as indicated in the preceding section, have a large role to play too. It is clear that there are differences in the quality or depth of engagement offered by, for example, regular and repeated activities against one-off visits from outreach initiatives. Furthermore, activities that may look similar in style or method of engagement may differ in the quality of activity or presentation. One bad experience can damage the reputation of the whole sector. It would be helpful, therefore, to develop some common quality standards for practitioners to use. As important, particularly in the context of this report, is that the engagement should be in support of teachers, good pedagogical practice, and CfE.

Recommendation 6.2
It is recommended that the basic engagement for all schools described in 6.3 below, being offered through the four providers together with the Science Centres and the major Science Festivals, are reviewed on a four year cycle by Education Scotland.

Availability of opportunities is a critical issue. For reasons of location and/or cost, not all schools across Scotland are currently able to access many of the practical STEM initiatives on offer. Schools in the Highlands and Islands in particular are distant from a science centre, although the number of science festivals in the region (seven) suggests that, at key points in the year at least, a wider range of activities are available to local schools in those particular areas. Yet there will also be other schools within our towns and cities that have very limited opportunities to access activities due to the costs involved. In both these cases it is important that science centres and other organisations offering outreach activities (including colleges, universities and research institutes) target their resources to reach those schools in most need, as well

as the ‘good customers’ in more affluent and/or populous areas. It is essential that all students, teachers and schools should be able to use and participate in a core of national Science engagements.

Recommendation 6.3
It is recommended that schools are supported by local authorities and the providers by the Scottish Government so as to ensure that all schools are enabled to benefit from a STEM Ambassador(s), a Generation Science visit, the establishment of a Scottish Council for Development and Industry (SCDI) Young Engineers and Science Clubs (YESC) and an annual visit out to a Science Centre or Festival.

There appears to be broad support for a network of regional ‘hubs’ to be established as a way to help co-ordinate and map local provision, publicise opportunities and address issues around the quality of STEM engagement activities. The idea of regional hubs for science promotion or STEM engagement is not a new one. STEMNET, the UK-wide organisation that promotes STEM and is funded by the UK Department for Business, Innovation and Skills (DBIS) to run the STEM Ambassador scheme, contracts four organisations in Scotland to deliver its programmes: Science Connects in west Scotland, Global Science in the east, Dundee Science Centre for the north-east and STEM North Scotland/University of the Highlands and Islands (UHI) for the Highlands and Islands. However, the STEMNET contracts mainly focus on providing advice to schools and the recruitment of STEM Ambassadors. As discussed above, young people are just as likely to explore ‘real life’ STEM with their families and friends outside school. Consequently, a hub network for this mix of school-based and family/public audience may sit more easily with other organisations, for example the science centres in Glasgow, Edinburgh, Dundee and Aberdeen, perhaps also working with UHI.

In addition, these regional hubs could play a key role in working with partner organisations to establish quality guidelines, identify funding opportunities and drive partnerships to widen provision and prevent duplication. In this way several of the existing issues around take-up of practical STEM initiatives by schools could be addressed, including the issues of quality and availability highlighted above.

These hubs should play a key liaison role with other providers (including STEMNET contract holders, science festivals, STEM outreach initiatives, industry programmes) and work together to establish guidance on how to evaluate the success and impact of activities.

Such hubs should also work with science engagement providers to map local provision of activities and assist partnerships to make the best use of resources and forge strong links with local and regional Professional (Teacher) Learning Communities (PLCs) and work with STEMNET contract holders to match schools and industry/university/colleges as appropriate, according to local research/business strengths and educational needs. To ensure appropriate geographical coverage, hubs

should, if necessary, establish smaller coordinating centres, e.g. Glasgow Science Centre's partnership with Whitelee Visitor Centre.

Hubs should also work with partners to raise awareness about the benefits of suitably evaluated activities and share best practice in order to provide teachers with assurance as to the quality of events and activities. Finally, these hubs would liaise with Scottish Government on future priorities and strategic aims for STEM engagement.

Recommendation 6.4
We therefore recommend that the Office of the Chief Scientific Advisor work with the Scottish Science Centre Network and the University of the Highlands and Islands to establish a network of regional STEM engagement hubs. These hubs should focus on improving access, quality and delivery of practical STEM activities to schools.

The development of co-ordination hubs would go some way to addressing some of the apparent concerns of teachers and the sector around the opportunities for practical STEM in the classroom. Yet a number of issues affecting take-up by teachers remain, particularly around quality, availability and awareness.

There are already a number of initiatives with strong industry buy-in that give young people access to practical STEM. These include, but are not limited to, the Shell Education Service, support by OPITO (the oil and gas industry organisation dealing with skills, training and workforce development) for the Institute of Physics' Lab in a Lorry touring laboratory, the Young Engineers and Science Clubs (YESC) run in Scotland by SCDI (Scottish Council for Development and Industry) with support from its member organisations, and the STEM Ambassador scheme.

In terms of funding science engagement initiatives, the current financial climate is having an impact on the ability of many organisations to raise funds from other sources in order to keep costs to schools down. Increased industry support for the initiatives highlighted in the paragraph above – perhaps in place of some companies' alternative plans for their own education initiatives – has the potential to make a real difference in the classroom. The Scottish Government is not in a position to make up the shortfall. Yet there should be scope for it to take a more strategic approach when funding some key initiatives. This may be particularly around continuing to ensure that funding is allocated to appropriate projects representing a good geographical reach across Scotland.

Recommendation 6.5
It is recommended that industry, rather than through individual contributions, should provide their support through the main providers listed in 6.3 so as to provide high quality, independently evaluated, educational benefit with national coverage.

Recommendation 6.6
It is recommended that any future science engagement funding available from the Office of the Chief Scientific Adviser should reflect the strategic priorities of this report alongside Scottish Government objectives.

The Role of Universities

Scotland's universities provide access to an enormous range of internationally-recognised STEM research. Scotland continues to excel as a science nation and ranks first in the world in terms of numbers of research citations relative to its GDP. This science excellence is an excellent resource to inspire and enthuse young people about science and the role STEM plays in all of our lives.

In many cases, our universities showcase their research by providing high quality outreach activities either as a structured programme of engagement or by individual researchers. The university sector also increasingly recognises that science communication skills are important for researchers so they may raise awareness of their science to the general public, media and policy-makers. University scientists work in partnership with the STEM Ambassador scheme and are regular contributors at Scotland's science centres and science festivals. In many cases, university scientists provide the backbone for year-round engagement activities. Individual science departments within universities actively support Higher, Advanced Higher and Baccalaureate science projects either by hosting senior pupils within their laboratories or by lending equipment to enable experiments to be done within schools. At present, this appears to be a rather *ad hoc* service and could benefit from a more strategic approach as part of a local engagement network or science learning community.

Research council funding now requires scientists to allocate some resource within research grants as part of an ‘Impact Plan’. The purpose of impact is to raise awareness with a variety of audiences, including school pupils and teachers. This process provides additional opportunities for science engagement providers to work in partnership with university researchers to deliver innovative and creative ways of bringing cutting-edge science into the classroom. Finally, university scientists also work with industry, teachers and CPD providers to develop and deliver practical and topical resources for classroom use.

This strong STEM research and teaching platform within the Scottish universities provides an excellent basis for partnerships to develop between ITE colleges and mainstream STEM departments within the universities that will support and enhance both science engagement and the development of new degrees to replace the B Ed recommendations in the Donaldson Report[12]. The extent to which this currently happens appears to be limited.

Recommendation 6.7
We recommend that Universities Scotland help and support universities by providing examples and case studies on how to work more closely with science engagement providers to fulfil the impact criteria of research council funding.

PART 7 BEYOND SCHOOL: FURTHER LEARNING, TRAINING AND EMPLOYMENT

Background and context

The impact and economic importance of science, engineering and technology seems certain to increase strongly in coming decades. As a result, opportunities to pursue careers in science, engineering and technology are predicted to grow dramatically over the period to 2020.

The Skills Investment Plan for the energy sector[83] alone suggests an average of 5,200 to 9,500 job opportunities per year to 2020, while Scotland's life sciences sector[84] has set the aspirational target for 2020 of doubling turnover to £6.2bn and Gross Value-Added (GVA) to £3bn. Scotland is already one of the UK's leading regions for new life sciences business creation and a successful investment magnet. In 2010, venture funding raised by our Life Sciences enterprises held up well, amounting to more than three times the 2005 total. The Scottish Life Sciences Skills Survey 2010[85] highlighted that across 156 responses approximately 1400 scientific and non-scientific roles would be required over the next two to three years in the Scottish life science sector. The industry's refreshed strategy now aims to double the sector's economic contribution to Scotland by 2020. Such figures combined with other key growth sectors such as chemical sciences as well as information technology and enabling technologies all confirm a healthy demand for a future workforce with STEM skills.

If we are to meet that projected employer demand across these growth sectors and maintain a competitive edge in the employment market, it is essential that we develop a highly-skilled workforce that is aligned and responsive to the future needs of the science base and the economy as a whole. Young people will be made aware of these opportunities if they are able to experience STEM careers and workplace learning opportunities at first hand.

Benefits and opportunities of STEM education

There are major benefits to individuals, society and the wider economy in encouraging uptake of STEM study amongst learners. At the SEEAG stakeholder conference (June 2011) the Chief Scientific Advisor presented evidence that people who have studied STEM subjects are well placed for jobs within and outwith the core STEM industries. The Department for Business Industry and Skills (DBIS) Research Paper[53] reinforces this view through the following observations:

- Within the workplace, few graduates interviewed used their specific degree subject knowledge a great deal (even those in STEM Specialist work), although their degree subject was perceived as vitally important in gaining such jobs. On the other hand, almost all the graduates – irrespective of employment sector – used the general and broader skills learned while doing a STEM degree to a much greater extent.

- Some skills of high value to non-STEM employers were unique to STEM graduates, such as a particularly logical approach to solving problems, enabling some STEM graduates to progress faster in their careers than non-STEM graduate colleagues.

- STEM generalist (and non-STEM) employers recruit STEM graduates for different reasons; some focused more on their numeracy and analytical skills, others their approaches to problem-solving, yet others their technical knowledge and skills. It was the ability to apply some STEM knowledge and derived employability skills more broadly which seemed to be most highly valued.

Transitions and pathways post-16 to further and higher education

Transitions in our education system and onwards into further and higher education are about ensuring smooth learning progression and cultural adjustments, clearly understood choices leading to appropriate qualifications, and well signposted pathways towards challenging and rewarding careers.

The transitions and pathways from secondary to further and higher education are the subject of close current scrutiny in the Scottish Government's 2011 post-16 education paper[14] to ensure that they are cost-effective and efficient, and that they impact positively on students' further learning, skills and job prospects at a time of rationalisation and education spending cuts. Scarce resources must be used to best effect. The main issues are as follows:

- There is the issue of pupils making the right choices and accessing the right advice earlier in their secondary education in order to have the right qualifications to enable them to find places in their chosen subjects at college and university and thereafter in their chosen careers.

- There is the long-standing question of ensuring much more effective use of the sixth year at school, where many learners have already obtained university places, and the better articulation of the sixth year with the first year of university.

There is the challenge of employers not finding the skilled graduates they require in Scotland. The SEEAG welcomes the focus of attention on transitions and pathways in post-16 education report[14]. This raises some specific issues for STEM education which we discuss below.

Post-16 Education

The Scottish Government's (2011) pre-legislative paper[14] sets out far-reaching proposals to reform the post-16 education and skill system to create more flexible and accessible learning opportunities and pathways, with a specific emphasis on young people. Section 4 of the paper discusses strengthening the alignment of non-advanced learning and skills with jobs and growth and refers both to the skills needs of the key economic sectors (including life

sciences and energy) and the importance of enabling learners to develop a broad range of knowledge, skills and attributes that will enhance lifelong job prospects. In section 7 the paper proposes a reform of the college sector through regionalisation of colleges to form larger, stronger, more influential institutions that can respond to local and regional demand within a national framework.

The SEEAG welcomes this more strategic approach to aligning the provision offered by colleges and training providers to the labour market and agrees that this may enhance progression into career opportunities in science, engineering and technology. There are two important points to make in relation to the regionalisation of colleges, which is being undertaken in a context of a severe reduction in funding. Firstly, provision in science and engineering is resource intensive and therefore vulnerable to cuts in expenditure, which presents a threat to expensive laboratory and workshop-based facilities. On the other hand, regionalisation offers an opportunity to develop new partnerships aligned with regional economic activity and priorities, and to invest in consolidating the best resources to create regional centres of excellence. These need to be described as measurable outcome targets.

Secondly, regionalisation should complement colleges' ability to work collaboratively at national level to support emerging economic priorities across Scotland; for example the recently formed national consortia of colleges will develop infrastructure and learning resources for both the renewable energy and life sciences sectors.

