NESTA
Fishmongers' Chambers
110 Upper Thames Street
London EC4R 3TW

T 020 7645 9500 (reception)
T 020 7645 9538 (enquiry line)
F 020 7645 9501

www.nesta.org.uk

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NESTA, the National Endowment for Science, Technology and the Arts, aims to be the strongest single catalyst for innovation in the UK. In everything we do, we are seeking to increase the UK's capacity to fulfil its vast innovative potential.

We invest in every stage of the innovation process; providing early stage seed capital for promising ideas for new products and services; investing in UK talent to ensure it stays in the UK; and experimenting with new ways of engaging the public in science, technology and the creative industries.

Foreword

Science enquiry learning matters – not just to science education, but to the future of scientific research and literacy in the UK. Its status in our schools is a matter of political and public concern.

This report, on the benefits of innovative approaches to science enquiry learning in primary and secondary education in the UK, is designed to disseminate the outcomes from projects and initiatives supported by NESTA. It is also intended to encourage wider debate and discussion regarding the state of science education in the UK, and the extent to which our education systems are able to integrate new and creative approaches to learning.

In a highly technological society such as ours the ability of learners to analyse and question in a scientific manner is increasingly important. Scientific literacy now needs to take its place alongside literacy and numeracy as a major part of the agenda to raise standards in schools.

This is not just for domestic reasons. The UK's future international competitiveness will be founded on our capacity to meet and exceed ever greater demands for innovation and productivity. It demands that our scientific research base and our general scientific literacy are strong enough to meet the challenge of our competitors.

This is why NESTA invests directly in innovations in science education. This investment has been a significant one: over £1.6 million for projects promoting science in schools and £3.5 million for projects supporting the public appreciation of science. This report showcases some of the NESTA funded and supported projects which represent innovations in science enquiry learning, alongside those supported by other organisations. It includes well-known initiatives such as Science Year which was extended to become Planet Science, but also projects that many readers may be less familiar with.

We recognise that the scale of the work that still needs to be done and the importance of the issues involved demand collaborative working. This is why NESTA has developed many partnerships in this area, and why we are keen to work closely with other organisations in the future.

Jonathan Kestenbaum
Chief Executive, NESTA

Too often teaching and learning in science fails to convey what many scientists and others regard as the 'wonder of science'

Executive summary

The UK needs more 'real science' in its school classrooms. Our economic competitiveness and capacity for innovation depends on it. We need to nurture new talent in scientific research and in the teaching of science, and support this research with a more informed public understanding of scientific processes.

There are worrying signs that our future capacity for innovation is threatened by the current state of science education in schools. There has been an increasing recognition, shared between practitioners and policymakers across the UK nations, of the need to make science learning more engaging and enjoyable. This has resulted in developments in curriculum design, teacher training and professional development, and in new teaching and learning resources.

However, significant problems remain. Too often teaching and learning in science fails to convey what many scientists regard as the intellectual discipline and excitement of exploring the unknown, indeed, the 'wonder of science'. The continuing imbalance between content and investigation in school science tends to convey that science is about only a fixed body of known facts. This neglects that it is also about the processes and skills necessary to discover these facts. This can give a misleading impression to learners.

Evidence from NESTA's projects, and those of other organisations, suggests that science enquiry learning could play an important role in reversing the apparent decline in young people's interest and engagement in school science.

Science enquiry learning is a type of science education that involves students raising questions and hypotheses, testing and revising these hypotheses based on experiments and observations, and presenting the conclusions to others. It is a form of experimental and investigative science learning that can support students to develop their understanding of the methods, outcomes and uses of science. As this implies, genuine science enquiry learning relies on a degree of student autonomy. Science enquiry in schools is not the same as the activities undertaken by working research scientists. However, as one form of learning amongst many it can offer an insight into 'real science'. This can include allowing students to work with scientists and other experts alongside their regular teachers.

NESTA's projects illustrate that science enquiry can engage students to develop their understanding of the processes of science, as well as the content of scientific knowledge. By giving students experiences that are closer to the reality of science, enquiry can encourage the capabilities and confidence to pursue further science learning, even amongst those students who are disaffected and in schools in challenging circumstances. These projects show that investigations and practical experiments can increase motivation, develop thinking skills, support collaborative working, and connect learning about science to the real-world.

Teachers recognise that science enquiry is a crucial element of science education. However, the opportunities for science enquiry learning, in particular more open-ended forms of practical experimental work, continue to be inhibited by familiar issues. These include resourcing, time, concerns about health and safety, and the perceived restrictions of curricula and assessment systems. Clearly, more open-ended learning can be difficult to organise, manage and resource. Yet this research shows that more innovative and creative approaches to science education can support the achievement of curriculum learning objectives, and encourage learners to consider further study in science.

Without opportunities for science enquiry, students may fail to develop skills and aptitudes such as the ability to collate, synthesise and analyse empirical evidence, and to ask critical questions. These are important academic capabilities. They are also life skills that are broadly applicable to virtually every field of learning or decision-making. Indeed, it could be argued that they are fundamental to active citizenship in a highly technological society.

This is why we need further innovation in this area. Collectively we must develop new approaches and methods. Most of the funding and support currently directed at innovations in science enquiry learning comes from charitable trusts, rather than government or local authorities, and tends to be developed in universities. This support is valuable, but it can be fragmented and lead to a lack of coordination.

It is also important, if innovations are to be sustainable, that teachers and schools are involved from the outset. This is because many innovative projects are ultimately reliant on the vision, enthusiasm and energy of individual teachers and school science departments – and their ability to overcome the numerous practical difficulties that exist in developing, implementing and managing such innovations. It is especially important that innovative teachers have the active support of senior school managers.

More sustainable innovations in this area would make it likely that students' engagement and motivation will be converted into longer-term gains in attainment. This would provide the evidence to reassure a greater number of teachers and schools that more science enquiry activities can be 'justified' within the perceived constraints of their national curricula, assessment systems and available resources.

To this end, more support needs to be devoted to the dissemination, transfer and testing of innovations that are developed. Similarly, more evaluation and monitoring of outcomes and impacts needs to be built into innovations. This situation is not unique to science enquiry learning. The state of innovation here can be used to raise important questions regarding the opportunities for innovation in science education as a whole and indeed the education system more generally.

The danger of the present situation is that the UK's generally high reputation in scientific research will decline – and with it, our future capacity for productivity and innovation, and our ability to develop new solutions to social and environmental issues.

The danger of the present situation is that the UK's generally high reputation in scientific research will decline

Recommendations

Science enquiry learning needs to be at the core of science education in the UK. Where it is currently weak or under threat, it should be encouraged and enhanced, especially through the development of innovative approaches. Collectively, we need to harness the potential of science enquiry to engage and motivate learners and to counter the misleading impressions of science that can be generated by an over-reliance on more 'traditional' forms of learning. However, at the moment, even though there are numerous innovative projects in science enquiry which aim to do just this, too few are able to demonstrate that their practices have been adopted more widely within the system.

For national policymakers:

- Recognise that unless science enquiry learning as practiced in schools is enhanced and extended there are likely to be negative consequences for scientific research and public scientific literacy in the UK.
- Promote more effectively the opportunities for science enquiry learning that already exist within the established national curricula.
- Challenge the misapprehensions that may exist amongst teachers and schools around risk, health and safety, and potential litigation relating to the practical experimental aspects of science enquiry learning.

For funding and support organisations:

- Create and support more opportunities for partnership with other similar organisations in order to co-ordinate the development of innovations and the transfer of professional knowledge of innovations in science education.
- Generate a stronger evidence base on the effectiveness of science enquiry learning by helping innovative projects to evaluate their outcomes and impacts.
- Support the sustainability of innovative projects by devoting more resources and support to dissemination, transfer and testing after the formal funding period has ended.

For teachers and schools:

- Take advantage of the opportunities in recent and forthcoming curriculum developments in the UK nations to enhance science enquiry activities.
- Network with other teachers, schools, subject associations and funding organisations in order to learn about new approaches to science enquiry.
- Consider the key elements of effective practice in innovative projects in science learning, such as dedicated project managers, making links to topics beyond the traditional science curriculum, making connections with the real lives of learners, and securing the commitment of senior management within schools.

More generally, all those involved in the education systems of the UK nations – from national policymakers and agencies, to local authorities and teachers - need to consider more systematically the nature of the barriers and enablers to the transfer and adoption of innovations in learning within the education system, and develop policies and resources that will encourage and support the dissemination and testing of innovations.

Science enquiry learning could help to reverse the apparent decline in young people's interest and engagement in school science, and the potentially serious consequences for the UK's science research base and its general scientific literacy

Contents

Background to the report

This report was compiled by NESTA, the National Endowment for Science, Technology and the Arts.

NESTA has invested in and supported a wide range of innovative projects related to science enquiry learning. This report is based on research and evaluation activities commissioned by NESTA and through these projects, as well as our own broader experience in funding innovations in science education. It disseminates the outcomes from selected projects, but it is also intended to encourage wider debate and discussion on the state of science education in the UK and the capacity of our education systems to integrate new and creative approaches to learning.

Section one of the report provides an initial discussion on the nature of science enquiry learning, its importance to UK economy and society, and the need for more innovation in this area. Section two illustrates the potential of innovations in science enquiry learning with evidence from a selection of NESTA funded and supported projects. Section three analyses the current extent and nature of innovations in science enquiry learning across the UK.

NESTA would like to acknowledge the work of its awardees, partners and the research and evaluation teams who have worked on the various activities and projects included in this report. Further explanation of the methodologies employed in the research and evaluation activities on which this report is based can be found in the various appendices.

1. The importance of science enquiry learning to the UK

This section of the report discusses the importance of science enquiry learning to the UK, in particular to the UK's capacity for innovation. It also notes that there are worrying signs that this capacity could be threatened by the current state of science education in schools across the UK. Background information on the various education systems of the UK nations can be found in Appendix 4.

1.1 The importance of science education to the UK

The UK Government has clearly identified scientific research and development as a key driver of productivity and innovation; its ambition is for the UK to maintain and reinforce a reputation not only for outstanding scientific and technological discovery and invention, but also as a world leader for turning knowledge into new products, processes and services.[1] As it states:

"The outputs we get from the science base, which include new knowledge, skilled people, new methodologies, and new networks, have contributed to improvements in the things that matter to us, such as our wealth, education, health, environment and culture."[2]

These ambitions require the nurturing of a future generation of highly-skilled science researchers and high-quality school science teachers. There are, of course, a wide range of issues that will determine the future supply of research scientists and science teachers, including pay and retention, and facilities and funding. However, both are likely to be threatened unless science as taught in school classrooms interests and enthuses learners to the extent that more of them consider further study and career options in science.

More broadly, science is an important area of human endeavour, and learning about science should be part of a diverse high-quality education for all. This has practical implications: a strong scientific and technological research base could be reinforced by an informed public understanding of scientific issues, especially potentially controversial issues. This is because higher levels of public scientific literacy and engagement with emerging areas of science could reduce the risk that innovative science and technology is stymied by unnecessarily uninformed or polarised opinion.

1.2 Concerns regarding science education in the UK

A range of data relating to school science indicates causes for concern. In terms of attainment, Ofsted's subject report on primary science in England suggests that recent student achievement in science has not improved significantly at either Key Stage 1 or 2, and nor has the quality of teaching.[3] In Wales, despite the recent improvement at Key Stage 3, science remains one of the weakest subjects at this level.[4] In Scotland, despite the slight improvement since 1995, student attainment in science at age 13 remains below the OECD average.[5]

> Science is an important area of human endeavour, and learning about science should be part of a diverse high-quality education for all

1.For example, HM Treasury (2004), Science and Innovation Investment Framework 2004-2014, (The Stationery Office, London).
2.p.149, ibid.
3.Office for Standards in Education (2004), Ofsted Subject Reports 2002/03, Science in Primary Schools, (Ofsted, London).
4.Estyn (2005), The Annual Report of Her Majesty's Chief Inspector of Education and Training in Wales 2003-2004, (Estyn, Cardiff).
5.Scottish Qualifications Authority (2005), SQA Issues Results for National Courses 2005, (SQA, Glasgow).

In terms of subject choices, there has been an historical decline in the numbers taking A Levels in Chemistry and Physics since 1991, by 12.6 per cent and 35.2 per cent respectively (compared to the overall numbers of A Level entries increasing by 12.1 per cent).[6] These trends at school level have fed through to higher education. While the number of higher education students being awarded qualifications in biological sciences has increased in the last ten years, in 'physical sciences' (that is, physics and chemistry) the number of higher and doctoral awards has not increased at the same rate, and there are actually fewer first degrees awarded (11,995 in 2003-2004 compared to 13,440 in 1994-1995).[7] This is, of course, in the context of a significant increase in the total number of students in higher education.