Recommendation 7.1
It is recommended that, as the reform of the post-16 education system is taken forward, the Scottish Government and the Scottish Funding Council (SFC) should prioritise the preservation of STEM provision and invest in the further development of capacity in colleges in STEM subjects at regional and national level, aligned with labour markets and economic priorities.

Secondary – Higher Education transitions and pathways

Universities are being strongly encouraged to promote access via more flexible and non-traditional routes, with the establishment of 'articulation hubs' linking colleges and universities around Scotland (ref) and the creation of pathways through college Higher National qualifications into second/third year at university. However, only about 3,600 students per year follow this learning pathway***. Students are largely still making traditional choices, along well-trodden pathways of progression, driven perhaps by financial constraints and concerns about poor employment prospects.***

Uptake of the Advanced Higher Grade qualifications and Science Baccalaureate is low, largely because these qualifications are not yet widely required for entry into most STEM courses at Scottish Universities. The quality

of the Advanced Higher relative to the A-level appears to be better recognised and the qualification more widely demanded in English universities, but this may quickly change. Fast-tracking of well-qualified students from school into second year of four-year university STEM degrees has been available for many years in some Scottish universities, but is not widely taken up, commonly for social reasons. This may change in coming years in response to financial pressures on students and parents. In addition, some Scottish universities have signalled their intention to move to three-year undergraduate degrees.

The narrow STEM discipline base of Scotland's secondary education system and in particular the restricted choice of SQA STEM qualifications provide obstacles to fast-tracking by able students if they do not yet have the appropriate subject knowledge to bypass first year at university in science disciplines that are not available at the senior level in schools. This same obstacle also restricts learners' awareness of the wide STEM subject choice available at universities and the diversity of subsequent STEM career pathways. While changes of subject choice are easily accommodated within the broad and flexible four year Scottish degree, as students become more aware of other STEM subjects and wider career opportunities, this becomes much harder to accommodate within three-year degrees. There are real and significant financial costs attached to wrong degree subject choice that can be ill-afforded by students and their parents and by universities. One solution to these problems is to make available a wider choice of (one-year) STEM Highers at sixth year to provide senior learners with a wider and more realistic perspective of STEM in higher education and in the world of work and at the same time to address the restricted STEM subject choice now available in the Senior Phase. The proposal for a revised UCAS 'post-qualification application' (PQA) system currently under discussion would also support more flexible and 'aware' pathways.

Recommendation 7.2
In order to broaden the STEM base and the awareness of young people about the nature and breadth of STEM subjects, it is recommended that a range of National 5 and Higher units and courses in more applied sciences such as Earth science and Biotechnology should be developed and promoted by SQA in the senior phase (see also recommendations 4.2 and 4.5).

While signposting of new and alternative pathways is important, this does not necessarily change the minds and routes for learners. Students are also agents of change, and should be consulted. It is also important that learning destinations are recognised and valued.

Recommendation 7.3
It is recommended that, as the Scottish Government, Scottish Funding Council and Skills Development Scotland (SDS) take forward proposals to develop and raise awareness of more flexible pathways from secondary education through further and higher education, specific consideration is given to enhancing choice of progression pathways in STEM subjects and to raising awareness of alternative progression options and pathways into work through effective STEM career management skills (see also recommendation 4.3).

Obstacles to choosing a STEM career

The DBIS paper[53] suggests that a STEM job or STEM career is not a clear concept and that final year university students studying more vocational subjects such as engineering definitely wish a career related to their degree. Between half and one third of students in other STEM degree subjects are not fully decided; reasons for seeking non-STEM employment included:

- other fields being seen as of more interest
- mixed perceptions about where earnings are best
- the profile and reputation of some major employers
- STEM had a less attractive image.

However, these reasons were felt by the Careers Research and Advisory Centre (CRAC) who conducted the research[86] to be perceptions arising from lack of real knowledge about STEM employment and unrealistic expectations among STEM graduates.

For employers, especially those in STEM Specialist sectors, the CRAC research confirms that many STEM graduates are attracted to other areas because of a lack of knowledge of STEM work and careers but also because the graduates perceive other areas to be of more interest. CRAC research also suggests this is more a case of ignorance rather than well-founded negative views. The paper concludes that with so many students apparently undecided and without well-founded views, there is much potential to help STEM students firm up career ideas while at university and beyond, especially in the first year or so after graduating when many appear to ‘drift away’ from STEM. It also suggests that STEM employers need to present their case more visibly, both in terms of the attractiveness of the offer and career prospects but also the opportunities for interesting and rewarding work within STEM employment sectors.

Transition to Work

Graduate entry into the SET workforce is not the only option. Alternative, attractive routes into work include progression into technician level jobs from HNC and HND courses in colleges and modern apprenticeships. There is a

strong tradition of apprenticeship training in the engineering industries and this is now being expanded into other sectors. The development of work-based progression routes and graduate apprenticeships will extend the value of alternatives to the traditional academic route, as well as meeting industry demand for a technician-level workforce. The Scottish Credit and Qualification Framework (SCQF) has an important role to play in supporting career paths that combine work and education in more flexible ways, as envisaged in the Scottish Government's recent paper post-16 education paper[14].

Recommendation 7.4
It is recommended that representative industry bodies consider and improve the presentation of employment and career opportunities to undergraduates.

Recommendation 7.5
It is recommended that representative industry bodies (Industry Advisory Boards) work with industry support organisations and Careers Guidance organisations (such as SDS) to consider, develop and promote relevant information on STEM careers and career pathways across all levels of education, identifying and promoting the transferability of STEM skills across the STEM Industries.

Gender equality across STEM

In Scotland, relatively similar proportions of males and females leave school with Higher Grade and Advanced Higher Grade qualifications in STEM subjects. A gender imbalance begins to show in higher education. There are over 200,000 people with a STEM degree, of whom 71% are male. This is much higher than the overall figures for graduates in Scotland, where 50% are male (Office of National Statistics, April 2009-March 2010).
According to the Scottish Resource Centre (2010), only 29% of female SET graduates in Scotland are working in the sector in which they are qualified, compared to 52% of male graduates[87]. In 2008 women accounted for only 5.2% of SET-based self-employment in the UK[88], 15% of all those employed in SET occupations (similar to the UK as a whole) and 19% of those employed in higher skilled SET occupations in Scotland (data from Annual Population Survey 2010). It has been estimated that increasing the participation of women in the UK labour market could be worth between £15 billion and £23 billion (1.3-2.0% GDP), with STEM accounting for at least £2 billion.

Although recent years have seen significant increases in the number of female STEM graduates and postgraduates, the numbers who proceed to take up senior positions in universities, research, business and industry remain proportionately much smaller than in the case of their male counterparts. In a straitened economy where education is free, the failure to provide a workplace where skilled individuals – whether male or female – can progress and thrive is a wasted investment in human capital and represents a serious loss of potential for Scotland.

Attracting and retaining more women in the STEM workforce to boost economic growth is a public policy challenge which demands public, private and third sector solutions. Recognising under-representation of women in STEM-based careers, particularly at senior level, the Royal Society of Edinburgh, with the involvement of the Chief Scientific Adviser for Scotland, has launched an inquiry into how Scotland might lift the barriers for STEM career paths and established a Working Group to develop a cohesive and comprehensive strategy for Scotland to increase both the proportion of women in the STEM workforce and the number who rise to senior positions in universities, institutes and business. The inquiry highlights that the under-representation of women in STEM is of particular concern given the strategic importance of this field; economic growth relies heavily on innovation and knowledge, especially in science and technology. The group is deliberately focusing on issues around those women already trained in STEM subjects as opposed to the take-up of science at schools. After a wide-ranging consultation process and a number of exploratory events, the group is preparing a series of practical and achievable recommendations. These will be targeted towards specific stakeholder groups including UK Government; Scottish Government; funders and investors; academies, learned and professional bodies and scientific societies; universities and research institutes, business and industry employers. The full report with recommendations is due in April 2012.

Employer concerns

Despite industry demand for employees with STEM skills, the UK education systems are struggling to provide them. The Confederation of British Industry (CBI)/Education Development International (EDI) education and skills survey for 2010[89], suggests there is an undersupply of STEM skills at all levels and the problem is likely to get worse. The CBI policy adviser on education and skills concludes that *"Over the next three years, more than half of all employers predict difficulty finding the STEM talent they need, which could act as a barrier to business growth in key areas such as low-carbon manufacturing and the creative industries".*

Employers in the UK's video-games and visual-effects industries voiced their concerns about a skills shortage in the Next Gen skills review[90], published by NESTA (National Endowment of Science, Technology and the Arts) in February 2011. Traditional UK science-based industries such as pharmaceuticals and chemicals are also concerned. The outgoing director general of the Association of the British Pharmaceutical Industry stated that: *"The UK pharmaceutical industry is highly successful and presents exciting opportunities for young people with the right skills. But we are facing a skills shortage in some areas, even allowing for global recruitment. The sector contributed a trade surplus of £7 billion to the UK economy in 2009".*

The Chemical Industries Association (CIA) [91] predicts a shortfall of 40,000 key workers at technical and operational level across the sector and related industries across the UK. To address this skills shortage, the CIA wants to see

the education system revised across secondary schools and further and higher education to include, among other things, revamped vocational education at 14-19, more specialist STEM-qualified teachers, new academies with science specialisms and an overhaul of CPD for science teachers.

The Science and Innovation Strategy for Scotland Consultation Paper (2006)[92] notes that in 2003, Scotland's businesses on average invested in research and development (R&D) at around half the rate as in the UK as a whole; at 40% of the OECD average; and at 30% of the target in the European Union for 2010. Over the last six years there has been some improvement in our figures, but clearly much remains to be done. Much investment is concentrated in a few sectors, many of them foreign-owned. Losing one or two firms could seriously reduce the Scottish figures but, conversely, attracting one or two major firms willing to spend substantial amounts on R&D could improve the figures dramatically. Total Scottish R&D puts Scotland in the 3rd quartile while business R&D is in the 4th quartile, reflecting relatively strong R&D performance by the public sector[93]. The increased capacity of Scotland to retain and use its wealth of STEM graduate talent to the benefit of its economy will depend on the strengthening and widening of its R&D base, particularly in business and industry.

Summary of concerns

The above research indicates that throughout education:

- ***there is a lack of clarity and understanding around the opportunities and career paths across the STEM industries and also the wider economic and personal opportunities that STEM skills would allow***
- ***learners are not always being given a clear steer on the range of skills and technical qualifications necessary to be successful in STEM careers***
- ***the perception of STEM industries and careers and job roles within STEM are not always viewed positively***
- ***there is a need to encourage a higher level of entrepreneurialism in STEM learners***
- ***there is a major failure to employ and retain sufficient women within the STEM workforce***
- ***there is significant weakness in Scotland's private sector R&D base that diminishes its economic capacity and leads to the loss from Scotland of much of its graduate talent.***

Current Initiatives

A range of agencies, stakeholders and partners are working to respond to many of the challenges highlighted above. Some key examples were presented to SEEAG and are summarised in the description below:

1. My World of Work (MyWOW)[94]

The Scottish Government's Career Information, Advice and Guidance (CIAG) Strategy reaffirms its commitment to the provision of all-age CIAG as a key element in the Scottish skills system, but highlights the compelling case for doing things differently in response to service user expectations. While positioning Skills Development Scotland (SDS) as the strategic lead in the development and delivery of CIAG services, the Strategy recognises the different roles of a range of partners and underlines the importance of working together to provide high quality CIAG. To successfully implement the CIAG strategy, SDS will make the most of modern technologies to offer a personalised service and work effectively with partners to develop and strengthen career management skills of individuals. The SDS aim is to offer customers an integrated service, comprising a mix of interventions through different channels including face to face, online, contact centre and through partners. The Curriculum for Excellence provides an ideal context within which to embed career management skills.

A key part of this activity is SDS's new online service '*My World of Work'*, which aims to help people plan, build and direct their career throughout their working lives. Providing information on skills, learning and employment, it supports the Scottish Government's ambitions for the improved delivery of an 'all age, universal careers service'. Customers can see jobs in action; build their CVs; search for vacancies and explore training opportunities in a way that is personal to them. There is a wide range of video clips of people talking about their job roles and a significant magazine element with exciting, current content that is relevant to the world of work.

MyWoW will enable and empower individuals to develop career management skills that will assist them in researching, learning and understanding their strengths and skills and how to match these to realistic career choices informed by up-to-date industry and labour market information from the STEM industries.

My WoW is part of the SDS wider ambition to provide a more integrated CIAG approach offering customers a mix and balance of services, involving face-to-face, online and through its contact centre. It will set out to connect the way that each individual lives, learns and works, offering them the greatest chance of making successful career decisions. The ambition of SDS for MyWOW is to develop a web service that builds on its valued face-to-face and contact centre services by providing people with additional support to help them plan a career, build on it and direct it so that, throughout their lives, they can choose options that maximise their potential.