Subject choices also reveal gender differences. At A Level 50 per cent more girls than boys take Biology, in Chemistry the entries are broadly equal, but in Physics nearly three-and-a-half times more boys than girls take the subject.[8] However, girls tend to do better when they do study these subjects, which suggests that the issue is not girls' ability but rather other factors. Girls tend to perceive science (negatively) as impersonal, value-free, and lacking creativity, and prefer more 'creative' and 'socially relevant' subjects that relate to human, global and environmental issues (in addition to the self-reinforcing perception that science is male-dominated and competitive).[9]

Similar issues exist in terms of ethnicity differences in participation and attainment in science learning. In science subjects, students from certain ethnic minority groups tend to under-perform in comparison to students from white ethnic groups.[10] Learners from Indian and Chinese backgrounds tend to achieve significantly better than other ethnic minority groups, while African-Caribbean learners have the lowest levels of achievement in science, both at GCSE level or equivalent and post-16. Of course, there are a wide range of inter-related factors that contribute to this situation, but it has been argued that the failure to address the problem of ethnic minority under-involvement in science, engineering and technology (SET) occupations will contribute to the severe shortages of labour in science and technology occupations, as well as continuing the under-representation of ethnic minority groups in these occupations.[11]

The trend in the number of students taking science subjects is reflected in the data relating to their interest in school science. The Trends in International Mathematics and Science Study (TIMSS) suggests that in England a declining interest in science is especially pronounced amongst primary-age learners.[12] Other studies suggest a similar disengagement amongst older learners.[13] It has been suggested that much current science teaching and the curriculum fails to support learners in being more critical and raising awareness of science-related careers and the importance of science to modern life.[14]

Such surveys also indicate some of the reasons; learners have suggested that secondary science in particular can feel rushed, dominated by content, repetitious, fragmented and lacking in opportunities for discussion and critical debate.[15] In particular, there appears to be some discrepancy in teacher and student views regarding the relevance of science lessons. In England at secondary level, for example, while 64 per cent of teachers feel that science learning relates to their students' daily lives in half or more of their science lessons, only 35 per cent of students agree.[16]

6.Joint Council for Qualifications (2005), National Provisional A Level (Curriculum 2000) GCE Results – June 2004 (All UK Candidates), (JCG, London). Data is copyright of the Joint Council for Qualifications.
7.2003-2004 data drawn from Higher Education Statistics Agency (2005), Table 14 – HE Qualifications Obtained in the UK by Mode of Study, Domicile, Gender and Subject Area 2003/04, (HESA, Cheltenham). 1994-1995 data drawn from Higher Education Statistics Agency (1996), Table 14a – Qualifications Obtained in the United Kingdom by Mode of Study, Domicile, Gender and Subject Area 1994/95, (HESA, Cheltenham).
8.Joint Council for Qualifications (2005), National Provisional A Level (Curriculum 2000) GCE Results – June 2004 (All UK Candidates), (JCG, London). Data is copyright of the Joint Council for Qualifications.
9.See Promoting SET for Women Unit, Department of Trade and Industry (2001), Get With It! Adopting a Creative Approach to Engaging Girls in Science, Engineering and Technology, (DTI, London).
10.The Science Engineering and Manufacturing Technologies Alliance (SEMTA), African-Caribbean Network for Science & Technology (ACNST), Sector Skills Development Agency (SSDA) (2004), SET 4 Equality, Ethnic Minorities into Science, Engineering and Technology (EMSET), (SEMTA/ACNST/SSDA, London).
11.The Science Engineering and Manufacturing Technologies Alliance (SEMTA), African-Caribbean Network for Science & Technology (ACNST), Sector Skills Development Agency (SSDA), (2004), SET 4 Equality, Ethnic Minorities into Science, Engineering and Technology (EMSET), (SEMTA/ACNST/SSDA, London). Also The Royal Society (2005), Science, Engineering and Technology and the UK's Ethnic Minority Population, (The Royal Society, London).
12.National Foundation for Educational Research/Department for Education and Skills (2004), Where England Stands in the Trends in International Mathematics and Science Study (TIMSS), National Report for England, (NFER/DfES, Slough/London).
13.Murphy, C., and Beggs, J. (2003), 'Children's Perceptions of School Science', School Science Review, 84 (308), pp.109-116.
14.In this case in England: Jenkins, E.W., and Nelson, N.W. (2005), 'Important but Not for Me: Student's Attitudes Towards Secondary School Science in England', Research in Science & Technological Education, vol.23, no.1, pp.41-57. Also Planet Science, Institute of Education, and the Science Museum (2003), Student Review of the Science Curriculum, (Planet Science, Institute of Education, and the Science Museum, London).
15.Osborne, J., and Collins, S. (2000), Pupils' and Parents' Views of the School Science Curriculum, (King's College London, London).
16.National Foundation for Educational Research/Department for Education and Skills (2004), Where England Stands in the Trends in International Mathematics and Science Study (TIMSS), National Report for England, (NFER/DfES, Slough/London).

The Roberts Review of 2002, which analysed the supply of SET skills, suggested that the emerging shortage of people with these skills and its consequent negative impact on research and development in the UK could act to constrain innovation.[17] More broadly, many people who would not typically be described as scientists work in professions that require scientific and technological skills, to varying degrees, as well as forms of familiarity with a range of scientific methods – and demand for these skills is likely to expand significantly over the next ten years.[18] Further, a strong background in science learning can provide valuable transferable learning to other subject areas and for lifelong learning, for example, a greater familiarity and confidence with the manipulation of numerical data, enhanced analytical and critical skills, and so on.

At the level of public literacy about science there appears to be a sizable minority of the public who do not equate science and scientific processes with investigation, experimentation or the testing of hypotheses.[19] A strengthening of the public understanding of these processes, even at a basic level and including the uncertainties of these processes, might help to support a more informed and critical engagement with potentially contentious areas of research.

The UK Government has recognised the dangers of the present situation and the need to achieve a 'step change' in the quality of science teachers in schools and universities, levels of attainment in science at GCSE level, the numbers of students choosing SET subjects in post-16 education and in higher education, and the proportion of better qualified students pursuing careers in science related research and development.[20] The measures it proposes to achieve these aims are welcome and necessary (the recruitment of skilled teachers, teacher training and continuing professional development, the use of ICT in science education, and schools partnering with higher education and industry). Yet this leaves unanswered the question as to which forms of teaching and learning are best able to engage and enthuse learners in science.

1.3 The importance of science enquiry learning

Science enquiry learning needs to be at the heart of science education. The available evidence base suggests that it could play an important role in reversing the apparent decline in young people's interest and engagement in school science, and the potentially serious consequences of this for the UK's science research base and general scientific literacy. This is because science enquiry can help learners to understand scientific processes as well as scientific content.[21] It allows science education to become something that learners participate in, rather than something they are subject to. It represents not only a potentially effective strategy for the teaching and learning of science; it can also serve to model aspects of scientific enterprise itself.

Science enquiry involves one or more of the following: raising questions and hypotheses; testing these hypotheses through practical investigations; revising the hypotheses based on observations and the interpretation of data; and presenting the findings to others. This can support an understanding and awareness of the methods of science, especially enquiry skills (forming hypotheses, planning experiments, interpreting data, and so on). Science enquiry often involves what is commonly referred to as 'practical work', that is, the observation and/or manipulation of objects, materials or phenomena under investigation.

Science enquiry learning needs to be at the heart of science education

17.HM Treasury (2002), SET for Success – The Supply of People with Science, Technology, Engineering and Mathematics Skills, The Report of Sir Gareth Robert's Review, (The Stationery Office, London).
18.Institute of Employment Research (2004), Working Futures: New Projections of Occupational Employment by Sector and Region, 2002-2012, Volume 1, National Report, (Institute of Employment Research, University of Warwick, Coventry).
19.Ibid.
20.Chapter 6, 'Science, Engineering and Technology Skills', in HM Treasury (2004), Science and Innovation Investment Framework 2004-2014, (The Stationery Office, London).
21.For a discussion of the distinction between scientific content and process see DeBoer, G.E. (1991), A History of Ideas in Science Education: Implications for Practice, (Teachers College Press, New York NY).

Such learning is evidence-based. Learners are engaged by questions that lend themselves to empirical investigation, and that lead to gathering and using data to construct explanations for scientific phenomena. Learners should also be encouraged and supported to communicate these explanations, and their evidence and reasoning behind these explanations.[22]

As this implies, science enquiry requires that learners are given some autonomy in how their investigations are carried out. Learners are given responsibility for aspects of decision-making, such as the planning, measuring, observation and analysis of data – though this will of course vary in degree by topic, stage and circumstance.[23] Science enquiry learning is of course closely related to the constructivist view of learning, of the learner as an active participant in building and developing their understanding. This was developed by cognitive psychologists such as Piaget, Vygotsky and Bruner, and has been applied specifically to science education by numerous educationalists and researchers.[24]

There is a growing evidence base that suggests that increasing the amount of practical, investigative work can have a marked positive effect on learners' enjoyment of science.[25] This is not to suggest that the use of approaches based on science enquiry guarantees that learning experiences will be engaging, motivating or effective. Any approach to learning can become routine, manufactured and stale in the absence of innovative approaches and ideas. Rather, science enquiry offers the possibility of an enhanced engagement in science education.

It has been suggested that, without science enquiry activities such as experiments and investigations, it will be difficult to capture the interest of learners at both primary and secondary level.[26] Surveys of students have suggested that there is a desire for more practical work, including extended investigations and greater learner autonomy, which could provide increased challenge and stimulation.[27]

International data reinforces this. The TIMSS study indicates that attitudes to science lessons at both primary and secondary level are more positive in schools where students perceive that investigation, observation and explanation of phenomena are frequently part of classroom activities.[28] The same study suggests a positive relationship at primary level between the amount of time spent on scientific investigation (as reported by students) and achievement in all areas of science.

In addition, science enquiry can encourage and support a wider, and more critical, engagement with topics of current scientific interest or controversy – something that the majority of students support.[29] This is important because the available evidence suggests that this real-world engagement can help to improve motivation. A recent systematic review of 'context-based' approaches to secondary school science (those which make explicit links between science, technology and society) suggests that these approaches can encourage significantly more positive attitudes to science learning than 'traditional' methods (and further, that such approaches helped to narrow the gap between boys' and girls' attitudes towards science learning).[30] The same review suggests that there is some evidence that such approaches can also improve conceptual understandings of science and scientific phenomena. They can encourage productive interactions amongst learners and between learners and teachers, in the form of collective problem-solving, planning, decision-making, and discussion.[31]

22.Northwest Regional Educational Laboratory (1999), Science Enquiry for the Classroom, A Literature Review, (Northwest Regional Educational Laboratory, Portland Oregon).
23.See King's College London (1998), ASE-King's Science Investigations in Schools (AKSIS) Project, Second Interim Report to the QCA November 1998, (King's College London, London).
24.For example, Harlen, W., and Osborne, R. (1985), 'A Model for Learning and Teaching Applied to Primary Science', Journal of Curriculum Studies, 2 (17), pp.133-146. Also Goldsworthy, A., Watson, R., and Wood Robinson, V. (2000), Science Investigations: Developing Understanding, (Association for Science Education, Hatfield).
25.For example, Murphy, C., Beggs, J. and Carlisle, K. (2004), 'Students as 'Catalysts' in the Classroom: the Impact of Co-Teaching between Science Student Teachers and Primary Classroom Teachers on Children's Enjoyment and Learning of Science', International Journal of Science Education, 26 (8), pp.1023-1035.
26.See Campbell, B. (2001), 'Pupils' Perceptions of Science Education at Primary and Secondary School', in Behrendt, H., Dahncke, H., Komorek, M., Duit, R., Graber, W., Kross, K., and Reiska, R., Research in Science Education, (Kluwer, London).
27.Osborne, J., and Collins, S. (2000), Pupils' and Parents' Views of the School Science Curriculum, (King's College London, London).
28.National Foundation for Educational Research/Department for Education and Skills (2004), Where England Stands in the Trends in International Mathematics and Science Study (TIMSS), National Report for England, (NFER/DfES, Slough/London).
29.Planet Science, Institute of Education, and the Science Museum (2003), Student Review of the Science Curriculum, (Planet Science, Institute of Education, and the Science Museum, London).
30.EPPI Centre (2005), The Effects of Context-Based and Science-Technology-Society (STS) Approaches in the Teaching of Secondary Science on Boys and Girls, and on Lower-Ability Pupils, (EPPI Centre, Institute of Education, London).
31.For example, Brown, A. (2004), 'Transforming Schools into Communities of Thinking and Learning About Serious Matters', in Scanlon, E. (ed.), Reconsidering Science Learning, (RoutledgeFalmer, London).

This data is reinforced by evidence from the UK's education inspectorates. For example, Ofsted's primary science report for England states that teaching remains most effective where students are actively involved in thinking through and carrying out science enquiry, and that some of the highest achievement and keenest motivation are linked to the good use of science enquiry.[32] As a result, it suggests, science enquiry skills should be taught in a systematic way by schools.

Teachers also support the significance of science enquiry. A nationwide survey commissioned by NESTA to complement this report shows that the overwhelming majority of science teachers (84 per cent) think that science enquiry is 'very important'.[33] Further, teachers think that science enquiry can have a significant positive impact on the attainment of their students (83 per cent), and on the development of problem-solving skills (85 per cent).

This said, it is important to be realistic about the scope of science enquiry. It might be better to regard classroom investigations and experiments as simulations of science research, because for example we do not expect school-age learners to make new breakthroughs in scientific discovery or understanding.[34] Science enquiry is able to model scientific practice, including its complexities and difficulties, as one form of learning amongst the many that are a necessary part of a broad and effective science education for young people.

1.4 Science enquiry in the UK national curricula

Science enquiry finds specific support in the various national curricula. In England, 'Scientific Enquiry' (Sc1) was given an increased prominence in the 2000 revisions to the National Curriculum, which promoted a wider variety of enquiry, and 'Excellence and Enjoyment' with its emphasis on enquiry, creativity, and group problem-solving at primary level.[35] In Northern Ireland, the Science and Technology learning area in the post-primary curriculum emphasises opportunities for authentic investigations and the development of science enquiry skills.[36] In Scotland, although the Scottish Executive's 'Science Strategy for Scotland' doesn't identify science enquiry as a particular area for development, it does identify two related objectives for science education: to lay the foundations for the development of Scotland's future scientists; and to give everyone the skills and confidence to act as informed and questioning citizens in relation to scientific issues.[37] In Wales, science enquiry is clearly identified as a central element of the science curriculum across the levels. Problem-solving, investigative and creative skills are highlighted in the programmes of study; in developing their investigative skills, students should on some occasions carry out the whole process of investigating an idea.[38]

1.5 The state of science enquiry learning

However, despite its status in these national curricula, significant barriers exist to the implementation and further development of science enquiry learning in UK schools.

The survey of UK science teachers commissioned alongside this report indicates some of the (familiar) barriers: a lack of time (cited by 64 per cent of teachers), resources (34 per cent), equipment and space (31 per cent).[39] Only 17 per cent of the science teachers surveyed think that their national curricula allow a lot of scope for practical experimental work.