The first phase of My World of Work is complete, went live in August 2011 and is currently in use by careers advisers across SDS and the education system. Driven by customer demand and insight it now provides the online tools that customers and colleagues said they would most value. SDS should continue to extend the relevance of My World of Work to STEM related careers and involve employers in contributing to its further development.

2. Sustainable STEM Learning Communities

Sustainable STEM Learning Communities will enable local key industries to raise awareness of their industry and the career paths and opportunities within them, whilst becoming better integrated across the education system and ultimately breaking down barriers to work experience for learners. These should interface locally or regionally with developing teacher and school networks, such as professional learning communities involving (for example) schools, colleges, universities and science centres, which SEEAG is advocating as local and regional support structures for delivery of professional development and implementation of CfE.

Examples

The Life Science sector is piloting Sustainable Learning Communities with Midlothian Council in Edinburgh and Lothians, with a further pilot in development in the West Highlands. The Sustainable Learning Communities model uses the former NASA Space School model to create a framework for local sustainable learning communities bringing together schools, further education, higher education and local iconic industry partners with a view to raising awareness of key sectors locally, providing productive industry and education links which allow the relevance of STEM and other subjects to be highlighted and supported within Curriculum for Excellence, relative to and with support from local industry. Pilot projects of this type will provide useful experience in order to develop further Sustainable Learning frameworks encompassing other key sectors and STEM related industries at a local and regional level.

3. STEM Transitions Programme

The STEM Transitions programme highlights and maps the various routes into STEM further study and careers whilst allowing the learner to experience the world of work enhancing their understanding of STEM job roles.

Example

SEMTA Scotland, the Sector Skills council for Life Sciences, along with SQA, Forth Valley College under the auspices of Scotland's Colleges Life Science and other partners including industry and SDS are in the process of developing and trialling a life science transitions programme highlighting the qualification routes and assisting the development of positive first destinations for learners studying either *Skills for Work Laboratory Science* or the Science Baccalaureate routes through integrating work experience in the sector with study. The programme is being trialled with Skills for Work level qualifications through Forth Valley College with consideration being given to widening the programme to include the Science Baccalaureate over the next year. The model, once evaluated, will be considered for other STEM subjects covered by Skills for Work, National Progression Award and Professional Development Award courses.

The transitions programme will interface with the Schools for Excellence Sustainable Learning Community model highlighted above.

4. Life Sciences Skills Partnership

The formation of provider hubs such as Life Sciences Skills Partnership, which may be replicated across other key sectors, allows providers, industry and partners to focus on developing the skills and qualifications required by STEM industries. Following on from the successful SDS/Scotland's Colleges Life Science Key Sector workshop the formation of *Life Sciences Skills Partnership* was agreed to inform and develop initiatives and interventions arising from the Scottish Life Sciences Skills Survey[85] conducted by the partners within the People work stream of the Life Sciences Industry Advisory Board.

The Life Science Modern Apprenticeships (MA) college core deliverers form, with partners including SDS and SEMTA Scotland, the steering group which will consider qualifications, community and industry engagement working within and partnering on projects such as those mentioned previously as well as aligning closely with the Life Sciences Industry Advisory Board *People* work stream in order to assist in delivering under the Life Sciences Skills ecosystem objectives.

5. Modern Apprenticeships

Modern Apprenticeships allow learners to learn and develop while working. Industry gains work ready candidates who are developing the most up to date skills and knowledge in fast-paced areas.

SDS is funding the Life Sciences MA and a new Wind Turbine Service Technician MA for the Energy sector developed in partnership with Renewable UK and Carnegie College. Working closely with Industry Advisory Boards and Sector Skills Councils, SDS and partners will continue to respond to industries' apprenticeship needs, with new and enhanced apprenticeships for the energy sector under discussion. A number of LAs are taking on Modern Apprentices to train as school technicians. This will create a virtuous circle of providing training leading to valuable jobs that themselves will make an important contribution to the improvement of STEM education. It is recommended that all Local Authorities should consider adopting this approach.

6. Traditional Apprenticeships

During the last few decades there has been a decline in traditional three- or four-year apprenticeships. The traditional apprenticeship model of training is more widely used in successful economies in Europe and beyond than in the UK[95]. Traditional apprenticeships, if provided on an appropriate basis, have a number of strengths which lead to a well skilled STEM workforce on a cost effective basis to both the apprentice and their employer. During the apprenticeship the apprentice earns a relatively low 'training wage' in return for the training received. The apprentice will initially be a cost to the employer but for at least the latter half of the apprenticeship should contribute positively to

the productivity of the employer thus more than recouping the costs of training. Research evidence[96] shows that whilst an apprenticeship in engineering is relatively expensive compared to other sectors this investment is, on average, paid back within two years. A traditional apprenticeship promotes a relatively strong psychological contract between the apprentice and employer resulting in lower staff turnover, a better fit between skills possessed by employees and the skills required by the employer and some control over skill-shortages potentially pushing up wage rates. There is also evidence that apprentices bring innovation into workplaces.

7. Industry Advisory Boards – Skills Groups

Industry Advisory Boards are keen to raise the profiles of their industries and the aptitudes, skills and qualifications required as well as current and future career paths and opportunities and do so in partnership with education and support agencies. SDS is heavily involved in the Energy Industry Advisory Board and recently published the Energy Skills Investment Plan[97].

SDS is also lead or co-lead for the public sector for the Life Sciences Industry Advisory Board *People* work stream and the Chemical Sciences Scotland Skills Group as well as lead for the SEEAG Workstream 4 on Further Learning Training and Employability in STEM. A key part of the work across these groups is taking cognisance of similarities in overall objectives to ensure information sharing to avoid duplication of effort and create consistency of message thereby allowing effective and productive partnership development.

8. STEM and Life Science Labour Market Information (LMI) Events

A series of LMI events are enhancing the STEM industry knowledge of careers advisers and guidance staff across SDS and the education system raising awareness with clients of the wide range and levels of career paths and opportunities within STEM industries.

In February 2011 SDS and SEMTA staged a Labour Market Information Event at the Glasgow Science Centre (GSC) for 60 careers and guidance advisors from across SDS, further and higher education. The day-long programme included feedback from employers across the spectrum of Life Sciences on what qualifications, skills and qualities they are looking for from a future workforce. A speed networking with a variety of employees and prospective employees on why they choose to study STEM subjects and ultimately enter a STEM career took up most of the afternoon.
Prospective employees included recent graduates, PhD students, modern apprentices and Science Baccalaureate students and included STEM demonstration sessions from GSC such as *“Who Wants to be a Scientist?”* and an overview of the up and coming BodyWorks display coming to the third floor of GSC.

Summary

These initiatives, all of which will undergo further development, represent significant progress against the agenda set by the Science and Engineering Education Action Plan and in response to the research evidence cited earlier in this section. Throughout this work, cognisance is being taken of the synergies and links across all of the SEEAG Plan workstreams and an effort is being made to more closely align progression across the education, academia, industry and the public sectors.

Moving Forward

As illustrated above, there are a plethora of initiatives and programmes aimed at improving awareness of STEM careers and enhancing progression into further and higher education and employment. Whilst continuing to progress these it is equally important for all stakeholders across the STEM landscape to find innovative ways to share and scale while encouraging consistency as well as equality of opportunity for STEM learners and STEM career seekers. A conference of SEEAG stakeholders gave the highest priority to co-ordinating existing activity and improving communication.

Recommendation 7.6
Education Scotland and SDS should work together to co-ordinate the provision of information on STEM related resources, activities and opportunities through effective communication networks and to encourage the participation of schools in activities that enhance awareness of STEM related careers. This should include capitalising on Curriculum for Excellence (CfE) by mapping existing and future STEM resources and activities to CfE and communicating this effectively to education and industry.

Recommendation 7.7
The organisations implementing the Career Information, Advice and Guidance (CIAG) strategy should recognise the importance of redressing negative or ill-informed perceptions of careers in science, engineering and technology through support for initiatives that enhance co-ordinated industry engagement with the education sector, including CPD, industry placements, and practical project work.

Recommendation 7.8
Employer bodies should:

- **invest more resources in overcoming the negative or ill-informed perceptions of STEM careers**
- **institute practical programmes to attract and retain a much greater number of women in STEM careers.**

Recommendation 7.9
SDS and others tasked with CIAG should promote greater gender equality in the STEM workforce through well chosen examples and case studies.

Recommendation 7.10
Employers should be encouraged to provide a greater number of traditional apprenticeships where appropriate training is provided over a three- or four-year period on a basis economic to both apprentice and employer.

PART 8 SUPPORTING A CREATIVE SCIENCE CULTURE

The issues and proposals raised in this report so far are set in our cultural environment; a Scottish culture that supports and encourages a deeper and stronger engagement with science and technology as easily as it does with, for instance, music or film, will make the attainment of the specific objectives easier whilst aiding the full expression of our creativity.

In consequence, SEEAG was asked to give consideration to how the wider cultural environment and the image of science and technology, nationally and internationally, can be strengthened and improved.

Public science engagement

The early model of 'one-way (or "deficit") communication' and education (for example, through presentations to audiences or distributing facts and information) has given way to a new model of 'two-way dialogue' in which scientists and others also listened to, and acted upon, the public's views, generating new or improved knowledge. Thus, over time, there has been a shift from public understanding of science to public science engagement, and it has become clear that these are not the same. The National Coordinating Centre for Public Engagement suggests that public engagement *"generates mutual benefit, with all parties learning from each other through sharing knowledge, expertise and skills. In the process, it can build trust, understanding and collaboration, and increases the sectors relevance to, and impact on, civil society".*

Science is inseparable from society and public science engagement can have a wide range of benefits individually and socially. These may include:

- better understanding of science and tackling perceptions and misunderstandings
- informed personal lifestyle choices and contributing to social and environmental challenges
- promoting skills and learning throughout life
- raising societal awareness of the strength of science done in Scotland
- creating a society that has an understanding of new technology and scientific advance
- increasing trust in the science process and promoting societal empowerment and involvement in the development of science-oriented policy
- promoting science as an integral part of culture – of equal importance to the arts and humanities.

Current public attitudes to science

The most comprehensive and recent survey of current views is the Public Attitudes to Science (2011) Report[98]. This builds on previous research and

provides further evidence that the UK public values science and is interested in finding more out about it:

- four-fifths (79%) agree that, *"on the whole, science will make our lives easier"* while just over half (54%) agree that *"the benefits of science are greater than any harmful effect"*
- four-fifths (82%) agree that *"science is such a big part of our lives that we should all take an interest"* and two-thirds (67%) think "*it is important to know about science in my daily life"*
- there is an appetite for hearing more about science, with half (51%) saying they hear and see too little information about science.

However, alongside these more positive highlights, there remain concerns about what scientists do 'behind closed doors', and the extent to which they consider the wider consequences of their work. More generally, the speed of development in science and the ethical dimensions of 'science going against nature' still worry many people. The extent of these concerns is topic dependent, with the survey indicating that, among the various topics explored, GM crops, nuclear power and animal experimentation are currently particularly contentious.

In addition, the research also highlights the challenge of public engagement with science. More people (56%) say they do not feel informed about science, and scientific research and developments than those who do (43%). In addition, while many are keen for the public to be involved in decision-making on science issues, most do not want to be personally involved.

Finally, a recent literature review[99] found evidence for the influence of childhood experiences on adult attitudes and interests around science and the arts, thereby reinforcing the need for public science engagement initiatives to reach young people through school or college or through engaging with parents and other family groups.

Platforms for Public Science Engagement

Current provision for public science engagement

The public science engagement sector in Scotland is complex, involving many institutions (public, private and charitable) and individuals (scientists, technologists and others) in its funding and delivery. Each of these pursues its own audiences with its own aims, purposes and motivations which may complement or overlap with those of others. In addition, there is a range of publics, each with its own interests, in part defined by geography, ethnicity, age or socio-economic parameters or by 'ease of reach'. Finally, public science engagement may take place within a number of locations.

This complexity presents both challenges and opportunities for the future of public science engagement in Scotland. In 2010, the Scottish Government Office of the Chief Scientific Adviser (OCSA) undertook a non-exhaustive review (unpublished) of Scotland's informal science landscape. Many of the

science engagement activities (for example, the Scottish science centres and festivals) reach children and young people of school/college age as well as adults while others focus on one or the other.

A number of these activities are funded by the Scottish Government and its associated agencies, authorities and Non Departmental Public Bodies (NDPBs), in pursuit of its science education and engagement goals. A number are funded by other organisations including: local authorities; business and industry; academia, the research councils and associated bodies; research institutes; professional bodies and institutes/institutions; trusts, endowments and other private and public benefactors; museums, zoos and gardens; and so on. The complexity of the sector illustrates the richness and variety of our scientific culture.

The opportunities in which the public can take part in science related activities may be viewed as 'platforms' for achieving public science engagement. Their role in relation to students, teachers and schools is dealt with in Part 6 of this report, while this section considers their role in relation to the general public of all ages.

Scottish science centres

Scotland has four science centres – Glasgow Science Centre, Dundee Science Centre, Our Dynamic Earth (Edinburgh) and Satrosphere (Aberdeen). All represent considerable investment from the public purse and provide a visible and physical, year-round focus and resource for public science engagement in each of the cities in which they are located. The scale, focus and content of each centre is different but common elements in their strategic visions include exciting and inspiring visitors of all ages with high quality science engagement experiences and demonstrating science and technology's importance and relevance to everyday life.

All of the centres offer a wide range of activities that may be grouped into two channels:

- 'in-reach': taking place within the centre (including permanent and temporary exhibitions, shows, events and educational programmes); in 2010-11, the four centres collectively attracted 593,500 visitors of which 73% were public visitors (adults/family) and 27% were education visits (schools and colleges)
- 'outreach': taking place outside the centre (including in community and other public venues, road shows, school events and satellite centres); in 2010-11, the four centres collectively reached 108,600 people of which 64% were public audiences and 36% were education audiences.

Recommendation 8.1
The outreach role of the science centres is as important as their in-reach role and the annual figures on outreach activity should be used to agree annual objectives between the centres and the Scottish Government.

In terms of visitor numbers alone, the centres are clearly an important public science engagement platform in Scotland. Visitor and omnibus surveys[100,101,102]conducted in 2008-10 revealed that while visitor profile, extent of outcomes delivered and level of satisfaction varied between centres, the overall picture across the four centres was of family-friendly venues delivering significant outcomes around science.

However, these surveys also highlighted some challenges in terms of equality of access to the centres, with social groups C2DE, ethnic minorities and disabled groups, and rural/remote communities less likely to be aware of and/or visit the centres. Transport subsidy funding provided to the centres by OCSA is intended to help address this to some extent by supporting visits for community groups from remote, socially and/or economically disadvantaged communities, but success in reaching these audiences has been mixed across the centres.

The centres have also increasingly attracted greater proportions of overseas visitors – particularly the centres in Edinburgh and Glasgow – indicating that they have gained ground in the attractions market. All the centres retain top level Visit Scotland ratings. This is worth noting in the context of Part 9 regarding Scotland's international reputation on science but it reinforces the issue of penetration of the Scottish domiciled population.

Scottish science festivals

Science festivals provide short, concentrated bursts of public science engagement which engage the public with a wide range of science and technology in an interactive and enjoyable manner. The concept of science festivals was invented and developed in Scotland by the Edinburgh International Science Festival (EISF) and has been copied all over the world.

Although some science festivals are more international in their profile (for example, the EISF), most generally have a local or regional feel, and are often established where there is local expertise or demand for public science engagement or where an enthusiastic interest group takes the lead. They give audiences a chance to discover science being done on their doorstep and further afield and can contribute to local, regional and/or civic pride. Depending on programming arrangements, they can reflect or promote local priorities or interests (e.g. engineering, biosciences or renewable energy). One of their great strengths is that they view attendees as participants rather than visitors or customers where the outcome of an event is partly the result of their own input.

Their lack of a permanent physical base allows festivals to be highly flexible and means that they can take place in parts of Scotland that may be distant from, or not have local access to, other opportunities for public science engagement such as a science centre or university outreach programme.

There are 17 science festivals across Scotland – a large number per head of population and comparing favourably to elsewhere in the UK. The Scottish festivals vary widely in ambition, scale and audience emphasis (young people or adults), collectively attracting 167,000 people in 2010-11 ranging from 70,000+ audiences at the largest festival to 1,500 at the smallest.

The 'bottom up', flexible format of the festivals allows them to be particularly responsive both in form and content to developments in science and technology and the social issues they raise. Along with other public science engagement platforms, the network of science festivals across Scotland provides a national vehicle to engage the public in debate on key scientific issues, thereby preparing fertile ground for more active and informed citizenship.

The combined provision of science centres and festivals in Scotland, clearly by far the best national provision within the British Isles and, anecdotally, within the world, provides a rich, responsive and vital part of our nation's education and culture. The initiative for most of them came from the bottom up but without the substantial and sustained support by the Scottish Government they would not be as successful.

Recommendation 8.2
The Scottish Government's support for science centres and science festivals is essential and effective and it is recommended that financial and other support should continue to be provide so that the centres and festivals may fulfil their valuable roles.

Discussions, talks, lectures and hands-on science

A number of organisations deliver public discussions, talks and lectures in a number of formats to a variety of audiences, and provide the public with the opportunity to meet and hear from practising scientists and to engage in debate on key scientific issues. This platform includes:

- *Cafés Scientifiques* (presentation-and-dialogue events to a non-specialist audience in non-threatening venues such as bookshops or theatres)
- the Royal Society of Edinburgh's series of lectures, debates and conferences on topical issues drawing on the expertise and knowledge of its Fellowship and other eminent scientists and researchers
- events organised by universities, many of which are around science, often in partnership with other science-based organisations such as science centres, festivals and research institutes; this agenda is largely driven by the UK research councils and Scottish Funding Council

- ‘Citizen Science’ programmes which involve adults and family groups in doing hands-on science – monitoring and recording of environmental or conservation targets and parameters – are run by a number of organisations including non-departmental public bodies (e.g. Scottish Environmental Protection Agency (SEPA), Scottish Natural Heritage (SNH) and conservation NGOs (e.g. Royal Society for the Protection of Birds, RSPB)
- initiatives delivered by a range of Government and publicly funded agencies, non-departmental public bodies and other research organisations, often in partnership with other organisations and platforms, usually in the context of particular strategic drivers (e.g. the Knowledge Transfer/Exchange strategy developed by Scottish Government’s Main Research Providers[103]).

The landscape is extraordinarily diverse in this area and co-ordination and co-operation are a significant challenge. There is clearly an opportunity to improve alignment within this area and all platforms should consider if co-operation with others will extend the range and depth of their reach.

Museums, libraries and visitor attractions

A number of institutions and visitor attractions deliver a range of public engagement, much (though not all) of it around science. These platforms benefit from being attractive to a broad cross-section of the public as they are seen as familiar, non-threatening, enjoyable family-oriented attractions that present their activities in ways that are not only educational and interesting but can be engaging and fun. Many also have their own formal education programmes that are referred to in Part 6. This platform includes:

- museums, libraries and galleries – national and local – provide opportunities to explore aspects of science and technology by offering experiences and activities utilising their collections and research activities; they also provide relevant venues for other organisations to deliver public science engagement activities

- zoos and conservation, rural, marine and environmental science organisations; examples include the Royal Zoological Society of Scotland (Edinburgh Zoo), the Royal Botanic Garden Edinburgh, the Scottish Seabird Centre, Deep Sea World and other marine/sea life centres and visitor centres at national and local nature reserves, National Parks, Forestry Commission sites and nature reserves.

Much of the public science engagement taking place in this area may not be explicitly presented as such to visitors. Science may be one element of a wider ‘cultural’ focus, so the impact of science linked to artefacts or collections may not be as strong as in a more focussed science centre, for example. This may be both a help (in that there is an opportunity to present science in a full context to parts of society that may otherwise be difficult to engage) and a hindrance (in that an opportunity is lost to illustrate to people that what they are learning about is science, and is part of their wider culture).

Cross-cutting issues applicable across platforms

Consideration of the above platforms highlighted a number of strengths and challenges, many of which are generic or cross-cutting in nature and apply to more than one of the platforms.

Structural issues

Although there are examples of good practice in Scotland, views received during the stakeholder consultation for this report[81] suggest that there is arguably too much competition, territoriality and duplication of effort and activity in some areas. The vigour and width of public science engagement is a great strength of Scottish life but whether funding derives from the public or private sector a more efficient application of available resources towards agreed and shared visions and goals with a wider geographical and social reach should be sought.

All funders of public science engagement may seek to drive increased partnerships or thematic focus through positive conditions of funding and this may continue to be one of the most effective levers. However, alongside this there is a need for a behavioural change in some parts of the sector and a need for all delivery organisations to move away from the rivalry and competition (highlighted by the SE21AP consultation process) and to embrace a spirit of co-operation and collaboration and recognise the wider benefits and greater good that may accrue from collective action. Research Councils and industry can play an important role in this and should be actively encouraged to develop long term partnerships with existing science engagement platforms.

Quality

The issue of quality in public science engagement has been repeatedly raised during consultations. Use of this term can be confusing unless the aim and context are made explicitly clear, as quality can relate to a number of aspects of public science engagement. For example, it may be used to relate to the quality of the science engagement activities themselves, the processes used to develop them, the approach(es) used to engage the public, the impact on the public, individual science communicators, or visitor facilities at venues etc. Clarity is needed therefore when calling for the development of measures of quality about exactly what is being assessed or judged.

To optimise the overall experience, impact and longer-term legacy on the recipient, all aspects of quality – background process and final product – need to be right, working well and properly aligned. Quality assessment and evaluation tools should be sensible, usable, appropriate, light-touch, reflective, quantitative and qualitative, and based on sound social science, consider people, processes and products, and incorporate feedback to enable responsive change.

Over the past few years the concept of quality and impact in relation to a number of publicly funded platforms has been reviewed. Some examples are: HMIEs review of the Scottish science centres' schools programmes in 2007[104] and follow-up in 2009[105]; the Evaluation Framework (based on a Results Chain logic model) developed for capturing a number of aspects of quality of experience and impact on those visiting the Scottish science centres; and OCSA's commissioned review of Generation Science – the primary school outreach initiative of the EISF – which generated guidelines that are now provided as a condition of grant in relation to a number of OCSA's other funding streams.

These have been very valuable, and for the major platforms, particularly those identified in section 6, regular independent review is essential.

Recommendation 8.3
Major public science engagement providers should undergo periodic review and evaluation by Education Scotland every four years to ensure provision of a high quality product and evaluate its medium-term impact. More established platforms should be encouraged to support smaller or less well-established ones.

Accessibility and awareness

It is vital that the whole population of Scotland has ready access to at least one public science engagement platform. Although the situation is improving, many opportunities are not available in some rural and semi-rural areas due to their remoteness and associated transport costs. A number of platforms claim to deliver across Scotland, but in reality this is not the case and/or the costs are prohibitive. This is not satisfactory. However, some platforms such as science festivals may provide, as discussed above, a more flexible and responsive solution.

Current accessibility should be assessed and kept under review so as to ensure that the overwhelming majority of the population can attend a public engagement in science event within half-an-hour's travel.

Recommendation 8.4
All public science engagement platforms should be encouraged or required by Government and other public funding bodies to collect, analyse and respond to, more detailed statistics on their audiences (around age, ethnicity, socio-economic status and geographic origin) to enable better targeting of opportunities at less engaged or more deprived or remote sections of the community.

Recommendation 8.5
Government should consider directing public funding to ensure these deprived or remote communities can benefit from the provision of public science engagement opportunities within half an hour's travel time.

Recommendation 8.6
All public science engagement platforms should be encouraged or required by Government and other public funding bodies to develop more customer led, bottom up, approaches to programming of activities: better understanding of, and response to, the science interests of both engaged audiences and non-engaged potential audiences.

Democracy

Some public science engagement initiatives contribute to the development and review of public policy and are an important element in our civic society. However, they should all be conscious of this potential role and seek to make such connections wherever possible in order to assist the democratic process. In particular, the Scottish science centres and festivals provide the opportunity to organise debates and discussions locally, and in cooperation nationally, on particular scientific and social issues.

Recommendation 8.7
All public science engagement platforms should be encouraged or required by Government and other public funding bodies to consider how they can better connect their audiences with public policy-making and other democratic and citizenship processes.

Media

Broadcast news and programming, TV, magazines and newspapers, and, increasingly, online content provide the key components for communication of our culture of science and technology. The growth of digital broadcasting has also increased opportunities, most notably on the BBC's range of channels. A detailed consideration of the issues at a UK level features in the 2010 report 'Science and the Media: Securing the Future' from the DBIS Science and Media expert group[106]. As most people find out about new developments in science through the media, it is important that we seek to ensure there is a wide and informed representation of science and technology.

There is a significant difference between 'programming' and 'news'. Whilst there is much to applaud in the range of science programmes, news coverage of science does not adequately reflect the breadth and quality of science research and innovations taking place in Scotland and elsewhere, and the impact they have on our lives. In print journalism, there are occasionally good science-based features, particularly in weekend supplements, but they do not

reflect fully the many aspects of the science taking place and coverage within news pages is limited.