Only 17 per cent of science teachers surveyed think that their national curricula allow a lot of scope for practical experimental work

32.Office for Standards in Education (2004), Ofsted Subject Reports 2002/03, Science in Primary Schools, (Ofsted, London). Also HM Inspectorate of Education (2005), Improving Achievement in Science in Primary and Secondary Schools, (HMIE, Livingston).
33.NESTA (2005), Science Enquiry Learning - Survey of UK Science Teachers Conducted by ICM, (NESTA, London).
34.Millar, R. (2004), The Role of Practical Work in the Teaching and Learning of Science, (University of York, York).
35.Department for Education and Skills (2003), Excellence and Enjoyment, A Strategy for Primary Schools, (DfES, London).
36.Council for the Curriculum Examinations and Assessment, (2003), Advice to the Minister for Education on Curriculum and Assessment at Key Stage 3, (CEA, Belfast).
37.Scottish Executive (2001), A Science Strategy for Scotland, (Stationary Office, Edinburgh).
38.Qualifications, Curriculum and Assessment Authority for Wales/National Assembly for Wales (2000), Science in the National Curriculum in Wales, (ACCAC/ National Assembly for Wales, Cardiff).
39.NESTA (2005), Science Enquiry Learning - Survey of UK Science Teachers Conducted by ICM, (NESTA, London).

In England, according to Ofsted's report on primary science, enquiry remains the most variable and vulnerable part of the science curriculum.[40] Science is largely taught in relatively short afternoon sessions lasting typically 60–75 minutes. This constrains teachers' ability to develop investigative activity. As a result, many investigations have become highly structured and give insufficient freedom for students to contribute their own ideas or reflect on outcomes. The recent Wellcome Trust survey indicated that many primary science teachers lack confidence in their teaching, particularly in carrying out simple investigations.[41] Ofsted's report on secondary science suggests that science enquiry remains too narrow and mechanistic at Key Stage 4 given the very strong focus on meeting GCSE examination requirements.[42]

According to a survey by The Campaign for Science and Technology, 77 per cent of secondary school science teachers in England are sometimes unable to carry out practical lessons.[43] The most common reasons are student behaviour (affecting 57 per cent of respondents), a lack of appropriate equipment, and class size. It would be reasonable to assume that the proportion of schools where behavioural problems commonly disrupt practical work, rather than force its cancellation, is even higher. Further, nearly nine out of ten of respondents in this survey suggest that there are problems with the current methods for assessing students' practical and investigative skills (the two most commonly cited issues are a lack of time and the emphasis on formulaic and prescriptive activities). The availability of school lab technicians has also been a recent area of concern.[44]

These issues are also reflected in the available data from Northern Ireland and Scotland. The Department of Education in Northern Ireland (DENI) in its 2001 survey on the teaching of science and technology in primary schools noted the need for more opportunities for students to devise their own investigations and receive regular formative assessment.[45] (However, DENI did note in its follow-up survey an improved progression and coherence in the development of students' investigative and experimental skills in nearly all schools).

The Scottish HM Inspectorate of Education's most recent report on science in primary and secondary schools noted that even by P6 and P7 (10-12 year olds) students tend to have had limited experience of carrying out investigations, despite the majority being able to explain how to conduct a fair investigation.[46] One of the main areas for improvement in courses at secondary level identified by the Inspectorate is the better development of the full range of investigative skills through practical work.[47] Similarly, the Scottish Science Advisory Committee (an independent committee which provides advice to Scottish ministers on science strategy, science priorities and science policy), noting the falling proportion of school pupils in Scotland taking higher sciences, has argued that the need to improve science education in Scottish schools is urgent.[48] This should include more specialist training and continuing professional development (CPD) for primary science teachers, better school infrastructures for science learning, and more science technicians available to schools so that students can have greater experience of 'hands-on' practical work.

40.Office for Standards in Education (Ofsted) (1999), A Review of Primary Schools in England, 1994 – 1998, (Ofsted, London).
41.Wellcome Trust (2005), Primary Horizons, Starting Out in Science, (Wellcome Trust, London).
42.Office for Standards in Education (2004), Ofsted Subject Reports 2002/03, Science in Secondary Schools, (Ofsted, London). Also see paragraph 40, House of Commons Science and Technology Committee (2002), Third Report of the Science and Technology Committee on Science Education from 14 to 19, (HC 508-I), (The Stationery Office, London).
43.The Save British Science Society (2004), SBS Survey of Secondary School Science Teachers, (SBS, London).
44.The Royal Society/Association for Science Education (2002), Supporting Success: Science Technicians in Schools and Colleges, (RS/ASE, London).
45.Education and Training Inspectorate, Department of Education in Northern Ireland (2001), A Survey of the Science and Technology Area of Study in a Sample of Northern Ireland Primary Schools 2000–1, (DENI, Belfast).
46.p.4, ibid.
47.p.16, ibid.
48.Scottish Science Advisory Committee (2003), Why Science Education Matters: Supporting and Improving Science Education in Scottish Schools, (SSAC, Edinburgh). Also: University of Glasgow/University of Paisley (2005), The School to University Transition in Science, Technology, Engineering and Mathematics Subjects, final Report, (University of Glasgow/University of Paisley, Glasgow/Paisley); Association for Science Education Scotland (2005), 3-18 Curriculum Review Science, A Submission by the Association for Science Education Scotland to the Review Committee, (ASE Scotland).

The Campaign for Science and Technology survey of Scottish secondary teachers reveals similar issues to the survey in England.[49] 83 per cent of secondary school science teachers in Scotland are sometimes unable to carry out practical lessons. While class size appears less of an issue in Scotland, student behaviour is again cited as a key issue (as in England, this affected 57 per cent of respondents). Many schools in Scotland have been cancelling 20 or more lessons each year, and again, nearly nine-out-of-ten of the respondents suggest that there are problems with the current methods for assessing students' practical and investigative skills.

These are significant issues. The next section of this report examines the evidence from projects that NESTA has funded and supported in the area of science enquiry learning: can innovative approaches increase learners' engagement in science, and can they overcome the barriers that can exist to this kind of work?

2. Evidence from NESTA projects in science enquiry learning

NESTA has funded and supported a range of innovative projects related to science enquiry learning, as part of its very diverse funding and support for innovation in education and learning more generally. This section of the report presents learning about beneficial approaches in science enquiry by using the outcomes from a selection of NESTA projects, based on the evaluation reports for these projects.

The web addresses for these NESTA projects can be found in Appendix 2. A summary description of the various methodological approaches taken in the evaluations of these projects can be found in Appendix 3.

2.1 Investigating scientific phenomena

As suggested above, science enquiry learning can allow for students to investigate scientific phenomena. This may or may not include the need for practical experiments, with varying degrees of 'authenticity'. In some investigations the students may have already been informed about what the expected outcomes are. In other investigations the students are allowed to 'discover' the outcomes during the course of the investigation (this is by far the most common form). In a few cases both the teacher and the students do not know the expected outcomes, although they may be able to hypothesise and make predictions.

Science Year/Planet Science

One of the key factors identified in the positive outcomes from the activities organised under Science Year/Planet Science was the focus on practical and investigative work.

In 2001 NESTA won the tender to manage Science Year, funded by the Department for Education and Skills (DfES) in England.[50] Science Year developed a range of activities and resources during the school year 2001-2002, and was renamed Planet Science in September 2002. The ongoing Planet Science website, which began as the portal for Science Year/Planet Science projects, includes the aim of encouraging more young people to continue their engagement in science post-16. The site includes teaching ideas and materials as well as quizzes, interactive games and practical activities for students and parents (there are also three e-newsletters aimed at primary and secondary students and teachers).

One of the key factors identified in the positive outcomes from Science Year/ Planet Science was the focus on practical and investigative work

49.The Save British Science Society (2004), SBS Survey on Scottish Secondary School Science, (SBS, London).
50.The Association for Science Education (ASE) and the British Association for the Advancement of Science (BA) were key Planet Science partners.

The initiative impacted on students in three key ways: increased co-operation between students; higher levels of student motivation; and more engaged students. Many teachers observed increased levels of co-operation when the students were involved in particular activities such as Whodunit (an investigation based on forensic science) and Giant Jump (in which over one million children and 5,000 schools jumped at the same time and measured the effect on their own homemade seismometers).

The evaluation found that students particularly identified practical investigations as a preferred form of learning; this was consistently reflected across all of the secondary students interviewed as part of the evaluation case studies for Science Year/Planet Science, and there was some evidence of increased knowledge retention as a consequence. Collectively, these projects generated a greater engagement in science, higher levels of student motivation (the most significant impact), supported the development of thinking skills including critical reasoning, and encouraged teachers to develop diverse ways of teaching science.

Another NESTA project worth noting here from a related curriculum area is Roboteers in Residence, in which expert roboteers worked with teams of young people to develop robots. This project encouraged students to solve practical problems as they arose and to explore the consequences of their decisions in a concrete and immediate way. This appears to have been a key factor in their enthusiastic engagement with what is often regarded as a difficult area of the design and technology curricula (electronic, mechanical and structural systems and control).

The role of ICT in investigation

Information and communication technology (ICT) can support science enquiry work: as a means of exploration (for example, through the use of control technologies or simulations); communication (for example, via email or online discussion groups, or through presentation technologies such as interactive whiteboards); and of course as a source of information (for example, CD-ROMs or internet websites).[51] Most obviously, ICT can provide simulations and representations of experiments and phenomena that may be difficult or impossible in classroom settings, but as with any area of new or developing practice there may be issues of resourcing (that is, access to appropriate technology and learning materials) and teacher confidence and skills.

Debating the Evidence

Debating the Evidence is a software 'learning environment' developed at NESTA Futurelab that is designed for pairs of students aged between 11 and 14 working at the same internet-connected computer. It is intended to raise awareness of risk and uncertainty in scientific reasoning and support students' collaboration in engaging with these issues, in particular in four areas that students can find problematic: thinking scientifically about evidence; working collaboratively; interpreting feedback; and responding to unpredictability.

51.NESTA Futurelab (2003), Literature Review in Primary Science and ICT, (NESTA Futurelab, Bristol).

The learners involved in this project found the interactive encounters with simulated scientific problems involving uncertain cause-effect relationships interesting and challenging, and such activity appears to improve learners' ability to examine sceptically how evidence is used. The rapid feedback on their predictions engages and supports learners in revising their theories, both individually and collectively. Without teacher intervention, in some cases learners were able to improve their thinking strategies following feedback from the software. Resources such as these could play an important role in the development of science enquiry learning and in helping learners make reasoned judgements about situations involving uncertainty. Further, such exercises could act as a useful precursor to classroom debates about the importance and limitations of scientific evidence.

Another NESTA project where ICT has extended the range of science enquiry experiences available to learners is Nestonauts. This project is based at Neston Primary School near Bath, and has involved building a 'Moonbase' (a geodesic dome) in the playground where students can conduct their own investigations. There are various 'zones' for different types of investigations, for example, a greenhouse zone for investigations into biological growth and climate. The findings from the evaluation of this project show that it has supported the students to enhance their ICT skills (for example, in the use of control technologies), and better understand the content of key curriculum areas (such as growth, light and forces).

> Practical experiments are important because they support increased familiarity with the objects and tools of science

2.2 Experimenting, observing and manipulating

Practical experiments - meaning exercises involving the observation and/or manipulation of the objects, materials or phenomena under investigation - are perhaps what most observers will think of first with regards to science enquiry. Such activities are important because they provide 'hands-on' engagement for learners and support increased familiarity with the objects and tools of science.

As noted above, practical experimental activity has been a strongly preferred element in the Science Year/Planet Science projects, and has been shown to be highly engaging and motivating for the students involved. Similarly, the Planet Science Curriculum Review report revealed that conducting experiments in class has been identified by students as one of the most effective and also most enjoyable teaching methods.[52]

Genetic Futures

Schools may not always have access to sufficient or appropriate resources for a range of experimental work. The Genetic Futures programme in 2003, marking the fiftieth anniversary of the discovery of the structure of DNA, was intended to inform and elicit the opinions of young people about the role of genetics in the modern world. As part of the regional events to which local schools were invited, students were able to use practical equipment that would not typically be available to them in their own schools (other activities included scenario-based discussions with experts and role playing exercises).

52.Planet Science, Institute of Education, and the Science Museum (2003), Student Review of the Science Curriculum, (Planet Science, Institute of Education, and the Science Museum, London).

Learning about science in the context of other subjects can help learners to appreciate the creative aspects of science

There were eight regional events, to which eight schools in each region were invited to send teachers, students (aged 14-16) and technicians (ultimately, 79 schools in total were involved in these events).
The programme's aims for the students were to increase their awareness and understanding of genetics, and to enhance their practical skills and knowledge of the scientific process to support their learning of Sc1 in the National Curriculum in England. It was also hoped that the programme would increase teachers' knowledge of DNA-related topics and their confidence in teaching Sc1 back in their school environments. NESTA was one of a range of sponsors for this programme, while the Centre for Science Education (CSE) at Sheffield Hallam University was responsible for its development, management and implementation.[53]

The students very much enjoyed the opportunity to conduct experiments that weren't typically available at school, for example being able to isolate their own DNA. The activities increased the students' understanding of DNA-related science and their ability to form opinions on the issues surrounding DNA-based technologies. The teachers reinforced these findings from the evaluation, and said that they would generally feel confident about repeating the workshops. However, they also noted that the lack of specialist equipment and technicians in their own schools would be key obstacles to repeating the practical elements of this programme.

2.3 Learning across the curriculum

Cross-curricular learning involving knowledge content and approaches from more than one school subject area can be more engaging and motivating for students for a number of reasons. Such forms of learning are in many respects more representative of the real world, both in terms of students' current experiences and their future applications, whether in a career that includes science-related activities or in terms of a wider public literacy. Learners who might assume that they do not like science learning can particularly benefit from such inter-disciplinary approaches. Learning about science in the context of other subjects can help learners to appreciate the creative aspects of science (for example, generating new hypotheses and visualising conceptual relationships between phenomena). A more holistic view can also allow teachers and students a more explicit consideration of what constitutes knowledge in different disciplines. Further, it can encourage, and indeed depend on, collaborative working and team building amongst teaching staff.

Motivate

Motivate is a programme that explores mathematics and science using real world examples. The programme was developed by the Millennium Mathematics Project at the University of Cambridge and was initially one of NESTA's early projects. Students participate in videoconferences with mathematicians and scientists, and collaborate on project work. The programme works with primary and secondary schools; topics have included fractals, energy, space and robots.

53.Other sponsors included The Medical Research Council (MRC), The Department for Education and Skills (DfES), The Royal Society, The Biotechnology and Biological Sciences Research Council (BBSRC), and the Department of Trade and Industry (DTI). The equipment was provided by Bio-Rad Laboratories.

The evaluation of the pilot year of this project reveals that the links forged between mathematics and science can have a positive impact on students' attitudes towards and interest in learning mathematics. Students' ability to see the relevance of mathematics to the real world was improved through the cross-curricular approach taken. In addition, the students valued the collaborative and discursive aspects of the work, and in some cases this increased students' confidence in their abilities in mathematics learning, including encouraging them to study mathematics at a higher level. As with many of the other projects identified in this report, students pointed to the opportunity to be more actively involved in the learning process as a particularly valuable aspect of this work.

2.4 Connecting science to the real-world

One way of trying to enthuse more learners about science is to emphasise the real world relevance of the subject of their studies. This can be particularly important in reaching students who might normally achieve lower results in science.

NESTA is supporting a number of current projects in this area.
Digital Science is a NESTA project in partnership with the Wellcome Trust that draws on real-world relevance. It aims to bring together curriculum developers and teachers with digital experts, designers and programmers to develop digital resources targeted at aspects of the newer science curriculum that are intended to address the desire of students to learn about science in the context of its relevance to contemporary society. These include the 21st Century Science GCSE and Science for Public Understanding AS Level.

The films for Learning project involves teachers and students at Thomas Hardye school in Dorset collaboratively making films to capture science and design and technology processes that would be too complex or dangerous for students to repeat for themselves or for their teachers to demonstrate. Thomas Hardye is working with Toolkit, a creative learning consultancy, to produce films that convey what teachers and students consider to be 'real science'. Another project supported by NESTA, the flipside magazine, is demonstrating that it is possible to communicate science topics to teenage audiences in a stimulating and engaging way.

A final initiative worth noting is Einstein Year, being co-ordinated by the Institute of Physics to celebrate the 100th anniversary of the publication of Einstein's seminal papers in 1905. Einstein Year projects, some of which are funded by NESTA, address many of the aspects discussed in this section of the report, including an emphasis on demonstrating the real world relevance of physical sciences to young people.

2.5 Collaborating with peers

Peer collaboration between students is an important and valuable aspect of many innovative projects in science enquiry learning. It can provide for more enjoyable and engaging activities, enhance topic understanding, and build confidence. It can also support the development of group working skills, which is of course a key interpersonal and social capability.

Peer collaboration between students is an important and valuable aspect of many innovative projects in science enquiry learning

Creative Space

The Creative Space initiative included a large amount of collaborative activity between students. Indeed, the organisation and development of the initiative was itself highly collaborative: teachers from ten schools in Greater Manchester and Leeds, together with artists, museum curators, scientists and PhD researchers, formed project teams in order to design school based projects which investigated scientific concepts through the exploration of 'space' (interpreted in a variety of different ways). Creative Space was organised by CapeUK, with support from the Centre for Science Education at Sheffield Hallam University, and funded by NESTA.

The projects included: a diverse investigation of the grounds of a primary school by the students which explored the relationships between animals, plants, climatic conditions and geology; an exploration of the properties of light using creative and exciting visual effects, again with primary students; and a collaboration between a primary and a secondary school to model the properties of sound. Some projects were more open-ended than others. For example, in one of the projects in a primary school the PhD researchers encouraged a student-centred approach to science investigation by allowing the students to propose their own areas of investigation (these included light, hovercraft and volcanoes).

The evaluation findings from these projects reveal a range of positive outcomes.[54] Students gained increased understanding of topic areas and demonstrated sustained time 'on task'. Their enthusiasm and interest in science was greatly increased; this grew as the sessions went on and they adjusted to this different way of learning. The students particularly enjoyed team working and the greater opportunities for discussion, as well as the opportunities for creative thinking. Further, the PhD researchers in each team acted as powerful role models, and helped to alter students' (often negative) views of scientists and scientific careers.

In particular, the teachers were struck by the student-centred nature of the projects and the benefits that occurred when they stood back and allowed students to discuss ideas and propose solutions. When they did, the students became more active, asking questions and taking more initiative. Creative activities that related to often 'difficult' or 'boring' curriculum areas were particularly welcomed by teachers, and because the activities placed particular emphasis on questioning, observation and investigation, they fitted well with Sc1 in the National Curriculum in England. Teachers (and students) were sometimes disconcerted by the more open-ended and unpredictable nature of some of the activities, especially in situations where students' understanding of the underlying science was incorrect. However, because the projects encouraged discussion and debate it was possible to ensure the tactful deconstruction of these incorrect understandings.

Other NESTA projects also demonstrate the value of peer collaboration. As described above, the Motivate project generated a very positive response from the opportunities for collaborative working between the students involved. Three-quarters of these students thought that discussing mathematics helped them to understand it better and increased their confidence in their own abilities in the subject. There was evidence from this project that explaining mathematics to peers helped the students to understand the subject better themselves, and consequently their own engagement and interest increased. Similarly, the evaluation of Science Year/Planet Science pointed to the importance of collaborative activity between students, in particular how much students enjoyed this aspect of the projects and how valuable they thought it was in terms of developing their ideas, understandings and confidence.

54.CapeUK (2005), Creative Space, Collaborative Approaches to Science Learning in Schools, (CapeUK, Leeds).

2.6 Inspiring through experts and role models

The active involvement of external experts and role models can be a very valuable aspect of science enquiry learning. Students can be motivated by being taught by working scientists and other adults with specific expertise and experience in a particular area. However, such experts do need to be carefully selected and need to be able to work effectively with a range of students with different abilities.[55] There needs to be good communication between role models, teachers and their students. Where role models visit schools it is important that they are clearly identified as being scientists as opposed to teachers.

Brain Games

The Brain Games project is a good illustration of the benefits for students of using external experts in formal learning environments. This project involved primary and secondary students working with mentors who were science postgraduates and science explainers based at a science learning centre (Explore-At-Bristol). The activities for the students involved learning about parts of the brain and their functions, including techniques for improving memory, and being asked to design and produce a game that used a variety of the brain's functions. Nearly 100 students participated in this project (60 from one secondary school and 38 from one primary school). The students also participated in talks with a neuroscientist and attended question and answer sessions with game designers. This latter group in particular helped to put the activity in a real life context and provided a sense of purpose for the students.

As the evaluation of this project notes, the students were highly motivated and engaged with the subject through these activities. Their understanding of the brain and links to behaviour was enhanced, as was their awareness of the thinking skills being used in the different tasks (however, it was difficult for the evaluators to determine whether any deeper understanding had been developed). The mentors were a key factor in this success; they brought a refreshing and youthful perspective to the students' learning. Their background in science communication was regarded as of greater importance than their teaching experience. Indeed, their lack of teaching experience was in one sense an asset in that it allowed new and often more spontaneous teaching approaches. The students particularly enjoyed the greater autonomy they had in this project, albeit guided, supported and facilitated by the mentors. On occasions where the mentors took too much control the students appeared to lose interest and a sense of ownership of their activities.

This motivation and engagement extended to students who, the teachers felt, would not normally be engaged or who were perceived as 'difficult' at school, and yet in this project they were seen to be working effectively in sustained and concentrated ways, and even taking work home with them. Improvements in students' teamwork (even though the teams were comprised of non-friendship groups), communication and presentation skills were also observed. The primary and secondary teachers involved in this project planned to use the Brain Games experience back in their schools.

55.The Royal Society (2004), A Study on the Efficacy of Role Model Programmes, Literature Review, (The Royal Society, London); The Royal Society (2004), A Study on the Efficacy of Role Model Programmes, Mapping Exercise, (The Royal Society, London). See also The Royal Society (2004), Taking a Leading Role, A Good Practice Guide, (The Royal Society, London).

The Birmingham ACRISAT (African-Caribbean Representation in Science and Technology) initiative conducted a mapping study of projects in Birmingham and found that there was a distinct lack of role models in science and technology from ethnic minority communities. The project then targeted funding to identify such role models in the hope that this might have a positive effect on students' attainment and interest. This was effective to an extent, although intensive input was needed; it may be that additional effort and funding is required to identify these role models in order that they can be deployed into future initiatives such as the SETNET science ambassadors scheme.[56]

2.7 Reaching the disengaged

As identified in the first section of this report, there is the need for innovative approaches to science learning (including those which harness the potential of science enquiry) that reach out to a wider range of learners. A major example of an initiative that has tested out such approaches is the Planet Science Outreach programme.

Planet Science Outreach

This programme, one of the legacy activities from Science Year/Planet Science, supported projects that reached out to schools in England with low levels of achievement in science and which had not benefited from other science education initiatives. The projects, targeted at Key Stages 2, 3 or 4 in England, focused on increasing students' enthusiasm for science and improving their attainment, especially amongst students who would not normally be involved in additional science activity, those from ethnic minority groups, potential high achievers who lack opportunities to excel in science, or those students at risk of disaffection.

The projects were highly diverse, in terms of the numbers of schools and geographical areas involved, the participating students and teachers, and different delivery approaches (from working directly with schools to more remote forms of delivery). For example, the Surprising Science project delivered by Newcastle's Life Science Centre provided a programme of demonstrations, hands-on investigations and extra-curricular visits delivered by young enthusiastic science explainers in some of the North East's most underachieving schools. Conversely, the e-Mission: Operation Montserrat project employed a distance learning approach. A 'mission control' centre was hosted by the National Space Centre in Leicester and linked with City Learning Centres across England. For the main stage of this project students worked in small teams to analyse data relating to a volcanic eruption and hurricane communicated from mission control, and made decisions about the evacuation of the inhabitants of a virtual island.

The Planet Science Outreach projects stimulated students' interest in science education. These positive outcomes were the result of a range of hands-on, practical and stimulating learning experiences in real life environments. Teachers almost unanimously reported changes in students' attitudes during the projects, with over half reporting significant changes in students' attitudes and motivation and almost as many mentioning their more positive views on continuing science education. Other positive outcomes included increased concentration, increased confidence (the hands-on experiences encouraging students to 'have a go'), improved communication and group working skills.

56.The Science, Engineering, Technology and Mathematics Network (SETNET) was established by the Department of Trade and Industry (DTI) to promote awareness of these areas among young people. A network of local SETPOINTS is the primary point of contact for schools, colleges and businesses wanting information and guidance about STEM initiatives and programmes.

Given the relatively short duration of the projects, it was expected that their benefits would be primarily motivational. However, a particularly positive finding is that teachers also observed changes in students that could contribute to improved attainment. Almost one third of teachers reported significant improvement in students' investigative and problem solving skills, while the same proportion felt that the new approaches had contributed to improving students' understanding of scientific concepts. Benefits witnessed by project managers and teachers included students' increased ability to ask relevant questions in class, improved recording of scientific data, improved skills in using scientific equipment, and stronger knowledge retention.

As a result, there were many qualitative reports of student performance exceeding teachers' expectations. In two cases, projects attempted to assess impacts on student attainment through specific evaluation activities. The Natural World of Science project tested the impact of the project on Key Stage 2 National Test results, with teachers in two primary schools providing predicted grades for students and actual results. These showed a 27 and 28 per cent increase respectively in the number of students gaining Level 5, compared to the predicted results. The Enhancing Science Uptake project sought to capture student achievement in terms of their engagement with and understanding of science, and their thinking and self-assessment skills. Again, teachers predicted achievements during the project for a sample of students, which were compared to performance observed by the teachers during the project. While findings varied across the schools and student groups involved, there were certainly many examples of performances above initial expectations during the different school projects.

As well as providing direct benefits to teachers and schools, the projects have created a sustainable legacy. They have done this by enthusing and inspiring teachers to incorporate the learning, content and delivery approaches into their school and providing the motivation to invest in opportunities for learners to experience inspirational science. It is important to note however that this required additional funding which was specifically for sustainability.

It is difficult to predict the precise extent of the longer-term benefits for the schools involved in these projects, but opportunities have been created for sustained change. For example, most projects left resources behind that teachers can continue to use, and teachers gained opportunities to share experiences and learning with colleagues at training, group feedback sessions and events. In a number of instances teachers' experiences have led them to explore funding opportunities that will allow their school to 'buy-in' the project in subsequent years, and schools have gained exposure to the wider educational work of other delivery organisations and partners in the projects. This has stimulated teachers' interest in other forms of collaboration. Some projects have taken more concrete steps to continue their activities with schools. To cite just one example, the Enhancing Science Uptake project is being formally included as part of the PGCE Science course at the Institute of Education, University of London.

However, the overriding issue identified from managing these projects is that project managers need to appreciate the significant amount of time and resources that are likely to be involved to engage schools and plan delivery, with several projects realising their initial main stage plans were over-ambitious in terms of scale and coverage. The hands-on support required by teachers to engage with activities was often greater than expected. Even when wholly committed to the project, teachers were not always able to contribute as much time as initially intended.

There is the need for innovative approaches to science learning including those which harness the potential of science enquiry that reach out to a wider range of learners

The development and dissemination of innovations in science enquiry learning requires increased and sustained collaboration between teachers

2.8 Supporting teacher development

The recent Wellcome Trust report on primary science pointed to the need for more continuing professional development (CPD) for primary science teachers.[57] Secondary teachers, whatever their current levels of knowledge and understanding, also need opportunities to keep up with areas of rapidly emerging science, such as biotechnology and space exploration, in line with examination board specifications.