New opportunities are afforded by new media (although these are also not accessed by all). Online versions of traditional media outlets provide the space to explore detailed science stories. Social media are increasingly people's first port of call for finding out about news and events. In the case of blogs or 'citizen journalism', in particular, they also offer the public increased opportunities for direct access to scientists themselves, without a journalistic 'filter'. The Beacons Project hosted a workshop in 2010 that explored a number of these issues[107].

Feedback from a number of media outlets (via survey questions and a number of meetings/discussions held by OCSA over the last 18 months) (unpublished) suggests there is no specific agenda to exclude science stories from coverage in the Scottish media and there are no particular barriers to them covering science stories from Scotland. However, a number of media professionals admitted that their organisation 'could do more' to cover science, engineering and technology.

With the exception of BBC Scotland, there are no specialist science correspondents working in the Scottish media. Science stories could therefore be picked up by health, business, general news or general features correspondents/writers. There are risks here: no-one is horizon-scanning and building contacts, and at the same time science stories may 'fall through the net'. However, this situation also presents opportunities for science coverage, as a number of writers at any media outlet have the potential to be engaged in any particular story.

Networking opportunities may have a role to play here, but will only be successful if both scientists and media have the time to devote to them. Feedback from the media suggested editors and their staff are unlikely to afford the time to attend such events on the regular basis required to achieve their full value. As one respondent described it, *"casual networking doesn't really work in a modern newspaper context – it has to be specifically aimed at producing a specific story. The reporter cannot justify the time otherwise."*

The internet explosion is also playing its part in public science engagement with an enormous diversity of formal and informal science related sites, blogs, surveys, journalism, multimedia etc. As in any other sphere in the media, the quality, accuracy and rigour or science-based material can be variable. The boundary between social media and more traditional Media is not clearly defined as many media organisations have websites that are heavily used by the public for a range of purposes including exploring science.

Nevertheless, the range and quality of coverage of science and technology within all media could be improved to address some of the problems and issues noted above and a brief proposal is described below.

Recommendation 8.8
It is recommended that the Scottish Government initiates a feasibility study into the establishment of a Scottish Media Centre (as outlined in the annex below).

International profile

The international image of Scotland is an amalgam of landscape, history, golf, arts and whisky. Scotland has a history and a current practice of outstanding scientific achievement but when science and technology are mentioned the reference is usually historical and around the enlightenment or other examples – James Watt, James Clerk Maxwell, the invention of telephones and television etc. – rather than around its current science strengths.

However, Scotland's science and research base continues to be among the best in the world today. Investment in Scotland's research base has produced very positive results in terms of quality and impact. The 'Evidence Report'[108] provides information on the performance of Scotland's research base relative to that of the 26 comparator countries responsible for around 95% of the world's top research. The report confirms that Scotland's research (which takes place primarily in the public sector) is cited by other researchers around the world more often than any other country, in comparison to its Gross Domestic Product (GDP). Scotland excels in agricultural sciences, pharmacology and toxicology, space sciences, and plant and animal sciences – all more than 50% above the world average in terms of relative citation impact.

However, the Anholt-GfK Roper Nation Brands Index (NBI) which assesses and monitors how Scotland's brand is perceived around the world by online panellists indicates that this reputation may not be well recognised internationally or among the wider public. Recent data indicate that Scotland ranked 24th out of 50 nations for its overseas reputation in making a major contribution to science and technology.

Resolving this apparent mismatch between reality and perception will require a multi-faceted approach from a wide range of partners, and work continues by a range of organisations, including (amongst others) Scottish Government and its enterprise agencies and partners, Scottish Development International and the higher education sector with the UK research councils.

Two proposals are recommended for further consideration and development.

1. Scottish Media Centre

Establishing a Scottish Media Centre, hosted by an independent third party, whose role would be to disseminate information on Scottish scientific research and technological departments and applications indirectly via the established media and directly through social media, would assist in overcoming the

misperceptions. A key role of the centre would be to engage with the international press, specialist and general, to promote the activities and successes and raise further awareness of Scotland's scientific and technological achievements. The centre would provide a link to addressing some of the recommendations set out in the 2010 report 'Science and the Media: Securing the Future' from the DBIS Science and Media expert group.

This is covered by recommendation 8.8.

2. EISF

Scotland has a unique asset in the EISF which retains a high reputation as the first of all festivals and for its programming but also for the unstinting support it has given to new festivals across the world. The EISF sees visits each year from international delegations; in addition the British Council organises substantial multi-country delegations to visit every two years.

More recently, it has been employed by the Government of Abu Dhabi to deliver a science festival in the United Arab Emirates which is intended to establish itself as a regional annual event, and has also been asked to present proposals to Nottingham and Beijing. Alongside the summer Edinburgh arts, fringe and book festivals, the EISF continues to emphasise the place of science in Scottish culture, both at home and internationally.

It has, in the past, acted as a showcase for Scottish Science both for the general participant but also for specialist audiences together with commercial and foreign Media. A greater emphasis on this role and its international marketing and reach should be encouraged and supported.

Recommendation 8.9
The Scottish Government should encourage and support the international role of the EISF.

Annex: Proposal for a Scottish Science Media Centre

Proposal

To establish a virtual centre, hosted by an independent third party, to disseminate information on Scottish scientific research and technological developments and applications indirectly via the established media and directly through social media.

Background

In order:

- to contribute to a situation in which the Scottish people are given access to news in this area and to contribute to a confident culture in which science and technology (S & T) is an established part

- to ensure wider knowledge of Scottish S & T outwith Scotland, it is necessary to obtain much wider coverage within all media than is currently the case.

This task is made more difficult with the decline of the traditional print media where there are no dedicated S & T reporters in Scotland, except for the very welcome recent appointment by BBC Scotland, and few even in Britain and the lesser but noticeable decline in the BBC and ITV networks' science and technology based output. In counterbalance to that has been the rapid and enormous growth of social media, a situation that continues but is also fluid and in many respects uncertain in its effect.

In these circumstances it is not sufficient any longer to rely upon 'news organs' seeking out 'news' or in many cases having even the ability to respond to S & T news when it demands coverage. In these circumstances it is necessary to be a provider of information in appropriate formats for the various, and very different, media.

Remit

- to source S &T 'stories' from around Scotland and deliver them appropriately to all media
- in particular to integrate elements from different sources to make a full and attractive story
- to provide a resource and signpost for journalists
- to arrange S & T events in Scotland that attract journalists and media attention
- to exploit social media
- to liaise with Scottish Schools of Journalism.

Format

A Scottish Science and Technology Media Centre would comprise of two journalists with a science and/or technological background or experience. They would be hosted by an appropriate organisation, itself independent of science and the media, providing accommodation, telecommunications and administrative support. They would report to a small Board comprised of representatives of the Media, S & T industry, Universities and Government, with a remit to provide a wide range of content representing the richness and quality of Scottish Science and Technology, which is both attractive and *suitable* for use by all forms of media.

They would work with existing practitioners in the field, notably public relations within universities, Government, research institutes and companies, particularly seeking to synthesise and generalise to create attractive and interesting 'stories'.

They would not only issue material but arrange events attractive to journalists and appropriate others, which would bring them to Scotland to allow direct engagement with scientists, technologists and processes.

Secondarily, they would provide a first port of call for journalists seeking information on an 'S & T story', directing them to the right institution/person to provide a response or background.

Composition of Board

A small Board of, say, seven people with appropriate experience and backgrounds who would provide overall leadership and guidance.

Cost

Staffing of two journalists with one administrator, requiring IT, an events budget and back up costs paid to the host: to a first approximation – £200,000.

Funding

The Science Media Centre in London shares some of the remit described above. Its base funders are two charities and the UK Government, but it also receives considerable funds from other charities, media organisations and industry, with such contributions being restricted to no more than 5% of the centre's income so as to ensure its independence.

A similar funding 'cocktail' should be explored for the Scottish Media Centre.

Targets

It would be necessary to identify appropriate criteria with some numbers based around additional and greater coverage in Scotland, Britain and internationally.

Length of trial

Three years, with evaluation commencing in the third year.

Next steps

If the broad idea finds favour then it needs to be expanded and refined, including comparison with experience in England, so that a formal proposal can be the subject of consultation.

List of recommendations

Part 2 Initial Teacher Education

Recommendation 2.1
It is recommended that the Scottish Government ensures that a clear and detailed record of the qualifications and capacities of the STEM teacher workforce in Scotland, particularly in the primary sector, is developed and maintained to inform the reform of initial teacher education and to address the weaknesses in STEM teaching in primary education measured in the 2008 TIMSS report.

Recommendation 2.2
The Scottish Government should adapt a programme to Scotland with similar aims and aspirations to the Teach First Programme.

Recommendation 2.3
It is recommended that Scottish Government, Universities and the General Teaching Council for Scotland (GTCS) support and implement the following Donaldson Report recommendations in relation to STEM Primary ITE:

Recommendation 12 (Donaldson Report)
Increased emphasis should be given to ensuring that primary students have sufficient understanding of the areas they are expected to teach.
Recommendation 13 (Donaldson Report)
Clear expectations about necessary prior learning for teacher education courses should be developed together with diagnostic assessments and online resources to allow students to reach that baseline in advance of formally embarking on a course. This mechanism could also be used to support existing teachers.
Recommendation 14 (Donaldson Report)
The professional component in programmes of initial teacher education should address more directly areas where teachers experience greatest difficulty and where we know that Scottish education needs to improve. That will require a radical reappraisal of present courses and of the guidelines provided by GTCS.

Recommendation 2.4
It is recommended that in order to move the profession to a stronger base the Scottish Government in partnership with universities establishes targets for increasing the number of trainee teachers admitted to Primary Teaching ITE with enhanced STEM qualifications by:

- **admitting an increased number of students with STEM qualifications up to and including degree level**
- **raising now the qualification requirement for Primary Teaching students to include a minimum of SCQF level 5 or above in a science and mathematics, increasing to SCQF level 6 or above in a science and mathematics within five years**
- **acquiring and making available on an annual basis data on the STEM qualifications of ITE applicants and recruits.**

Recommendation 2.5
It is recommended that the National Partnership Group considers the particular needs of primary schools and their teachers.

Part 3 Professional Development

Recommendation 3.1
It is recommended that the Scottish Government ensures effective implementation of CfE by providing funding to support an increase in the time provision for CPD to 50 hours per year for all STEM teachers, and that primary teachers devote at least 15 hours per year to STEM CPD.

Recommendation 3.2
It is recommended that STEM CPD providers ensure CPD quality by embedding new relevant content and knowledge within appropriate contexts and with effective pedagogy and delivery, and engage teachers and pupils in active, hands-on investigative learning.

Recommendation 3.3
It is recommended that virtual learning environments are recognised as a support – and not as a substitute – for interactive, hands-on CPD.

Recommendations 3.4
It is recommended that teachers and schools, in partnership with CPD providers and local authorities, should plan and evaluate CPD, taking into account its impact on young people's longer term progress and achievements.

This is consonant with recommendations 34 and 37 in the Donaldson Report.

Recommendation 3.5
It is recommended that the following should be subject to ongoing evaluation and feedback by Education Scotland in partnership with local authorities:

- **The strengths, weaknesses, impacts and costs of various models.**
- **The quality and impact of externally provided CPD.**
- **The role and impact of CPD in improving and updating pedagogy, improving assessment literacy, developing subject knowledge, increasing teacher confidence and its effect on pupil learning environment and experience.**
- **How teachers themselves best respond to professional development (what works best for them, how they can best be supported, how they can contribute to the development of their colleagues).**
- **How teachers can influence and engage with CPD development and strategy.**

Recommendation 3.6
It is recommended that a greater range of CPD undertaken by teachers should be formally accredited.

Recommendation 3.7
It is recommended that Education Scotland continues to expand the focus of STEM-Central and for STEM-Central to become the entry portal for teachers to Education Scotland STEM materials.

This is in agreement with the SSAC Report Recommendation 7[17] (see also recommendation 6.1 of this report).

Recommendation 3.8
It is recommended that Education Scotland should develop CPDFind to make it more user friendly for both CPD providers and for teachers. It should be easy to post and retrieve information about CPD events.

Recommendation 3.9
It is recommended that industry, universities and colleges work collaboratively with CPD providers and other partners to ensure the evaluated quality, relevance, appropriateness and longer term impact on learners of the support they provide. Partnership working between industry and CPD providers should be strongly encouraged rather than directly with schools.

Part 4 The New Curriculum: Additional Challenges

Recommendation 4.1
It is recommended that SEEAG and the Deans of Science and Engineering Group working with STEM-Ed Scotland and teachers from all STEM subjects lead and organize a project to exemplify good interdisciplinary and cross-curricular teaching and learning, emphasising its foundation on sound subject knowledge, and to make these examples and associated CPD widely available to teachers.

Recommendation 4.2
It is recommended to universities that more graduates in, for example, engineering, electronics, earth and environmental science disciplines should be encouraged and recruited into teaching in order to broaden and enrich the discipline knowledge base of the profession and to contribute to developing and enhancing interdisciplinary approaches to science learning and teaching.

Recommendation 4.3
It is recommended that Scottish universities give much greater recognition to the Advanced Higher and Science Baccalaureate qualifications in order to promote a higher level of uptake across Scottish schools and colleges, and to encourage more flexible pathways to college and university entry.

Recommendation 4.4
It is recommended that Education Scotland provides national guidance to schools to ensure that schools devote sufficient curriculum time to the study of STEM subjects to allow pupils to develop a deep learning of the pillars of knowledge and skills of STEM as well as an understanding of the practical and interdisciplinary nature of STEM.

Recommendation 4.5
It is recommended that SQA develop mechanisms for increasing the breadth of CfE STEM subject qualifications provision, and that Education Scotland and universities provide the necessary support for the redevelopment and delivery of these qualifications nationally.

Recommendation 4.6
SEEAG supports the SSAC Recommendation 9[17] that there should be close monitoring by Education Scotland of the curriculum models introduced across Scotland to ensure that a sufficient breadth of opportunity to study the full range of sciences is available to all pupils across Scotland.

Recommendation 4.8
It is recommended that SQA develop exemplars of interdisciplinary questions, together with assessments that measure the different inputs from the different sciences.

Recommendation 4.9
It is recommended that SQA assessments should use a broader range of interdisciplinary contexts within which to locate examination questions, and explore innovative courses (perhaps units within courses) which deliberately blur traditional subject boundaries. These courses should include innovative assessment methods (synoptic questions, extended assignments and collaborative project work)[42].

Recommendation 4.10
It is recommended that Education Scotland initiates and supports a programme to implement the teaching of thinking and problem-solving skills within the STEM curriculum in order to raise academic achievement.

Recommendation 4.11
It is recommended that SSERC build on its previous work and that of The Royal Society to research the cost of adequately delivering the STEM curriculum at all stages in Scottish schools. Budget recommendations should be based on reasonable assumptions for use of consumable materials by pupils and the writing off costs of equipment over sensible lifetimes. These figures should be widely circulated and regularly updated.

Recommendation 4.12
It is recommended that schools and their local authorities ensure pupils are provided with quality learning experiences where they can develop the skills of practical investigation and problem solving. This can only be done when there is sufficient equipment for hands-on pupil practical work in small groups or individually. Schools must be provided with adequate funds to provide and maintain sufficient equipment for effective hands-on experiences for all pupils based on the figures provided in SSERC's recommendations in 4.11 above.

Recommendation 4.13
It is recommended that Education Scotland in carrying out their inspection of schools should review and comment on the school's allocation of resources against SSERC's recommendations in 4.11 above.

Recommendation 4.14
It is recommended that local authorities and schools ensure that STEM departments and faculties have sufficient well trained, specialist technicians to ensure delivery of practical STEM work within CfE, and that in parallel with recommendation 2.1 the Scottish Government ensures that a clear and detailed record of the number, qualifications and capacities of the STEM technician force in Scotland is collected and maintained.

Recommendation 4.15
It is recommended that the Scottish Government should implement a numeracy and mathematics action plan based on the findings of the national survey, that this implementation recognises the fundamental role of numeracy and mathematics plays as a foundation to science, and ensures that these are more widely used in an interdisciplinary way in the teaching of science, engineering and technology.

Recommendation 4.16
It is recommended that the Scottish Government and Education Scotland support and ensure the wider development of skills and expertise in the teaching of early years (emergent) science by identifying and building upon existing expertise in Scotland, and through teacher education and professional development.

Part 5 Support Structures for Teachers and Learners of STEM Subjects

Recommendation 5.1
It is recommended that the Scottish Government consider the development of hub schools as proposed in the Donaldson Report[12] and that hub schools with a STEM specialism fulfil the additional role of centres of excellence in STEM, with strong links to professional learning communities, universities (including ITE faculties and STEM departments) and industry, and with the capacity to make available a broad provision in science subjects and interdisciplinary science teaching.

Recommendation 5.2
It is recommended that Education Scotland and local authorities ensure that support and resources are made available to stimulate the development and growth of Professional Learning Communities in STEM learning and teaching, with strong links to universities and/or colleges where possible.

Recommendation 5.3
It is recommended that the Scottish Government ensures that support and resources are made available to professional societies, colleges, universities, science centres and other stakeholders to support and extend Professional Learning Community networks.

Recommendation 5.4
It is recommended that LAs establish and maintain a record of professional (teacher) learning communities in their authorities, and Education Scotland develops and maintains a profile of learning communities across Scotland, as a basis for stimulating their wider establishment and development, and to document examples of good practice.

Recommendation 5.5
In order to ensure that industry input into the curriculum and CPD is aligned with students and teachers needs and CfE in future it is recommended that Education Scotland ensure that all industry engagement is developed and delivered in partnership with appropriate pedagogical partners (see also recommendation 6.6).

Recommendation 5.6
Building on the proven success and large scale of SSERC's work, delivered with support from Local Authorities and the Scottish Government, it is recommended to the Scottish Government that SSERC, working with partner organisations and linked to the NSLC in York, becomes Scotland's national science learning centre, with enhanced

provision to deliver a wider range of support for STEM teaching and learning.

Recommendation 5.7
It is recommended that local authorities and headteachers ensure a supportive framework is in place to allow senior and middle managers and leaders to support and facilitate all those delivering STEM education to our young people. The leadership provided previously by those in the roles such as LA subject advisers and subject principal teachers is still required. LAs and head teachers should ensure that sufficient staff with the range of expertise required across the whole STEM spectrum be employed to provide leadership for STEM education in schools.

Part 6 Real Life Science, Engineering and Technology: Increasing Young Peoples' Engagement and Understanding

Recommendation 6.1
It is recommended that STEM Central be extended and supported by Education Scotland so as to develop it into a useful 'one stop shop' for teachers, learners and parents in terms of practical STEM and science engagement ideas, activities and providers. This support should include encouraging STEM engagement providers to contribute information and links to/from STEM Central.

Recommendation 6.2
It is recommended that the basic engagement for all schools described in 6.3 below, being offered through the four providers together with the Science Centres and the major Science Festivals, are reviewed on a four-year cycle by Education Scotland.

Recommendation 6.3
It is recommended that schools are supported by local authorities and the providers by the Scottish Government so as to ensure that all schools are enabled to benefit from a STEM Ambassador(s), a Generation Science visit, the establishment of a Scottish Council for Development and Industry (SCDI) Young Engineers and Science Clubs (YESC) and an annual visit out to a Science Centre or Festival.

Recommendation 6.4
We therefore recommend that the Office of the Chief Scientific Advisor work with the Scottish Science Centre Network and the University of the Highlands and Islands to establish a network of regional STEM engagement hubs. These hubs should focus on improving access, quality and delivery of practical STEM activities to schools.

Recommendation 6.5
It is recommended that industry, rather than through individual contributions, should provide their support through the main providers listed in 6.3 so as to provide high quality, independently evaluated, educational benefit with national coverage.

Recommendation 6.6
It is recommended that any future science engagement funding available from the Office of the Chief Scientific Adviser should reflect the strategic priorities of this report alongside Scottish Government objectives.

Recommendation 6.7

We recommend that Universities Scotland help and support universities by providing examples and case studies on how to work more closely with science engagement providers to fulfil the impact criteria of research council funding.

Part 7 Beyond School: Further Learning, Training and Employment

Recommendation 7.1
It is recommended that, as the reform of the post-16 education system is taken forward, the Scottish Government and the Scottish Funding Council (SFC) should prioritise the preservation of STEM provision and invest in the further development of capacity in colleges in STEM subjects at regional and national level, aligned with labour markets and economic priorities.

Recommendation 7.2
In order to broaden the STEM base and the awareness of young people about the nature and breadth of STEM subjects, it is recommended that a range of National 5 and Higher units and courses in more applied sciences such as Earth science and Biotechnology should be developed and promoted by SQA in the senior phase. (see also recommendations 4.2 and 4.5).

Recommendation 7.3
It is recommended that, as the Scottish Government, Scottish Funding Council and Skills Development Scotland (SDS) take forward proposals to develop and raise awareness of more flexible pathways from secondary education through further and higher education, specific consideration is given to enhancing choice of progression pathways in STEM subjects and to raising awareness of alternative progression options and pathways into work through effective STEM career management skills (see also recommendation 4.3).

Recommendation 7.4
It is recommended that representative industry bodies consider and improve the presentation of employment and career opportunities to undergraduates.

Recommendation 7.5
It is recommended that representative industry bodies (Industry Advisory Boards) work with industry support organisations and Careers Guidance organisations (such as SDS) to consider, develop and promote relevant information on STEM careers and career pathways across all levels of education, identifying and promoting the transferability of STEM skills across the STEM Industries.

Recommendation 7.6
Education Scotland and SDS should work together to co-ordinate the provision of information on STEM related resources, activities and

opportunities through effective communication networks and to encourage the participation of schools in activities that enhance awareness of STEM related careers. This should include capitalising on Curriculum for Excellence (CfE) by mapping existing and future STEM resources and activities to CfE and communicating this effectively to education and industry.

Recommendation 7.7
The organisations implementing the Career Information, Advice and Guidance (CIAG) strategy should recognise the importance of redressing negative or ill-informed perceptions of careers in science, engineering and technology through support for initiatives that enhance co-ordinated industry engagement with the education sector, including CPD, industry placements, and practical project work.

Recommendation 7.8
Employer bodies should:

- **invest more resources in overcoming the negative or ill-informed perceptions of STEM careers**
- **institute practical programmes to attract and retain a much greater number of women in STEM careers.**

Recommendation 7.9
SDS and others tasked with CIAG should promote greater gender equality in the STEM workforce through well chosen examples and case studies.

Recommendation 7.10
Employers should be encouraged to provide a greater number of traditional apprenticeships where appropriate training is provided over a three- or four-year period on a basis economic to both apprentice and employer.

Part 8 Supporting a Creative Science Culture

Recommendation 8.1
The outreach role of the science centres is as important as their in-reach role and the annual figures on outreach activity should be used to agree annual objectives between the centres and the Scottish Government.

Recommendation 8.2
The Scottish Government's support for science centres and science festivals is essential and effective and it is recommended that financial and other support should continue to be provide so that the centres and Festivals may fulfil their valuable roles.

Recommendation 8.3
Major public science engagement providers should undergo periodic review and evaluation by Education Scotland every four years to ensure provision of a high quality product and evaluate its medium-term impact. More established platforms should be encouraged to support smaller or less well established ones.

Recommendation 8.4
All public science engagement platforms should be encouraged or required by Government and other public funding bodies to collect, analyse and respond to, more detailed statistics on their audiences (around age, ethnicity, socio-economic status and geographic origin) to enable better targeting of opportunities at less engaged or more deprived or remote sections of the community.

Recommendation 8.5
Government should consider directing public funding to ensure these deprived or remote communities can benefit from the provision of public science engagement opportunities within half an hour's travel time.

Recommendation 8.6
All public science engagement platforms should be encouraged or required by Government and other public funding bodies to develop more customer led, bottom up, approaches to programming of activities: better understanding of, and response to, the science interests of both engaged audiences and non-engaged potential audiences.

Recommendation 8.7
All public science engagement platforms should be encouraged or required by Government and other public funding bodies to consider

how they can better connect their audiences with public policy-making and other democratic and citizenship processes.

Recommendation 8.8
It is recommended that the Scottish Government initiate a feasibility study into the establishment of a Scottish Media Centre.

Recommendation 8.9
The Scottish Government should encourage and support the international role of EISF.