NESTA's projects to date have not focused on formal teacher CPD, but they do demonstrate how teachers can be provided with informal CPD. One valuable method is through the involvement of external experts. The Genetic Futures project helped to increase teachers' understanding of genetics, and the teachers who participated said that they would generally feel confident about repeating the workshops in their schools, resources permitting. There was a similar outcome from the Brain Games project, in particular because of the impact of the scientists and mentors on the teachers.

Another method is through collaborations, both between teachers and between teachers and other professionals. For example, the Creative Space projects, because of the collaborations with artists and researchers, encouraged teachers to allow their students increased autonomy in their learning and to accept greater unpredictability. Many of the Planet Science Outreach projects depended on effective collaborations between teachers, who benefited from the opportunity to identify or experience new resources and approaches through collaborative activity. This included opportunities for the development of cross-curricular working. This was felt most strongly by teachers in the e-Mission: Operation Montserrat project as a result of a close link to the Geography syllabus. The Enhancing Pupil Motivation project saw established teachers benefiting from the new ideas and approaches of Beginning Teachers (and of course the Beginning Teachers benefiting from extended teaching and planning experiences in real schools). In a number of instances the schools involved gained exposure to the work of other delivery organisations and partners, and this has stimulated teacher interest in further collaboration.

The development and dissemination of innovations in science enquiry learning, or in any other area of the curriculum, obviously requires increased and sustained collaboration between teachers. An example of an initiative designed to encourage this is the National Collaborative project. This DfES project is intended to improve the academic achievement of low-attaining students by carefully tailoring approaches to teaching, evaluating their effectiveness and then sharing what works. NESTA's contribution includes expertise from the worlds of science and technology, financial support for individual schools and the promotion of new teaching and learning strategies.

These NESTA projects demonstrate the potential of innovative approaches to science enquiry. Clearly, more can still be done, particularly in the areas relating to inclusion, but the projects cited do suggest lines for further development. Yet to what extent, beyond these examples, are innovative approaches being supported and encouraged across the UK?

57.Wellcome Trust (2005), Primary Horizons, Starting Out in Science, (Wellcome Trust, London).

3. Innovations in science enquiry learning across the UK

This section of the report looks at the extent and nature of innovative projects in science enquiry learning across the UK. The analysis is based on the results of an initial 'mapping' exercise into the funding and support of innovations in this area beyond NESTA's own work, the types of innovations funded, and the available information relating to their outcomes. Where appropriate, the findings from this survey are compared to a review of NESTA's own funding and support for innovations in science learning more generally.

'Innovation' here refers to the development of new approaches and practices, which reflects NESTA's remit for supporting and promoting innovation. This means that this survey does not include a range of other projects and initiatives which although relevant to science enquiry learning are not innovative in this sense. Further, this survey includes only projects that have been adopted by or incorporated into institutions or collaborative groups of practitioners; for reasons of scale it does not try to capture the innovative practices of individual teachers. It also concentrates on more recent projects (those that have operated within the last five years). This means that some significant activity is not included here, for example the AKSIS project (The Association for Science Education - King's College London Science Investigations in Schools) and its influential publications.[58]

Nearly 60 innovative projects and activities related to science enquiry learning have been identified through this survey. This is in addition to 48 NESTA-funded projects in science learning and 22 Science Year/Planet Science projects which are used in comparison. Inevitably, such a survey is necessarily provisional in that it does not represent an exhaustive or definitive 'map' and cannot claim to capture every innovation in science enquiry. Nevertheless, it can be used as an initial indication of the extent, range and nature of innovation in this field, the common themes and approaches, and to highlight issues for further consideration.

The methodology for the mapping exercise is explained further in Appendix 5 and a list of the projects included in this section can be found in Appendix 6. Further explanation of the methodology for the review of NESTA funding and support for science learning projects, along with a full list of the projects included in the review, can be found in Appendix 7.

3.1 Funders and developers

A distinction should be drawn between the funders and the developers of innovative projects. Funding is dealt with first, followed by development.

The sources of funding for the projects identified are shown in table 1.

Table 1: Distribution of funders

Funder	Number of projects supported (in whole or in part)
Charitable trusts	32
Government	9
Professional bodies	4
Business (direct funding)	3
European Union	1
Higher education	1

58.For example, Goldsworthy, A., Watson, R., and Wood Robinson, V. (2000), Science Investigations: Developing Understanding, (Association for Science Education, Hatfield).

The bulk of the support for innovative work comes from charitable trusts, for example, the 21st Century Science Project relies largely on such funding. Funding from government and local authorities is most commonly associated with government initiatives, for example, the Key Stage 3 Strategy in England.

Several of these projects have also received some form of industrial support in finance or in kind, but such support is perhaps the most difficult to identify. Industrial support is often distributed through charities. The funding through charitable trusts is numerically under-represented here, partly through the absence of weighting for the scale of the work, and also because only a small sample of the over three hundred projects funded through the RSPG scheme have been included here. The RSPG sample comprises mostly smaller projects that place a particular emphasis on science enquiry and which are also in many cases clearly innovative. It is also important to note that projects might be funded by one institution but might be located and developed in another institution.

There are six main organisations or initiatives through which projects are funded:

→ The Gatsby Charitable Foundation's Technical Education programme.

→ The Wellcome Trust.

→ The Royal Society's Partnership Grants scheme (RSPG).

→ The AstraZeneca Science Teaching Trust (AZSTT).

→ The Salters' Institute.

→ The Nuffield Foundation.

Examples of projects funded by these organisations and initiatives include:

→ The Science Enhancement Programme, the SKEES Project, Expert Teachers of Scientific Enquiry, Teaching Ideas and Evidence in Science at Key Stage 3: Scientific Enquiry, Contemporary Contexts for Science Enquiry, the Tower Hamlets Gatsby Project, and the Primary Science Enhancement Programme - Children Challenging Industry (The Gatsby Charitable Foundation's Technical Education programme).

→ 21st Century Science (The Wellcome Trust).

→ The Sky's the Limit, Science in the Real World: Liaison Project, Soapy Solutions, and Environmental pollutants and effects on historic buildings of York (The Royal Society's Partnership Grants scheme).

→ Planning Scientific Enquiry, Science Transition AstraZeneca Science Teaching Trust York (STAY), North Yorkshire AstraZeneca Science Pedagogy and Progression Project (NYASPP), Science Students in Primary Schools (SSIPS), and Science in The New Curriculum (SiNC) (The AstraZeneca Science Teaching Trust).

→ Teaching Ideas and Evidence in Science at Key Stage 3: Scientific Enquiry, Salters-Nuffield Advanced Biology (SNAB), Salters' Chemistry Club, Salters' Festival of Chemistry, Salters' Chemistry Club (The Salters' Institute).

→ Science Bursaries for Schools and Colleges, Re:act (Nuffield Advanced Chemistry), 21st Century Science (The Nuffield Foundation).

The range of activities supported by these organisations is large, and many figure here in their own right as substantial, separately institutionalised projects.

It should be noted that NESTA is a slightly different type of funder in this landscape, in that it views itself as a 'seed funder', helping to get a broader range of early stage projects to get off the ground and to attract further funding. 31 of the 48 science learning projects have been successful in attracting often significant levels of further funding from other sources (an average reporting £150,000, three times NESTA's typical award), and this is unlikely to have happened without NESTA's initial support.

There are two broad approaches to the funding for science enquiry projects. The first can be described as 'pro-active'. In this type of funding, the funding organisation has a relatively specific idea of the work that needs to be done. The funder will commonly set up some kind of central team (sometimes after competitive tendering) with responsibility for developing the project. This team then recruits schools and teachers to participate. In the case of local authority-based activity this can occur relatively systematically, with teachers or students involved from every school (Gifted and Talented Science Master Class, and Planning Scientific Enquiry). Projects supported by charities usually involve a more ad hoc set of participants. Schools and teachers are involved, either with the work itself as the main outcome, or in trialling resources that are then made more widely available. Although such projects tend to be developed first within specific settings, it is usually the intention of the developers that there will be some later dissemination and transfer.

The second main form of funding is best described as 'responsive'. A funding source invites applications and schools (usually in partnership with a company or higher education institution) need to take positive steps to be involved. Perhaps the most wide-ranging of these schemes is The Royal Society's Partnership Grants (RSPG) scheme, in which schools submit a bid to a committee, and whose applications are funded if it is judged that they meet the standards of quality required. A similar approach is employed by The Salters' Institute in some of the wide range of different initiatives it supports: competitions, residentials and its Festivals of Chemistry (Salters' Chemistry Club and Salters' Festival of Chemistry). There are several other initiatives in which schools are required to 'opt in' (Science Bursaries for Schools and Colleges, Sustainable Educational Environmental Developmental Sessions Clubs, Science Education 3-18 Small Grants Scheme, and The BA Young People's Programme).

Responsive funding tends to produce more innovative projects and outputs than pro-active funding. This is because pro-active funding tends to relate directly to national curricula and national government policy, and is often targeted on improving measurable performance in schools. For this reason such activity tends to be less innovative in comparison, but it is nonetheless important as part of the continuum of developmental activities in this field.

The interactions between the many funders can be complex. There is a high degree of co-funding, and some smaller industrial funders tend to channel their resources through the infrastructures of larger funders (notably The Salters' Institute).

Much innovative activity in science enquiry learning is dependent on the energy and initiative of individuals, particularly staff in schools

The types of developers of the projects included in this survey are shown in table 2.

Table 2: Types of project developers

Type	Number of projects
Higher education	22
Local authority	7
School	6
Professional body	2
Commercial body	1
Charity	1

It is apparent that, with the exception of activities undertaken in responsive mode by individual schools, work of this kind is mainly located in universities and to a lesser extent local authorities. It is not difficult to suggest reasons for this pattern: universities are often keen to raise funds, the activities involved may form the basis of research activity, and universities are not so directly under pressure to focus on government initiatives as schools and local authorities. In comparison, NESTA tends to fund a higher number of individuals and collaborations between different kinds of organisations; again this reflects its seed funding role.

Much innovative activity in science enquiry learning is dependent on the energy and initiative of individuals, particularly staff in schools. There is a wider question about how it might be possible to support and encourage more teachers, who have not participated in schemes like the RSPG, to develop innovative activities of their own and to share these with their peers.

Despite the fact that there are a small number of major funders, the overlapping nature of the sources and streams of funding as noted above can be confusing from the perspective of an individual teacher or group of teachers who might be interested in receiving support for developing an innovation.

3.2 Geographical distribution

In most cases innovations are funded by organisations which have headquarters in London, and are developed or undertaken by teams in other parts of the UK. Further, most of the innovations in this field are UK-wide in their eventual intended reach (which is not to say that they necessarily achieve this). That is, the developers and funders hope that such activities may be adopted by or be useful to many more teachers across the country. For the pro-active projects identified here, there is limited evidence of impact from local networks (as compared to national networks and organisations). As a result, it is not that meaningful to try to determine whether one part of the UK is more innovative than any other.

That said, there is no obvious higher education-based centre of innovative activity in Scotland or Wales. The AZSTT Science Students in Primary Schools and Science in The New Curriculum projects suggest that Northern Ireland is a slight exception to the UK-wide generalisation suggested above in being to some degree a hub of innovative activity.

Informal data suggests that the RSPG scheme receives proportionately fewer applications from Northern Ireland than from Wales and England. A parallel and broadly similar scheme which has been established in Scotland and funded by the Scottish Executive (Science Education 3-18 Small Grants Scheme), has meant that applications for the RSPG scheme from Scotland have fallen.

The significant activity supported by the Scottish Executive appears to be mainly based around websites (Science Education 3-18 Small Grants Scheme, Scottish Executive Education Department A Curriculum for Excellence 3-18, Science Transition in Scotland, Improving Science Education 5-14, and South Ayrshire Investigation Pack). Generally however this activity is broader than science enquiry. There is some emphasis on enquiry in the Science Education 3-18 Small Grants Scheme.

There is a small amount of similar activity in Wales, associated with the Welsh Key Stage 3 strategy ('Bridging the Gap': Bridging Units focusing on investigations in Science), and there is a similar emphasis within the English Key Stage 3 Strategy.

There are only a few local centres of major activity: King's College London, with the legacy of the AKSIS project; the University of York, with its strong tradition of curriculum development work; and Queen's University in Belfast, particularly through links with AZSTT. Local authority-supported activity is a partial exception to this pattern, but, as already suggested, this does not occur on any significant scale.

Informal data suggests that distribution across the English regions in the RSPG scheme is relatively uniform. AZSTT projects tend to be larger, and perhaps lend themselves to a geographical analysis. The geographical pattern of AZSTT projects with a significant science enquiry element is shown in table 3. There is no obvious pattern to the data, though it might be seen to show that closeness to London could be a factor.

Table 3: Geographical location of AZSTT projects with a significant science enquiry element

Location	Number of projects
North West	6
London and South East	5
Yorkshire and Humberside	3
Northern Ireland	2
South West	2
North East	1
Wales	1
Scotland	1
East Midlands	1

3.3 Target audiences

Most of the innovations in this survey are targeted at primary and secondary schools and teachers. It is difficult to identify examples of sustained activity in the informal and voluntary sector, such as museums or science centres. Perhaps the most significant example of cross-institutional activity is the programme for co-ordinating and supporting science clubs known as sciZmic, which has a significant element of more open-ended activity; many of the clubs turn out to be based in schools. Much of the wider activity that exists outside of schools is supported by web-based materials only, and is not a focus here. Further, the extensive enquiry work occurring within undergraduate courses has not been included in this survey; such work is close to being a standard requirement of courses and so cannot properly be described as innovative.

The distribution of the projects by age of target learners is shown in table 4.

Table 4: Distribution of projects by age of learners

Key stage	Number of projects[59]
1	12
2	29
3	33
4	10
5	5

It is apparent that there is an approximately equal distribution between the primary and secondary phase, and that post-16 activity is somewhat under-represented. Activity is in some cases targeted on 'Gifted and Talented' students (for example, Gifted and Talented Science Master Class, Soapy Solutions, and Micro-organisms in the Environment), while in one case it is focused on learners with special needs (The Sky's the Limit). In comparison, NESTA's general funding and support for science learning projects tends to have more of a focus on secondary students and teachers, while Science Year/Planet Science projects are fairly evenly balanced between primary and secondary levels.