BIBLIOGRAPHY

1. Information extracted from Scottish Government Key Sector Report: Energy Sector, May 2009. http://www.scotland.gov.uk/Publications/2009/05/energysectorreport/pdf
2. Information extracted from Scottish Government Key Sector Report: Life Sciences, January 2010. http://www.scotland.gov.uk/Publications/2010/01/26105228/8
3. Information extracted from Scottish Government Key Sector Report: Creative Industries, December 2009. http://www.scotland.gov.uk/Publications/2009/11/24133819/8
4. A Low Carbon Economic Strategy for Scotland: Scotland – a Low Carbon Society, November 2010. http://www.scotland.gov.uk/News/Releases/2010/11/15102614; http://www.scotland.gov.uk/Publications/2010/11/15085756/0
5. Why Science Education Matters. Scottish Science Advisory Committee. 2003.
6. Trends in International Maths and Science Survey (TIMSS) 2007. OECD, 2008.
7. Mathematics and science leagues tables 09/12/2008. http://scotland.gov.uk/News/Releases/2008/12/09163549
8. Programme for International Student Assessment (PISA) 2009 survey, Highlights from Scotland's results. Statistics Publication Notice, Scottish Government, 2010.
9. PISA (2009) Results: What students know and can do. OECD, 2010.
10. Quality and equity of schooling in Scotland. OECD, 2007.
11. Action Plan on Science and Engineering for the 21st Century. http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/Plan
12. Teaching Scotland's Future, Report of a review of teacher education in Scotland. (Donaldson G), Scottish Government, 2011.
13. Science and mathematics education, 5-14: A 'state of the nation' report. The Royal Society, 2010.
14. Putting learners at the centre: delivering our ambitions for post-16 education. Scottish Government, September 2011. http://www.scotland.gov.uk/Publications/2011/09/15103949/15
15. Devolved School Management, (Cameron D), Scottish Government, 2011.
16. Advancing professionalism in teaching, Report of the review of teacher employment in Scotland. (McCormac G), Scottish Government, 2011.
17. Science education: Enhancing Support for schools through collaboration. Scottish Science Advisory Council, January, 2012. http://www.scottishscience.org.uk/node/122
18. Scottish Science and Engineering Education Action Plan, Teaching Excellence Initiative: Input from Deans of Science & Engineering. Report to SEEAG, 2010.
19. The high cost of low educational performance – the long-run economic impact of improving PISA outcomes. OECD Programme for International Student Assessment (PISA) 2007.

20. The economic cost of the US education system. McKinsey & Co, 2010.
21. How the world's best performing schools systems come out on top. McKinsey & Co, 2007.
22. How to be top. The Economist, October 18, 2007.
23. The link between teacher quality and student outcomes: a research synthesis. Goe, Washington DC: National Comprehensive Center for Teacher Quality, 2007.
24. Physics in schools and colleges: teacher deployment and student outcome. Smithers, A and Robinson, P, University of Buckingham, 2005.
25. Primary science and mathematics education: getting the basics right. Royal Society 'State of the Nation' report on 5-14 science and mathematics education in the UK (2010).
26. The UK's science and mathematics teaching workforce: A 'State of the Nation' report. The Royal Society, 2007.
27. www.teachforamerica.org
28. www.teachfirst.org.uk
29. Rising to the challenge: a review of the Teach First Initial Teacher Training programme, OFSTED, Jan 2008.
30. Those who can, teach. The Economist, July 30, 2011.
31. Confidence and Understanding in Teaching Science and Technology in Primary Schools, Harlen W., Holroyd C., and Byrne M., Scottish Council for Research in Education, p195, p212, 1995.
32. Primary Teachers' Understanding of Concepts in Science and Technology. Harlen W. and Holroyd C. The Scottish Office Education and Industry Department, p6, 1997.
33. 2007 Scottish Survey of Achievement, Headline Report and Supporting Evidence, Scottish Government, June 2008.
34. Teaching Profession for the 21st Century, McCrone, G. A.,2001.
35. Does teacher professional development have effects on teaching and learning? Blank, RK, de las Alas, N, Smith C, Analysis of evaluation findings for programs for maths and science teachers in 14 states in Report from the National Science Foundation, 2008.
36. A status report on teacher development in the United States and abroad. Darling-Hammond, L, Wei, RC, Adree, A, Richardson, N and Orphanos S, Dallas, Texas; National Staff Development Council, 2009.
37. Synthesis of research and evaluation projects concerned with capacity-building through teachers' professional development: final report. Bolsm R & Weindling D, London, UK: General Teaching Council for England, 2006.
38. What do specialists do in CPD programmes for which there is evidence of positive outcomes for pupils and teachers? Cordingley P, Bell M, Isham C, Evans D and Firth A, Technical Report. Research Evidence in Education Library. London: EPPI-Centre, Social Science Research Unit, Institute of Education, University of London, 2007.
39. What is teacher learning? P. Kelly, Oxford Review of Education 32(4), 505-519, 2006.
40. SSERC's Support for Science Education in Scotland through CPD. External Evaluation Final Report, Scottish Centre for Research in Education (SCRE), University of Glasgow, 2011.
41. www.ltscotland.org.uk/stemcentral/index.asp

42. www.ltscotland.org.uk/cpdfind/index.asp
43. Science and Engineering Education Advisory Group (SEEAG) and Deans of Science Group: Report of Subgroup on Interdisciplinary Teaching and Learning, February 2011. http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/DeansofScienceInterdisciplinaryLearning
44. http://www.gla.ac.uk/stem/routemapforstemeducation/
45. Improving uptake and enhancing achievement in science in Scottish schools, Jackson, J, (2007).
46. Provision of support for Scottish teachers of STEM subjects. Jackson, J, Paper for SEEAG, 2011. www.scotland.gov.uk/seeag.
47. Preparing for the transfer from school and college science and mathematics education to UK STEM higher education. A State of the Nation Report, The Royal Society, Feb 2011.
48. Higher Order Skills Excellence Group report. 2011. http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/excellence/HigherOrderSkills
49. 30 years on – a large antiFlynn effect? The Piagntian test Volume and heaviness norms 1975-2003. Shayer M et al, British Journal of Educational Psychology 77 (1) 25-41,2007.
50. 30 years on – a large antiFlynn effect? (II). 13- and 14-year olds. Piagetian tests of formal operational norms 1976-2006/7. Shayer M & Ginsberg D, British Journal of Educational Psychology 77 (1) 25-41, (2009).
51. Dimming. The Economist, November 1, 2008.
52. Thinking to improve teaching and learning. Adey P, McGuinness C and Topping K.
53. Department for Business Innovation and Skills, Research Paper Number 30, STEM Graduates in Non STEM Jobs, March 2011. http://www.bis.gov.uk/assets/biscore/further-education-skills/docs/s/11-770-stem-graduates-in-non-stem-jobs-executive-summary.pdf
54. Standards and Quality in Secondary Schools 1995-2000: The Sciences, HMIe, 2001. http://www.hmie.gov.uk/documents/publication/sqssc.html
55. Science Teaching Resources: 11-16 year olds, London, The Royal Society, 1997.
56. Physics Equipment Lists, SSERC, 2001. www.sserc.org.uk
57. Funding Survey, SSERC Bulletin, (2001), 203, 4-8, 2001. SSERC.
58. The Funding of Scottish Physics Departments, Scottish Science Issues, 32, 6-11, 2001, ASE.
59. Boffins in battle of the budgets, Times Educational Supplement Scotland, 12 Mar 2004, 4, TES Scotland.
60. The Royal Society, Supporting Success: science technicians in schools and colleges, January 2002
61. Mathematics Excellence Group report, March 2011 http://www.scotland.gov.uk/Resource/Doc/91982/0114466.pdf
62. The paradigm shifts. Journal of Emergent Science 1: 3-4, 2011.

63. Preschool pathways to science: facilitating scientific ways of thinking, talking, doing and understanding. Gelman R, Brenneman K, Macdonald G and Roman M 2010, Paul Brookes Publishing Co, Baltimore.
64. Training the preschool scientist in waiting. Amsel E and Johnston A, Journal of Developmental Psychology 31: 484-486, 2010.
65. Director of Education Survey, SEEAG. http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/DirectorsofEducationSurvey.
66. How the world's most improved school systems keep getting better, McKinsey, 2010.
67. Liberating Learning, Economist August 20th-26th, p27-28, 2010.
68. Reviews of National Policies for Education - Quality and Equity of Schooling in Scotland. http://www.oecd.org/document/18/0,3746,en_2649_39263231_39744402_1_1_1_1,00.html
69. Continuing to Build Excellence in Teaching: The Scottish Government's Response to Teaching Scotland's Future, March 2011.
70. STEM teachers in professional learning communities: from good teachers to great teaching. Fulton, K and Britton, T, National Commission on Teaching and America's Future, 2011. www.nctaf.org
71. STEM teachers in professional learning communities: a knowledge synthesis. Fulton K, Doerr H and Britton T, National Commission on Teaching and America's Future, 2010. www.nctaf.org
72. The current and future UK science workforce. Science Council, 2011. http://www.sciencecouncil.org/content/science-workforce
73. Capturing the leadership premium. McKinsey & Co, 2010.
74. Tears, laughter and camaraderie: professional development of head teachers. Woods et al, School Leadership and Management, 29, 253-275, 2009.
75. Improving School Leadership: Executive Summaries Beatriz Pont, Deborah Nusche, Hunter Moorman and David Hopkins, OECD, 2008.
76. Leadership and Strategic Management in Education, Bush T & Coleman M, Paul Chapman Publishing, 2000.
77. Modern Approaches to Understanding and Managing Organisations, Boleman L & Deal T, Jossey-Bass, 1984.
78. Middle Management – the key to organisational success? Peter Earley, in David Middlewood and Jacky Lumby, Strategic Management in Schools and Colleges, Paul Chapman Publishing, 1998.
79. 'Exploring young people's views of science education' Research published by Wellcome Trust, 2011. http://www.wellcome.ac.uk/stellent/groups/corporatesite/@msh_peda/documents/web_document/wtvm052732.pdf
80. 'Science and Engineering Education Advisory Group Workstream 3 Report' published by Scottish Government, 2011. http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/Reports/workstream3newversion
81. 'Stakeholder Consultation Report' published by Scottish Government, 2011. http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/ConsultationReport

82. ‘Science and Technology Committee - Ninth Report: Practical experiments in school science lessons and science field trips’ UK Parliament, September 2011. http://www.publications.parliament.uk/pa/cm201012/cmselect/cmsctech/1060/106002.htm
83. Skills Investment Plan for Energy http://www.skillsdevelopmentscotland.co.uk/our-story/key-publications/skills-investment-plan-for-the-energy-sector.aspx
84. Scottish Life Sciences Strategy 2011, Creating Wealth, Promoting Health http://www.lifesciencesscotland.com/media/14388/lss-strategy-2011.pdf
85. Scottish Life Sciences Quantitative Skills Survey Summary 2010 Life Sciences Industry Advisory Board http://www.lifesciencesscotland.com/connections/news/news-content/scottish-life-sciences-employer-skills-survey-2010.aspx
86. Career Information, Advice and Guidance in Scotland: A Framework for Service Redesign and Improvement, Scottish Government. http://www.icg-uk.org/ciag_in_scotland.html
87. Scottish Resource Centre for Women in Science, Engineering and Technology, Annual Report, Edinburgh: Scottish Resource Centre for Women in SET, 2010.
88. UK Resource Centre for Women in Science, Engineering and Technology Annual Review 2008-2009.
89. Building for Growth: business priorities for education and skills. Education Skills Survey CBI/EDI, 2011. http://www.cbi.org.uk/business-issues/education-and-skills/in-focus/education-and-skills-survey/
90. Next Gen. Transforming the UK into the world’s leading talent hub for the video games and visual effects industries. NESTA A Review by Ian Livingstone and Alex Hope. http://www.nesta.org.uk/publications/assets/features/next_gen
91. Science Education Britain’s next deficit? Chemical Industries Alliance, Steve Elliott, Chief Executive, Chemical Industries Association October 2010. www.cia.org.uk/Portals/0/Documents/Education%20leaflet_finalLR.pdf
92. Science and Innovation Strategy for Scotland: Consultation Paper, Scottish Government, October 2006.
93. D. MacRae, Chief Economist, Bank of Scotland, Presentation to Scottish Council for Development and Industry, 8.12.11.
94. Skills Development Scotland, My World of Work. http://myworldofwork.skillsdevelopmentscotland.co.uk/
95. The State of Apprenticeships in 2010:International Comparisons – Australia, Austria, England, France, Germany, Ireland, Sweden, Switzerland. Hilary Steedman, London School of Economics, August 2010.
96. The Net Benefit to Employer Investment in Apprenticeship Training. Chris Hasluck, Terence Hogarth, Beate Baldauf and Geoff Briscoe, University of Warwick, November 2010.
97. Skills Development Scotland, Energy Skills Investment Plan: http://www.skillsdevelopmentscotland.co.uk/our-story/key-publications/skills-investment-plan-for-the-energy-sector.aspx

98. Department for Business, Innovation & Skills, Public Attitudes to Science, 2011. Available from: http://bit.ly/jXpXfr.
99. Starting Young?: Links Between Childhood and Adult Participation in Culture and Science - A Literature Review, Scottish Government, 2011a. Available from: http://bit.ly/hGGwKt.
100. Final Visitor Research Report 2008-10: Scottish Science Centre Evaluation. Scottish Government, 2011b. Available from: http://bit.ly/rsALz9.
101. Science Centre Research: Omnibus Survey 2009 Report. Scottish Government. 2011c. Available from: http://bit.ly/tXBlWw.
102. Science Centre Research: Omnibus Survey 2010 Report, Scottish Government, 2011d. Available from http://bit.ly/tRFjnr.
103. Scottish Government Main Research Providers Knowledge Transfer/Exchange Strategy, 2011. Available from: http://bit.ly/oreWUc.
104. Review of the contribution of the Scottish science centres network to formal and informal science education, Her Majesty's Inspectorate of Education, 2007. Available from: http://bit.ly/txaiuH.
105. Review of the contribution of the Scottish science centres network to formal and informal science education: Report of Follow-Through Visits by HM Inspectorate of Education, Her Majesty's Inspectorate of Education, 2009. Available from: http://bit.ly/tdQ2QT.
106. Science and Media: Securing the Future. A report of the Science and the Media Expert Group. Department for Business, Innovation & Skills, 2010. Available from: http://bit.ly/c0iODY.
107. Report of the Engaging Citizens 2010 conference. National Co-ordinating Centre for Public Engagement, 2010. Available from: http://bit.ly/rAe6Ct.
108. International Comparative Performance of Scotland's Research Base. Scottish Government, 2010. Available from: http://bit.ly/bXA27j.