3.4 Types of innovation

The majority of the projects in this study appear to interpret science enquiry along the lines of 'traditional' Sc1 activity in the National Curriculum in England, and use the Sc1 structure as their starting point. However, many projects seek to use investigations and experiments based on variables to inform more original and sophisticated activity, such as designing an 'environmental garden' (Science in the Real World: Liaison Project), manufacturing a product (Fabrication of Gold Nanowires), controlling an artefact (Sustainable Educational Environmental Developmental Sessions Clubs), or conducting an environmental enquiry (Environmental Pollutants and Effects on Historic Buildings of York).

59.There is some 'double counting' here, since many projects cover more than one stage. See below for more analysis on transitional projects.

There is a great diversity of approaches taken; some projects involve placements (Science Bursaries for Schools and Colleges), working with scientists (Royal Society Partnership Grants Scheme), activity in industrial contexts (Primary Science Enhancement Programme - Children Challenging Industry), residentials (Salters' Chemistry Club), or competitive projects (Salters' Festival of Chemistry).

A small number of projects involve a focus on collecting empirical evidence (sometimes focusing explicitly on its quality) but appear to allow scope for learner autonomy in collection and interpretation (Teaching Ideas and Evidence in Science at Key Stage 3: Scientific Enquiry, and Bradford Robotic Telescope – Earth and Space Learning Programme). The emphasis in several of the projects is on disentangling the skills of science enquiry, assessing them and sometimes teaching them directly (for example, Improving Science Together, and AKSIS: ASE-Kings Science Investigations in Schools). Such projects have been included here where it is judged that there is at least some prima facie evidence they might move beyond the 'traditional' mode.

Some projects are innovative in their use of novel scientific topic or materials (for example, Contemporary Contexts for Science Enquiry, Fabrication of Nanowires, and the Bradford Robotic Telescope – Earth and Space Learning Programme). Other projects are innovative through the involvement of various groups, such as: university staff or students (Environmental Pollutants and Effects on Historic Buildings of York, Fabrication of Gold Nanowires, or Researchers in Residence); industrial scientists (A Robot's Story - What is Happening Now?, The Sky's the Limit, Science in the Real World: Liaison Project, Soapy Solutions, Primary Science Enhancement Programme - Children Challenging Industry, and Improving Science Together); or parents (Micro-organisms in the Environment, first Investigators and Young Investigators, and the BA Young People's Programme).

Activity which focuses on evidence in science is a growing area, prominently supported by the 21st Century Science Project and a range of other projects (for example, within the Nuffield Foundation). Related to this area is the Science UPD8 project, which uses the internet for the rapid distribution of classroom activities based on contemporary science issues. Only one project in this study operates commercially (Sustainable Educational Environmental Developmental Sessions Clubs).

That the majority of the projects in this study use the Sc1 structure as their starting point suggests that, as argued elsewhere in this report, it is possible to develop a range of innovative activities by starting within conventional frameworks such as national curricula. Alternatively, one local authority-based project sets out to reform the entire English Key Stage 3 science curriculum on the basis of enquiry (Tower Hamlets Gatsby Project). Further, coursework assessment is more open and flexible in some of the innovative courses included here (Salters-Nuffield Advanced Biology, 21st Century Science Project, Advancing Physics, and the Advanced Higher exams in Scotland). These forms of innovation, though they are not always the most radical, are of course intended to be sustainable as long-term interventions.

Many projects seek to use investigations and experiments based on variables to inform more original and sophisticated activity

3.5 Outputs

The intended outputs from these projects are identified in table 5.

Table 5: Types of intended outputs

Resources for teachers to use with learners (may include extensive trialling in the classroom). Resources include booklets, CD-ROMs, websites.	20
Project activity involving work with learners (for example, PhD students conducting activities with learners).	17
Teacher Continuing Professional Development (CPD), or in one case the development of a CPD package for use by trainers.	8
Whole course evelopment with a significant enquiry emphasis	4
Online support for students	1

The outputs for NESTA science learning projects are similarly diverse, but they also tend towards physical products. There is a skew towards eLearning (online and CD-ROM), balanced by a roughly equal number seeking to effect change in more traditional ways by organising events such as workshops or training sessions (for example, this is common amongst Science Year/Planet Science projects).

Although several of the large (non-NESTA) initiatives are subject to formal evaluation, these are not yet in the public domain. Informal feedback on projects and activities, whilst generally positive in nature, are of course unreliable measures of their effectiveness. Some projects have however demonstrated a degree of longevity and a capacity to attract further funding, which might be an indicator of effectiveness (for example, Science Bursaries for Schools and Colleges, Salters' Chemistry Club, and the Primary Science Enhancement Programme - Children Challenging Industry). Others appear to have spawned further projects (for example, Science Transition AstraZeneca Science Teaching Trust York, and the North Yorkshire AstraZeneca Science Pedagogy and Progression Project). There is little available data measuring the impact of the projects on student learning and enthusiasm.

Most of NESTA's science learning projects can be regarded as being primarily 'informational', that is, focused on providing new and innovative resources, rather than being more fully-fledged programmes that are designed to develop the skills or professional practices of teachers. This reflects their pilot nature, in that they represent opportunities to develop and test out new approaches. The majority of NESTA projects anticipate greater medium to long-term impacts, although a minority are able to demonstrate the development of new knowledge and skills in their target audiences within the lifespan of the project. Science Year/Planet Science projects, as part of a more focussed initiative, tend to provide greater evidence of impact, again in the area of new knowledge and skills amongst target audiences.

Responses from the NESTA science learning projects indicate that the process of managing the projects on the ground has required a shift in the culture of institutions, in particular towards allowing greater collaboration and creativity in projects. However, in many cases, project managers have suggested that they have received little commitment from the senior managements of their organisations, and that progress has occurred despite rather than because of institutional factors.

3.6 Dissemination

For innovative projects that are targeted on a particular set of schools (for example, initiatives involving a local authority as a partner) the focus is often on dissemination only within the locality. Further, the practices may be too closely related to their original settings and to the teachers who created them. However, the wider dissemination of these practices could encourage further teacher-led innovation.

Other projects generate resources that are intended to be made available to a wider range of schools (for example, the Science Enhancement Programme – King's Enhancing Enquiries in Schools, Expert Teachers of Scientific Enquiry, Teaching Ideas and Evidence in Science at Key Stage 3: Scientific Enquiry, Improving Science Together, first Investigators and Young Investigators, and AKSIS INSET). However, on its own the publication of printed or online materials can be an ineffective method of dissemination, given the competing demands that teachers have on their time. Some projects attempt to encourage the adoption of innovative practices through more personalised and interactive forms of dissemination and by championing their practices 'on the ground' (for example, the Tower Hamlets Gatsby Project, Primary Science Enhancement Programme - Children Challenging Industry, South Ayrshire Investigation Pack, the Bubbles Science Transition Project Sheffield).

The results of this initial survey suggest a wide diversity of innovative projects in science enquiry, the key role played by a relatively small number of major funders in supporting these projects, and the possibility of using the existing national curricula with their emphasis on enquiry as starting-points for developing new approaches and resources. However, there is more work to be done in order to enhance the evaluation, dissemination and transfer of these innovations.

The findings from this section of the report, along with those from section two, are discussed further in the final section of the report.

Teachers and others may have the energy, initiative and ideas, but they are hampered from influencing UK national education systems by insufficient investment in practice-led research and development

Science enquiry can help learners to develop their understanding of the processes of science as well as the content of scientific knowledge

4. Conclusions

4.1 The potential of science enquiry

The potential of science enquiry to engage and motivate learners is clear from the outcomes from NESTA projects, those projects funded and supported by other organisations, and from the broader research literature. Science enquiry can help learners to develop their understanding of the processes of science as well as the content of scientific knowledge. As a result it can support gains in motivation and attainment, even by young people who have previously been unengaged by science education and in schools in challenging circumstances.

Outcomes from NESTA's projects illustrate a range of elements of science enquiry learning and their benefits to learners:

- → Student investigations of scientific phenomena that can increase motivation and develop thinking skills (for example, Science Year/Planet Science projects).
- → Practical experiments with 'hands-on' engagement that can increase familiarity with the objects and tools of science (for example, the Genetic Futures project).
- → Learning across the curriculum to draw on students' other interests and strengths (for example the Motivate project).
- → Encouraging collaborative working, learning and problem-solving between students (for example the Creative Space project).
- → Inspiring learners through experts and role models who may use more spontaneous teaching approaches, as well as sharing their applied, real-world knowledge and experience (for example Brain Games).
- → Trialling innovative collaborations to capture the interest and raise the attainment of low-achieving and disengaged students (for example the Planet Science Outreach programme).
- → Communicating the links between science learning and the real world, using attractive media such as simulations, games, film, magazine and events (for example Digital Science initiative, and the flipside magazine).

These elements rely on developing the skills and enthusiasm of teachers and other educators, as well as students themselves.

4.2 Learner autonomy

Science enquiry relies on some degree of learner autonomy in relation to decision-making about key aspects of their work (such as aims, methods and outcomes), otherwise it can degenerate into another form of rote learning. This greater autonomy for learners and the chance to pursue unanticipated questions can challenge more traditional forms of pedagogy in science. The success of innovations often therefore rests on improving the confidence of educators in managing autonomy. However, evidence from the teachers involved in NESTA projects and others demonstrates the benefits of this both for teachers and their students. Any attempt to plan for more systemic innovation and increased learner autonomy must recognise that it relies upon confident, well-prepared teachers.

4.3 Curricula and assessment systems

Over half of the total projects surveyed in the initial mapping exercise of innovations in science enquiry included in this report appear to interpret enquiry as 'traditional' Sc1 activity. This and other evidence from NESTA projects suggests that much is possible within current structures. Innovative and creative approaches can be enquiry-led and also support higher attainment and the achievement of national curriculum learning objectives. The perception that the current national curricula necessarily inhibit science enquiry work can be challenged.

4.4 Evaluation

Evaluation needs to play a consistent and sustained role in the funding and support of innovative projects, particularly the evaluation of what learners have gained. Organisations such as NESTA need to play a stronger role in helping to generate a deeper evidence base on the effectiveness of science enquiry learning by supporting projects to evaluate outcomes and impacts in a rigorous manner.

4.5 Dissemination and transfer

Similarly, such organisations need to support the sustainability of projects that have demonstrated initial benefits by devoting more resources to dissemination, transfer and testing after the formal funding period has ended. Although this would demand more resourcing and longer-term planning from funding organisations, it would enhance the value received from their original investments and for the education system as a whole.

4.6 Challenging the current state of science enquiry

Teachers recognise that science enquiry is a crucial element of science education but many feel that they don't have sufficient time, resources or knowledge to support this effectively. This situation needs to be challenged through the practical demonstration of alternatives and their success. In order for this to happen, more teachers need to feel encouraged and have the capacity to act as the facilitators of greater science experimentation and investigation in the classroom, rather than limited by resources and the curriculum and assessment systems that they operate within.

NESTA's projects and others illustrate how teachers and schools can be involved in new approaches to science experimentation and investigation. Some of these projects also demonstrate that the curriculum and assessment systems are not inevitable barriers to this kind of work. Policymakers and advisors could do more to promote the opportunities for science enquiry work that already exist within the established national curricula, using projects such as these as convincing examples.

At the same time, it is important that policymakers and advisors challenge the causes of the apparent decline in the opportunities for practical experimental activities in science classes. These include the fears held by many teachers and schools regarding the physical dangers in conducting experimental work, their sense of how restrictive the regulatory framework is, and what the risks are of litigation if anything should go wrong. Policymakers should challenge these perceptions on the basis that science enquiry in schools has a long-term relationship to the health of scientific research and public scientific literacy in the UK.

Teachers recognise that science enquiry is a crucial element of science education but many feel that they don't have sufficient time, resources or knowledge to support this effectively

A more transparent, centralised and well-publicised 'gateway' of support and advice to help turn innovative ideas into generalised practices might be desirable

4.7 Embedding innovation in education

Innovative ideas and initiatives need time and funding if they are to be tested in everyday settings, and then adopted into mainstream practice. Teachers and others may have the energy, initiative and ideas, but they are hampered from influencing UK national education systems by insufficient investment in practice-led research and development.

There are some positive developments in this area. For example, in England, the national and regional Science Learning Centres are offering a range of opportunities for CPD that are focused on improving teachers' science knowledge and translating this into classroom practice. The new contractual entitlement for Preparation and Assessment (PPA) from September 2005 should help more teachers to learn about new approaches in science education and to use them in lessons.

However, significant problems remain in terms of the development of new approaches. Most of the funding and support that is currently directed at innovations in science enquiry learning comes from charitable trusts rather than government or local authorities, and tends to be developed in universities. This support is valuable, but it can be fragmented and lead to a lack of co-ordination in this crucial area. The systems of funding and support that enable innovative activity in this area are complex, often overlapping, and sometimes impenetrable. A more transparent, centralised and well-publicised 'gateway' of support and advice to help turn innovative ideas into generalised practices might be desirable. Further, given the current dependence on charitable trusts and universities, there is a greater role for national and local government in promoting and advocating innovation in this area.

At the same time, the determining influence on the development and success of innovative approaches remains the vision, enthusiasm and energy of individual teachers and school departments. Many practical difficulties exist in developing and managing innovative projects for the teachers and departments involved, including engaging other teachers and schools (due to time pressures and limited resources), coping with the burdens of project management and administration, securing partners, and ensuring sustainability.

The latter is particularly important. The greater sustainability of innovative approaches to science enquiry learning is crucial in order to ensure that the enhanced engagement and motivation of learners is converted into gains in attainment. This would help to reassure a greater number of teachers and schools that more science enquiry work can be 'justified' within the perceived constraints of their national curricula, assessment systems and available resources.