SEEAG MEMBERSHIP

Professor Anne Glover is Co-Chair of the Advisory Group. She was Chief Scientific Adviser for Scotland, with the role of enhancing Scotland's reputation as a science nation, from August 2006 to December 2011. Professor Glover holds a Personal Chair of Molecular and Cell Biology at the University of Aberdeen, and has honorary positions at the Rowett and Macaulay Institutes. She is an elected Fellow of the Royal Society of Edinburgh, a member of the Natural Environment Research Council, and a Fellow of the American Academy of Microbiology. Most of her academic career has been spent at the University of Aberdeen where she has an active research group pursuing a variety of areas from microbial diversity to the development and application of whole cell biosensors (biological sensors) for environmental monitoring and investigating how organisms respond to stress at a cellular level.

Professor Glover has now taken up post as the Chief Scientific Adviser to the European Commission.

Dr Ian Wall, Co-Chair. Until he retired recently Ian Wall was CEO of The EDI Group, a property and development Company, whose shares were owned by City of Edinburgh Council but was autonomous in its operation. It was responsible for developments across Scotland including Edinburgh Park, office developments in North Ayrshire and PARC, the Urban Regeneration Company redeveloping Craigmillar.

He is currently a member of the Court of Heriot Watt University and non-executive director of a number of organisations including The Edinburgh International Science Festival, which he invented, the International Centre for Mathematical Sciences, Children In Scotland, Glasgow Housing Association, Shelter UK, The Scottish Regeneration Forum and is Chair of WASPS Trust and the Scottish Poetry Library.

Stuart Allison is currently a Quality Improvement Manager in East Renfrewshire Council (ERC) – Education Department. He has chaired various National Quality Assurance Groups for assessment exemplars to support Curriculum for Excellence, recently completed a term as a member of the SCQF Quality Committee. Before working for ERC he was an International Project Manager employed by the Scottish Qualifications Authority and a senior consultant on Assessment and Evaluation having responsibility for World Bank and US Aid education development projects in Latvia, FYR Macedonia and the Kingdom of Lesotho.

Dr Janet Lowe CBE FRSE is a former Principal of Lauder College, Dunfermline (now Carnegie College). Janet is now a member of the boards of the Scottish Funding Council and Skills Development Scotland. She was Chair of their joint Skills Committee from 2005 and 2011. Janet is a member of the Court of the University of Dundee and also holds an honorary professorship at Stirling University.

Stuart Farmer is Head of Physics at Robert Gordon's College, Aberdeen. He has over twenty five years' teaching experience in a variety of Scottish schools and has been involved in many curriculum and assessment development projects. He is a Council member and Trustee of the Association for Science Education and Treasurer of the Institute of Physics in Scotland. He is a Chartered Science Teacher, has organised and delivered a wide range of teacher professional development across Scotland and beyond and is dedicated to promoting excellence in science teaching and learning.

Dr Heather Reid OBE is a physicist who presented the BBC Scotland weather forecast for over 15 years. She has successfully combined her TV role with promoting science to young people and the general public. She is Director of Public Engagement for Glasgow, City of Science, a Trustee of Glasgow Science Centre and former Chair of the Institute of Physics in Scotland. She also works closely with Education Scotland, SSERC and several universities.

Colin Graham is Professor of Experimental Geochemistry in the School of GeoSciences at the University of Edinburgh and Fellow of the Royal Society of Edinburgh (RSE). A founder of the Scottish Earth Science Education Forum (SESEF), which supports the teaching of earth and environmental science in Scottish schools, he serves on the RSE Education Committee, the Scottish Government's Higher Order Skills Group, and the SQA Qualifications Development Team for Environmental Science. He has a particular interest in interdisciplinary and cross-context science education, and the cascading of research ideas into classroom teaching and learning.

Janette Harkess joined SCDI as Director of Policy and Research in 2009. Previously, she was one of the most senior women in Scottish journalism holding the post of Deputy Editor of *The Herald*, Scotland for four years. Janette is an honorary Vice President of the Journalists' Charity; Vice-chair of Culture Sparks and sits on the boards of Scottish Youth Theatre and Common Purpose, Glasgow; she is a Commissioner to Scotland's Poverty Truth Commission and sits on the Church of Scotland's Economics Commission. In December 2011 Janette was appointed Head of Media for the Glasgow 2014 Commonwealth Games.

APPENDIX 3

LIST OF CONTRIBUTORS

Written Evidence

- Gillian Black, Director of Policy Affairs, OPITO
- Deans of Science and Engineering
- Schools Science Education Research Centre (SSERC)
- Janette Kean, ASE
- Local Authority representatives through the Directors of Education survey
- Professor Jack Jackson
- Moyna Kennedy, STEMNET
- Scottish Council for Development and Industry (SCDI)

Representation at SEEAG meetings

August 2010

- Graham Donaldson, in his capacity as Chair of review of teacher education
- The following contributed to SEEAG's Excellence Group considerations:
    - Lord Robert Winston, Imperial College, London
    - Dr Janet Brown, Chief Executive, Scottish Qualifications Authority (SQA)
    - Professor Stuart Monro, Scientific Director, Our Dynamic Earth
    - Professor Alyson Tobin, Scottish Deans of Science and Engineering
    - Fred Young, Chief Executive, Scottish Schools Equipment Research Centre
    - Margaret Anne Johnston, St Luke's School, East Renfrewshire

November 2010

- Alyson Tobin, Scottish Deans of Science and Engineering on the Excellence Group work

May 2011

- Louise Smith, CEO of Dundee Science Centre
- Wendy French, Development Officer, Learning and Teaching Scotland

July 2011

- Dr Janet Brown, SQA
- Alison Plummer, SQA

September 2011

- Professor Jack Jackson

Stand-alone Meetings

- 8 March 2011 – Dr Robin Hoyle and Sharon Macnab, Glasgow Science Centre; Hannah Crookes and Linda Leuchars, Dundee Science Centre; Gemma Catton, Satrosphere; and Dr Christine Angus and Prof Stuart Monro, Dynamic Earth
- 23 November 2011 – Meeting with Scottish Science Advisory Group
- 29 November 2011 – Meeting with STEMNET Contract Holders
- 16 December 2011 – Meeting with Moyna Kennedy, STEMNET
- 16 December 2011 – Meeting with Professor Jim Hough, Scottish Science Advisory Council

Representation at SEEAG Stakeholder Sessions – invitees

15 March 2011- Robert Gordon College

- Tom Horner, British Science Association
- Claire Thorne, RCUK Digital Economy Research, Aberdeen University
- Ken Skeldon, Aberdeen University
- Sam Cordiner, TechFest SetPoint
- John Graham, Aberdeenshire City Council
- Margaret Ritchie, Torry Academy
- Susan Walker, Aberdeen College
- Lynn Scanlon, Aberdeen City Council
- Ian Armstrong, Area Adviser, SCDI
- Mike Duncan, OPITO
- Louise Smith, Dundee Science Centre
- Alastair Dixon, Aboyne Academy
- Clare Neely, Macaulay Land Use Research Institute
- Mary Mackay, Whitehills School
- 6 Robert Gordon's College pupils and teachers

10 May 2011 – Dundee Science Centre

- Susan Kellington, Balcurvie Primary School, Fife
- Mary Logue, Angus Council Education Department
- Rhona Duncan, Menzieshill High School, Dundee
- Dr Paul Campbell, Public Engagement Champion, University of Dundee
- Prof John Palfreyman, Abertay University, Head of Contemporary Sciences
- Jennifer Young, Techfest Setpoint, Tayside Manager
- Prof Alyson Tobin, Dean of Science, University of St Andrews
- Dr Alan Bruce, Abertay University

- Brian Carroll, Harris Academy
- Prof Brian Hudson, University of Dundee, Associate Dean, School of Education, Social Work and Community Education
- June Jelly, Dundee City Council Education Development Services
- Dr Ken Scott-Brown, Abertay University
- Sarah Chew, Techfest Setpoint

12 July – Stirling Management Centre

- Dr Jenny Rodgers, Royal Society of Chemistry, Regional Co-ordinator, Scotland
- Kevin Price, CEO, Scottish Stem Cell Network
- Anne Conrad, Human Health/Chemicals Policy, Environmental Futures and Trends Unit, Scottish Environment Protection Agency
- David Pirie, Chief Officer for Science and Strategy, SEPA
- Steuart Cuthbert, Field Officer Scotland, Association for Science Education
- Tony Bragg, Quality Improvement Officer, Falkirk Council
- Sandra Lowson, Director, Global Web Limited
- Frank McKeever, Global Science

6 September 2011 – Royal Society of Edinburgh

- Lord Sutherland of Houndwood, Education Committee Convener
- Professor Sally Brown, Deputy Convener of Education Committee
- Professor Geoffrey Boulton, Member
- Keir Bloomer, Member
- Professor Graham Donaldson, Member
- Bristow Muldoon, Parliamentary Liaison Officer
- William Hardie, Secretary to the Education Committee

Peer reviewers

- Professor Susan Deacon
- Professor Lindsay Paterson
- Fred Young
- Moyna Kennedy
- Professor Alyson Tobin
- Gordon Doig, Institute of Physics
- Christina Potter, Principal, Dundee College
- Nicola Nielsen, Education Scotland
- Professor Stuart Monro, Our Dynamic Earth
- Professor Graham Donaldson

APPENDIX 4

SUPPORTING DOCUMENTS AND EVIDENCE

Submissions from external bodies		
Paper	Date	Weblink
STEMNET Scotland submission	December 2009	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/STEMNETScotland
SSERC – Initial Response to SEEAG	March 2010	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/SSERCSumbission
OPITO paper	July 2010	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/PaperfromOPITO
Deans of Science paper on excellence work	August 2010	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/Deans%20of%20ScienceandEngineering
Note of meeting between Ian Wall, John Tease, and Gordon Murray	October 2010	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/CommitteeProgressReport
Paper from Janette Kean on excellence in primary education	January 2011	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/ExcellenceinScineceEducation
Further paper from Deans of Science on excellence	January 2011	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/DeansofScienceExcellenceinEducation
Paper from Deans of Science on interdisciplinary learning	February 2011	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/DeansofScienceInterdisciplinaryLearning
Note from SEEAG Aberdeen stakeholder meeting	March 2011	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/RobertGordonColl
CPD Mapping paper	May 2011	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/CPDMappingProject

Local Authority CPD paper	June 2011	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/LocalAuthorityReport
Stakeholder conference report	July 2011	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/ConsultationReport/ConsultationReportpdf
Paper from SCDI on Young Engineers and Science Clubs	July 2011	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/YoungEngineersandScienceClubs
Paper on Glasgow Science Centre community engagement	Sep 2011	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/GlasgowScienceCentreCommunityEngagement
Paper on Dundee Science Centre outreach	Sep 2011	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/DundeeScienceCentreOutreach
Paper from Jack Jackson on centres of excellence	Sep 2011	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/CentresofExcellence
Directors of Education survey response	October 2011	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/CatalogueofEvidence/DirectorsofEducationSurvey
Excellence Group reports		
Paper	Date	Weblink
Science excellence group report	March 2011	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/excellence/ScienceExcellenceGroup
Technologies Excellence Group	March 2011	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/excellence/TechnologiesReport
Mathematics Excellence Group	March 2011	http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/excellence/MathematicsReport

Workstream reports		
Paper	Date	Weblink
Workstream 1&2 report		http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/Reports/Workstreamreport1and2
Workstream 3		http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/Reports/workstream3newversion
Workstream 4		http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/Reports/Workstream4report
Workstream 5		http://www.scotland.gov.uk/Topics/Education/Schools/curriculum/ACE/Science/SEEAG/Reports/workstream5

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