The barriers described here are not unique to science enquiry learning, and so the state of innovation in this area can be used to raise important questions regarding the opportunities for innovation in science education as a whole and indeed the education system more generally.

This report has argued for more innovation in science enquiry by pointing to the benefits that have been gained from new and creative approaches in this area. However, this would also need to be supported by the better co-ordination and utilisation of the innovations that are developed. The education sector needs to think more collaboratively about how new and creative ideas and approaches can feed into a more coherent programme of innovation, and, if proven effective, into sustained practice.

Education in the UK needs to harness the potential of science enquiry learning to engage and motivate learners and to counter the misleading impressions of science that can be generated by the imbalance in much classroom science between content and enquiry. Yet this issue has relevance beyond how science is taught in schools; it should be a matter of public and political concern. As the 2002 report from the House of Commons Science and Technology committee suggested:

"Students need to have acquired knowledge and skills beyond the ability to remember scientific facts. This is described... as 'scientific literacy'. Defining scientific literacy - or what an individual would need to be able to do in order to be scientifically literate - is not straightforward... In addition, much of the scientific knowledge acquired at school is forgotten by adulthood. Rather, what is needed is a much better understanding of the practices, processes and limits of scientific knowledge. Developing such an understanding is essential if individuals are to be able to make personal decisions and to participate in the public debate about the moral and ethical dilemmas increasingly posed by scientific advances.... What is important is not that citizens should be able to remember and recall solely a large body of scientific facts, but that they should understand how science works and how it is based on the analysis and interpretation of evidence. Crucially, citizens should be able to use their understanding of science, so that science can help rather than scare them."[60]

Education in the UK needs to harness the potential of science enquiry learning to engage and motivate learners and to counter misleading impressions of science

60.Paragraph 86, House of Commons Science and Technology Committee (2002), Third Report of the Science and Technology Committee on Science Education from 14 to 19, (HC 508-I), (The Stationery Office, London).

The education sector needs to think more collaboratively about how new and creative ideas and approaches can feed into a more coherent programme of innovation, and, if proven effective, into sustained practice

Appendix 1 - NESTA's support for innovations in science learning

NESTA's Learning Programme aims to support innovative ways of learning that provide models for others to follow, and to enhance an appreciation of science, technology and the arts in people of all ages.

Its main objectives are to:

- Source innovative projects that may help to improve practice and/or policy in key strategic areas of learning.
- Bring together on projects talented individuals and organisations who are committed to exploring and sharing new approaches in the fields of formal and informal education.
- Achieve significant benefits for project participants, be they learners, teachers or educationalists.
- Become a useful resource to policymakers and practitioners on innovation in learning.

NESTA has a range of other initiatives in science learning and science communication.

FameLab is a NESTA initiative with the Cheltenham Science Festival, a nationwide competition to find a new generation of talented science communicators who can inspire and excite public imagination.

Ignite!, also part of NESTA's Fellowship Programme, supports exceptionally creative young people aged between 10 and 21 years-old. It aims to stimulate creativity through distinctive and inspirational environments and to improve understanding of the development of creativity and innovation in young people.

NESTA FutureLab brings together creative, technical and educational communities in programmes of practical experimentation in order to pioneer ways of using new technologies to transform the learning experience. As a 'blue-skies' research facility and creative incubator, NESTA Futurelab provides research and development support to those with new ideas for compelling interactive learning resources.

More information is available on the NESTA website: www.nesta.org.uk

Appendix 2 – NESTA projects in science enquiry learning – webography

Birmingham Acrisat
http://www.NESTA.org.uk/ourawardees/profiles/3880/

Brain Games:
http://www.NESTA.org.uk/ourawardees/profiles/1170/

Creative Space:
http://www.NESTA.org.uk/ourawardees/profiles/3047/
http://www.capeuk.org

Debating the Evidence:
http://www.NESTAfuturelab.org/showcase/debating_evidence/debating_evidence.htm

Digital Science:
http://www.NESTA.org.uk/ourawardees/profiles/4767/

Einstein Year:
www.einsteinyear.org

films for Learning
http://www.thomas-hardye.dorset.sch.uk/news/Community/filmsForLearning.htm

flipside:
www.flipside.org.uk

Genetic Futures:
http://extra.shu.ac.uk/cse/geneticfutures/
http://www.NESTA.org.uk/ourawardees/profiles/3985/

Giant Jump:
http://www.planet-science.com/about_sy/events/jump/index.html

Motivate:
http://www.motivate.maths.org/

National Collaborative
http://www.NESTA.org.uk/nationalcollaborative/

Nestonauts:
http://www.NESTA.org.uk/ourawardees/profiles/3703/

Outer Space/Inner Space
http://www.NESTA.org.uk/ourawardees/profiles/3379/
http://newton.ex.ac.uk/staff/ASP/play/

Planet Science Outreach
http://www.planet-science.com/about_sy/outreach/index.html

Science Alliance
http://www.creativitycentre.com/sciencealliance
http://www.NESTA.org.uk/ourawardees/profiles/3942/

Science Year/Planet Science:
www.planet-science.com

Whodunit:
http://www.planet-science.com/whodunit/

Appendix 3 – Evaluations of NESTA projects in science enquiry learning – methodologies

findings from NESTA-supported projects in science enquiry learning are derived from independent and project evaluation reports. A brief description of the methodologies employed in each case is provided below under the project or programme name.

Brain Games

The evaluators from Wessex SATRO, The University of Bath, attended the Brain Games activities on nine different days. Interviews were conducted with students and teachers, debrief sessions were held with the mentors, and the activities were observed.

Creative Space

This project was evaluated by the Centre for Science Education at Sheffield Hallam University. Activities across the various projects were observed, and interviews conducted with the professional groups involved in the projects (teachers, artists, researchers), as well as the students.

Debating the Evidence

After consultation with teachers and a usability study with gifted and talented students, Debating the Evidence was trialled and evaluated with Year 8 learners. The study focused on the impact of the software rather than the creation of a learning environment in which the software would be embedded with additional teaching and material resources. The evaluation was undertaken in the top Year 8 science class at a voluntary aided comprehensive school. In this school 77 per cent of the students received five GCSEs grade A*-C in 2004 (the national average was 53.7 per cent). Two sessions using the software were arranged. Data was used from the 13 pairs of learners that attended both sessions. The learners were ranked in terms of their responses to the tasks, and field notes and video recordings of the classes were also collated. At the end of the sessions three learners were interviewed by the researcher, in order to identify their understanding of covariance and the task. For more explanation and findings see Facer, K., Ulicsak M., and Howard-Jones, P. (2005), Debating the Evidence, Research Report, (NESTA Futurelab, Bristol).

Genetic Futures

The evaluation of the Genetic Futures programme, including the regional events and the national forum, was conducted by The Centre for Science Education (CSE) at Sheffield Hallam University. The evaluators employed evaluation forms for teachers and students. The key findings were based on a random sample of these evaluation responses.

Motivate

The first pilot year of the project was externally evaluated through student and teacher questionnaires. These were followed up by interviews with a sample of students and one teacher from each of the participating schools for each unit of the project (The Motivate programme continues to be evaluated through interviews and feedback from teachers in participating schools).

Nestonauts

This evaluation, by Bath Spa university, collated a range of evidence: documentary sources (the project proposal, funding application forms, project updates and so on); observations of lessons and learning activities; samples of students' work; interviews with the project management team; and an online questionnaire.

Outer Space/Inner Space

The School of Physics at the University of Exeter was commissioned to evaluate the impact of this activity. The evaluation activities included pre- and post- written questionnaires with students, structured telephone interviews with science teachers, and a workshop with stakeholders and interviews with staff from the University's School of Physics. The evaluation was conducted by e.

Planet Science Outreach

GHK were commissioned in March 2003 to evaluate the delivery and impacts of the pilot and main stages of the Planet Science Outreach programme. In the pilot, the evaluation assessed each project against its own objectives, and provided an overview of the common issues encountered, summarising key considerations for the programme's main stage. In the main stage, the evaluation's focus was on identifying impact and the key lessons for delivering outreach approaches around science education to schools in challenging circumstances.

The evaluation methodology comprised project visits by the GHK team, the development of generic and project-specific evaluation frameworks, the production of self-evaluation reports by project managers, and survey work with participating pupils and teachers. The study team also had the opportunity to observe projects at work 'on the ground', as well as attending a series of debriefing events with projects, pupils and teachers. In addition, a number of projects undertook additional evaluation activities to address specific issues associated with their approaches – all of which have been used to inform the final report.

Roboteers in Residence

This evaluation was conducted by Professor Richard Kimbell, Technology Education Research Unit (TERU), Goldsmiths College. The methodology involved questionnaires and interviews with the roboteers, FE staff and students, systematic observation of working sessions with these groups, and the recording of this work for later analysis.

Science Year/Planet Science

The National Foundation for Educational Research (NFER) conducted a major evaluation of Science Year and Planet Science in 2003, including student attitudes towards science and the Science Year/Planet Science activities, the views of their schools, the impacts of these activities, and the views of the strategic partners involved in the initiative.

The evaluation involved the analysis of the evaluations of individual initiatives (a total of 25 previous evaluations were reviewed), an online survey of secondary school students who used Science Year/Planet Science materials, telephone interviews with LEA science advisors/inspectors, face-to-face interviews with three strategic partners, and case studies in primary and secondary schools including interviews with key personnel and students.

Appendix 4 - Background on the education systems in the UK nations

Key stages, year groups and student age in the UK curricula

For the purposes of easier comparison, table 6 below shows the stages, year groups and student age groups used in school-based education in each UK nation.[61]

Table 6 Comparison of stages, year groups and student ages in the UK nations' school curricula up to age 16

Age	England		Northern Ireland		Scotland		Wales	
	Key stage	Year group	Key stage	Year group	Stage	Year group	Key stage	Year group
4-5	-	-	1	P1	-	-	-	-
5-6	1	1		P2	5-14 Curriculum	P1	1[62]	1
6-7		2		P3		P2		2
7-8	2	3		P4		P3	2	3
8-9		4	2	P5		P4	4	
9-10		5		P6		P5		5
10-11		6		P7		P6		6
11-12	3	7	3	8		P7	3	7
12-13		8		9		S1		8
13-14		9		10		S2		9
14-15	4	10	4	11	Standard Grade	S3	4	10
15-16		11		12		S4		11

England

The National Curriculum in England documents set out the statutory requirements and entitlement for all students in a number of areas of learning. It also establishes national standards in the subjects that it includes. The National Curriculum is statutory and applies to all students in state schools, voluntary-aided, voluntary-controlled and special schools (the curriculum authority in England is the Qualifications and Curriculum Authority, QCA). In addition, the literacy and numeracy strategies (for primary) and schemes of work in other subjects are in very wide use. These documents are not statutory, but they have a central place in the learning and teaching plans of most schools.

For each key stage and for each subject, the National Curriculum is made up of two areas: programmes of study (which set out what students should be taught in each subject); and level descriptions (which set out the expected standards of students' performance). It is for schools to choose how they organise their school curriculum to include the programmes of study. The National Curriculum tests are national examinations that are taken in mathematics, English and science at the end of Key Stage 1 (age 7 years), Key Stage 2 (age 11 years) and Key Stage 3 (age 14 years). The tests assess the levels of attainment reached by each student in the specific subject.

61.Note that 'key stage' is a term generally used in England, Northern Ireland and Wales but not in Scotland. In Scotland one might refer to 'age range' rather than key stage.
62.In Wales pilots have begun for a new Foundation Phase curriculum for three to seven year-olds to replace Key Stage 1. By 2008 the Foundation Phase should replace Key Stage 1 in all schools.

At primary level, most schools in England will make use of the literacy and numeracy strategies. These strategies are, like the schemes of work in other subjects of the curriculum, based on the statutory programmes of study but go further in terms of specific areas, learning strategies and skills, and also in terms of support and planning. At Key Stage 4 (GCSE level) students may study all the subjects in the National Curriculum, plus numerous additional subjects. Different examining boards offer GCSEs (the common specifications for GCSE syllabuses are set by the Qualifications and Curriculum Authority, in conjunction with the Qualifications, Curriculum and Assessment Authority for Wales and the Council for the Curriculum Examination and Assessment in Northern Ireland). For this reason, while the curricula of the GCSE courses are generally similar between the examining boards offering the particular GCSE, they are not identical.

Northern Ireland

In Northern Ireland (and Scotland and Wales) there are no direct equivalents to the English schemes of work. Further, a review of the Northern Ireland Curriculum at Key Stage 1 and Key Stage 2 was completed in 2004; the review of Key Stage 3 and Key Stage 4 is being completed. The revised curriculum will be implemented from 2006. The new curriculum is a significant departure from what existed before, as well as differing substantially from the other UK curricula (the curriculum authority in Northern Ireland is the Council for the Curriculum, Examinations and Assessment, CCEA).

The changes are designed to increase the degree of professional discretion teachers may exercise in matching the curriculum to the needs of learners, as well as to reflect new understanding of the learning process and bring an increased emphasis on the development of skills for lifelong learning. Overall the revised curriculum aims to: reduce the level of prescription in the statutory requirements; put greater emphasis on what learners can do in terms of their skills and competencies; make connections across different parts of the curriculum more explicit; and use assessment as a tool for improving learning, not just as a means of reporting on it.

The revised curriculum consists of areas and, within these, a number of strands. The key requirements of each area and strand are specified, and below them a selection of elements (describing concepts, skills, areas of knowledge and so on) for teachers to select from to develop the main requirements of the strand in question. These elements are not prescribed, and it is up to the practitioner to decide what use to make of these elements in their teaching. While the main requirements are specific to the area and strand, they are not subject-specific, and indeed may relate to more than one subject. The areas of the revised curriculum are broader and more encompassing than the traditional notion of a 'subject'. The curriculum also includes the Irish language in Irish speaking schools.

Scotland

The 5-14 National Guidelines for Scotland are quite different from the curricula of the other UK nations (the curriculum authority in Scotland is the Scottish Qualifications Authority, SQA). The guidelines are not prescribed by statute, although the subjects themselves are. In addition, the curriculum in Scotland is in a period of review, and it is likely that there will be significant developments over the next few years.

Responsibility for the management and delivery of the curriculum belongs to education authorities and head teachers, or in the case of independent schools, the boards of governors and head teachers. The guidelines are produced by the Scottish Executive Education Department (SEED) and Learning and Teaching Scotland (LTS). They cover the five subject areas of Mathematics, Language, Environmental Studies, Expressive Arts, and Religious and Moral Education. As well as these areas, there are a number of cross-curricular aspects to the 5-14 Curriculum (Personal and Social Development, Enterprise in Education, Education for Citizenship, the Culture of Scotland, and Information and Communications Technology).

The guidelines also differ from the other UK curricula in that the programmes of study are not structured by key stage. Each subject's programme of study is presented in terms of a progression of attainment levels from the beginning of primary through to the end of secondary. These provide an indication of what students should know or be able to do at each level of attainment (but note that they are not 'students should be taught to' statements as in England). However, as each attainment target refers to a specific area of knowledge, understanding or skill, it is possible at this level to compare them with, for example, the teaching requirements in England.

In August 2001 a circular on flexibility in the curriculum was issued to schools, encouraging them to take more innovative and flexible approaches to the curriculum and identifying the need of the individual learner as being at the heart of the curriculum. This enables schools to deviate from the models outlined in the curriculum guidelines where there is a clear educational benefit for pupils. Further, national tests for attainment in 5–14 are being discontinued. Assessment materials have recently been made available for teachers to use in student assessment in English language and mathematics. The Scottish Higher examinations are the focus of study after the 5–14 guidelines. As with GCSEs in the rest of the UK, there are a large number of subjects available for study.

The 'national debate on education' in 2002 led to a review of the curriculum in 2003 to identify the purposes of 3-18 education and the principles for the design of the curriculum. A Curriculum for Excellence, published in 2004, was produced as a template for phased reform to generate a single 3-18 curriculum in Scotland. A sequence of reviews of different learning areas will be conducted against the principles in this document. The first of these is science.

Wales

The National Curriculum for Wales exists in two versions, Welsh and English, reflecting the bilingual context (the curriculum authority in Wales is the Qualifications, Curriculum and Assessment Authority for Wales, ACCAC). In addition, the National Curriculum for Wales is entering a period of review and is likely to be significantly revised over the next few years.

The structure of the current National Curriculum is closer to that of England than the other UK nations' curricula, but there are important differences. There is, for example, no direct equivalent of the breadth of study sections in the programmes of study for subjects. However, there are generally some recommendations on range and focus within subjects ('pupils should be given opportunities to'). As with the National Curriculum for England, teaching requirements are the 'students should be taught' statements within each programme of study. Each programme of study has one or more attainment outcomes. These are major sections within the programme of study.

A number of skills are intended to be integrated appropriately across the National Curriculum; these include IT skills, mathematical skills, problem-solving skills and creative skills. Sometimes these skills are explicitly linked to sections of a programme of study. At the end of Key Stages 1, 2 and 3, standards of students' performance are set out in eight level descriptions of increasing difficulty. These levels are equivalent to those in the National Curriculum for England. It should also be noted that National Tests for 7 year-olds have ended (along with league tables of test scores for individual primary and secondary schools), and those for 11 and 14 year-olds will be abolished by 2006.

Appendix 5 – Mapping innovations in science enquiry – methodology

NESTA commissioned the Centre for Studies in Science and Mathematics Education at the University of Leeds to analyse the extent of innovative projects in science enquiry teaching and learning across the regions and nations of the UK.

The definition of 'science enquiry' used for this aspect of the study was the same as in the rest of this report, that is, activity in which:

- learners are responsible for some elements of decision-making about key aspects of their work, such as aims, methods and outcomes, though not necessarily all of these;
- learners undertake activities such as raising questions and hypotheses, designing and carrying out the enquiry, revising it based on observations and findings, and presenting the conclusions to others;
- learners develop their understanding and awareness about the methods of science, its outcomes or its uses.

This was deliberately kept broad in order to capture a range of activities. Similarly, potential respondents were not given a definition of 'innovation', since the innovative character of the projects might derive from various characteristics. These include the form of enquiry employed, the context of topic or materials, the location, the social relations involved, or the intended outcomes, particularly in terms of forms of professional development.

In order to identify innovative activities in science enquiry, the researchers contacted the major networks for science education, including:

- Association for Science Education (ASE).
- Association of Science Education Tutors (ASET).
- National Advisers and Inspectors Group for Science (NAIGS).
- Regional field Officers (ASE).
- National and Regional Committees of ASE.
- Northern Ireland Science Education Network.
- Science section of the Specialist Schools Trust.

The researchers also approached key regulatory bodies, for example:

- Qualifications and Curriculum Authority.
- Council for the Curriculum, Examinations and Assessment.
- Scottish Executive Education Department.
- Ofsted.
- HMIE (Scottish Inspectorate).

In addition, the researchers contacted the education departments of the professional science associations, principally:

- Institute of Biology.
- Institute of Physics.
- Royal Society of Chemistry.
- Royal Society.

The researchers also contacted a range of other potential informants, including:

- SETNET.
- Centre for British Teachers.
- ecsite-uk: the UK Network of Science Centres and Museums.
- Improving Science Education 5-14 (Scotland).
- Scottish Schools Equipment Research Centre.
- The 59 Club (the association of independent school Heads of Science).

In some cases the researchers were able to put appeals for information on websites, in newsletters or in other publications. They also established a simple website for the project. It was of course necessary for the researchers to prioritise within the resources available for this project, and so they focused on projects which appeared to have the strongest element of enquiry in them. Respondents were invited to contact the researchers directly with suggestions and basic contact details, which were then pursued. Data relating to the projects was gathered against a basic pro forma.

Appendix 6 – Science enquiry projects across the UK

This list of science enquiry projects refers to the projects discussed in section three of the report. It should be noted that not all of these projects are on-going, but that information regarding them may still be available. Website addresses are provided where available.

21st Century Science
http://www.21stcenturyscience.org

Advanced Higher exams (Scotland)
http://www.sqa.org.uk/

Advancing Physics
http://advancingphysics.iop.org/products/assessment.html

AKSIS: ASE-Kings Science Investigations in Schools
http://www.kcl.ac.uk/depsta/education/research/AKSIS.html

AKSIS INSET (in-service training)
http://www.kcl.ac.uk/depsta/education/research/AKSIS.html

AstraZeneca Science Teaching Trust (AZSTT)
http://www.azteachscience.co.uk/

The BA Young People's Programme
http://www.the-ba.net/the-ba/ResourcesforLearning/aboutypp.htm

Bradford Robotic Telescope – Earth and Space Learning Programme
http://www.telescope.org/

'Bridging the Gap': Bridging Units Focussing on Investigations in Science
http://www.accac.org.uk/uploads/documents/1515.pdf

Bubbles Science Transition Project (Sheffield)
http://www2.sheffield.gov.uk/services/education/goodpractice/transition/science.htm

Cognitive Acceleration through Science Education (CASE)
http://www.kcl.ac.uk/depsta/education/case.html

Contemporary Contexts for Science Enquiry
http://www.sep.org.uk/info.htm

Data Loggers in Science
www.standards.dfes.gov.uk/keystage3/

Environmental Pollutants and Effects on Historic Buildings of York
http://www.royalsoc.ac.uk/partnership

Expert Teachers of Scientific Enquiry

Fabrication of Gold Nanowires
http://www.royalsoc.ac.uk/partnership

first Investigators and Young Investigators
http://www.the-ba.net/the-ba/ResourcesforLearning/firstInvestigators/Whatisfi.htm

Gifted and Talented Science Master Class
www.standards.dfes.gov.uk/keystage3/casestudies/cs_sc_agt

Improving Science Education (ISE) 5-14
http://www.ise5-14.org.uk

Improving Science Together
http://www.azteachscience.co.uk/

Key Stage 3 Strategy
http://www.standards.dfes.gov.uk/keystage3/respub/sc_enquiry
http://www.standards.dfes.gov.uk/keystage3/downloads/sc_enquiry_40pres.ppt
http://www.standards.dfes.gov.uk/keystage3/downloads/sc_enquiry_30pnotes.pdf
http://www.standards.dfes.gov.uk/keystage3/downloads/sc_enq_int019605.pdf

Lab in a Lorry
http://www.labinalorry.org.uk/

Micro-organisms in the Environment
http://www.royalsoc.ac.uk/partnership

North Yorkshire AstraZeneca Science Pedagogy and Progression Project (NYASPP)
http://www.york.ac.uk/depts/educ/projs/STAY/NYASPPNov04.htm
http://www.azteachscience.co.uk/code/trust/york.htm

The Nuffield Foundation
http://www.nuffieldfoundation.org/
http://www.nuffieldcurriculumcentre.org/

Passport: A Bridging Project for Key Stage 2 into Key Stage 3
http://www.sycd.co.uk/who_am_i/passport/activity.htm

Planning Scientific Enquiry

Primary Connexions
http://www.qub.ac.uk/home/QueensintheCommunity/OutreachDirectory/ProjectDetails/?proj_cd=PRIMX

Primary Science Enhancement Programme (PSEP) Children Challenging Industry (CCI)
http://www.gravityisahat.com/product_psep/home.htm
http://www.york.ac.uk/org/ciec/stempartners/case_studies/cieccpd.htm

Re:act (Nuffield Advanced Chemistry)
http://www.chemistry-react.org/go/Tutorial/Tutorial_4646.html

Researchers in Residence (RinR) (previously Pupil Researcher Initiative)
http://extra.shu.ac.uk/rinr/site/home

A Robot's Story (What is Happening Now?)
www.wickedrobots.co.uk
www.robofest-europe.org/Britain/index.php

Royal Society Partnership Grants Scheme
http://www.royalsoc.ac.uk/partnership

Salters' Chemistry Club
http://www.salters.co.uk/camps/contact.htm
http://www.salters.co.uk/club/projects.htm
www.schoolscience.co.uk/teachers/chemclub/index.html

Salters' Institute
http://www.salters.co.uk/institute/

Salters-Nuffield Advanced Biology (SNAB)
http://www.advancedbiology.org

Science Bursaries for Schools and Colleges
http://www.nuffieldfoundation.org/go/grants/scibsc/page_97.html

Science Education 3-18 Small Grants Scheme
http://www.scienceeducation3-18.com/smallgrantsround2further.htm

Science Enhancement Programme (SEP)
http://www.sep.org.uk/info.htm

Science Students in Primary Schools (SSIPS)
http://www.azteachscience.co.uk/code/trust/queens.htm

Science in The New Curriculum (SiNC)
http://www.azteachscience.co.uk/code/trust/belfast.htm

Science in the Real World: Liaison Project
http://www.royalsoc.ac.uk/partnership
Also www.linkproject.ik.org

Science Transition AstraZeneca Science Teaching Trust York (STAY)
www.york.ac.uk/depts/educ/projs/STAY/STAYNov04.htm
www.york.ac.uk/depts/educ/projs/STAY/ScienceTransitionProjects.htm
www.azteachscience.co.uk/code/project/project.html

Science Transition in Scotland
http://www.sciencetransitionscotland.org.uk/index.html

Science UPD8
http://www.upd8.org.uk

SciZmic
http://www.scizmic.net/

Scottish Executive Education Department, A Curriculum for Excellence 3-18
http://www.scienceeducation3-18.com/documents/directory.doc
http://www.scienceeducation3-18.com/projects.htm

Sharing Science Across Ireland

The SKEES Project (Science Enhancement Programme – King's Enhancing Enquiries in Schools)
http://www.kcl.ac.uk/depsta/education/skeesproject.html

The Sky's the Limit
http://www.royalsoc.ac.uk/partnership

Soapy Solutions
http://www.royalsoc.ac.uk/partnership

South Ayrshire Investigation Pack

Sustainable Educational Environmental Developmental Sessions (SEEDS Clubs)
http://www.spherescience.co.uk/aboutseeds.htm

Teaching Ideas and Evidence in Science at Key Stage 3: Scientific Enquiry

Tower Hamlets Gatsby Project

Wellcome Trust Education Programme
http://www.wellcome.ac.uk/doc_WTD003248.html

Wild over Waterways
http://www.wow4water.net/grownups/index.asp

Appendix 7 – Review of NESTA's funding and support for science learning projects – methodology

NESTA commissioned Bath Spa University College to review its support for science learning projects.

The principal evaluation questions focused on the perceived or actual needs that each innovation proposed to meet, and the outcomes achieved in terms of Harland and Kinder's model of outcomes.[63] This model, based on staff development outcomes as a result of in-service training, refers to a number of different kinds of outcomes, broadly grouped under informational (teachers briefed about the background and facts relating to the innovation) and new knowledge and skills (deeper and more critical understanding of curriculum content and teaching approaches). The ultimate criterion is impact on practice, which looks at the extent to which an innovation has become embedded within the institutional culture of the organisation concerned, with support from senior management and clear monitoring of outcomes for student learning.

Subsidiary research questions included whether some models of NESTA's support or management have been more effective than others, and whether any of these outcomes would have been achieved without NESTA's support.

The researchers used a combination of web-based and documentary evidence to summarise NESTA's support for all 48 projects designated under the heading 'Science Learning', together with 22 of the 36 projects supported through Science Year (now Planet Science). Additionally, a web-based survey was conducted of a sample of 32 projects, both Science Learning and Science Year/Planet Science, in order to gather quantitative evaluation data from awardees, and compare these data with projects funded by the AstraZeneca Science Teaching Trust (AZSTT). In order to provide more in-depth analysis and evaluation, ten NESTA (including one Science Year/Planet Science) and two AZSTT projects were selected for detailed case study.

63.Harland, J., and Kinder, K. (1997), 'Teachers' Continuing Professional Development: Framing a Model of Outcomes', British Journal of In-Service Education, vol.23, no.1, pp.71-84.