Supporting STEM in schools and colleges in England

The role of research

A report for Universities UK

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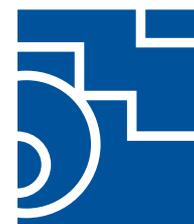
Universities UK

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About the authors

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Executive summary

Context

STEM is the acronym used in England for science, technology, engineering and mathematics. STEM subjects are a central plank in developing the UK's skills base. Specialist knowledge in these subjects not only underpins many high-tech sectors – such as IT and engineering – but is also important for creativity and developing new ideas. This report demonstrates the role of social science research, and specifically education research, which sets out to sustain and develop the STEM skills base in England. It does this through presenting research that is taking place within education departments in English higher education institutions. The report presents case studies of research which is aimed, ultimately, at improving attainment and participation in STEM subjects, although there are various other routes through which higher education institutions can, and do, affect this.

STEM skills are important across different career paths and other aspects of life. At the specialist end, the supply of high-skilled STEM graduates contributes to the competitiveness and productivity of the economy; but at other levels, elements of STEM skills are needed to take part in many aspects of life and society. STEM-related knowledge and skills are necessary across nearly all areas of employment and are crucial in many sectors. Schools and colleges have an important role in the STEM skills supply chain, both in nurturing enough students to the necessary attainment level (and with the necessary enthusiasm) to continue to study these subjects beyond school and college, and in developing a range of abilities in STEM-related areas more generally for all young people.

Prior attainment and choices made in terms of future study at ages 14 and 16 determine both the level of more general STEM skills in the population and also the numbers of students with the necessary skills to continue studying STEM subjects post-16. The general trend for entries for sciences and mathematics A-level as a percentage of all A-level entries has been downwards over the last 15 years, although in mathematics there have been encouraging increases in percentages in recent years. Nonetheless, with the exception of further mathematics, the proportion of students studying STEM subjects currently remains below that of 10 years ago. Gender and subject choices made at 14 continue to be key factors in determining whether or not a student studies STEM subjects post-16.

In international comparisons of mathematical and science understanding, England performs well overall. However, in order to ensure the UK remains competitive in the knowledge economy and is not constrained in its productivity due to a limited supply of skilled individuals, it will be increasingly important for schools and colleges to work across the ability spectrum to ensure that increased numbers of the population have

functional mathematical skills as well as high-level specialist STEM skills. In order to achieve this, the two key aims must be to increase attainment *and* participation in STEM subjects at all levels of compulsory and post-compulsory education. Education research has an important role to play in supporting this agenda. Although the UK has a long history of internationally renowned education research in STEM subjects, much remains to be understood. A 2007 review commissioned by the Economic and Social Research Council (ESRC) (Morris, 2007) determined areas where more research was needed, including how to develop approaches to teaching that increase students' confidence in engaging with complex issues and enable them to mobilise a variety of problem solving methods. The case studies presented in this report address many of the areas raised.

Case studies

Case studies of research undertaken in education departments in English higher education institutions make up the main body of this report. The case studies are divided into five groups relating to their main focus, although many clearly cover more than one issue. The first group, examined under the heading 'Understanding the problem', consists of projects that investigate regional, national and international challenges, with much of the work directed at policymakers. The majority of the education research undertaken in institutions in England in STEM areas appears to focus on aspects of teaching and learning, which we have examined in three areas: focusing on pedagogy, on the curriculum and resources, and on assessment. The fifth and final group covers research on learning outside of the classroom.

Understanding the problem (case studies 1-4)

Case study 1 describes a project undertaken by researchers at the University of Exeter into the demand and supply of STEM subjects in the south west. The research team were commissioned by the South West Regional Development Agency to undertake analysis to understand STEM skills in the region. Using both primary and secondary research, evidence was collected on policy context, demand side, supply side and stakeholder views. Quantitative analysis using a range of data sources (such as the National Employer Skills Survey and the National Pupil Database) was used to give a picture of both the future demand and supply of STEM skills in the region. This was contextualised with qualitative data collected in interviews. The project reports and findings have been endorsed by the South West Regional Employment and Skills Partnership and have fed into the region's planning in this area.

The second case study reports research undertaken by researchers at King's College London which comprised a systemic literature review of research that explored the factors related to the teaching and learning of mathematics in high-attaining countries. This work, funded by the Nuffield Foundation, produced a written report which drew out 14 themes from the review, for which there was the strongest evidence but which could also provide insight into mathematics education in England. The team found that in the high-attaining countries studied, enjoyment and attainment in mathematics did not appear to be related, nor was there a positive link between confidence and attainment. They also found that use of textbooks in English mathematics classrooms was relatively low and that English textbooks used routine examples and were less mathematically coherent than those used in high-attaining countries. A key finding was that high attainment in international assessments appeared to be more closely related to the similarity between the country's curriculum and the questions in the international assessment than to the quality of the teaching.

Understanding the participation of girls in physics was the objective of the research in the third case study. The initial stages of this project were funded by the Institute of Physics and involved a review of the literature in this area by Patricia Murphy and Liz Whitelegg at the Open University. The second part of this work involved an exploration of effective practice in schools that had high physics participation rates for girls post-16. A key outcome of these two reports was *A Teachers' Guide for Action*, which outlined effective strategies for use in schools. There have been considerable developments following on from this project. The initial two reports provided the foundation for an action research project funded by the then Department for Children, Schools and Families (DCSF). This project was used to disseminate the work. Engaging schools and teachers in this way was seen as much more effective, in terms of changing practice, than simply distributing reports.

UPMAP (Understanding Participation rates in post-16 Mathematics And Physics) is an ongoing project that aims to deepen understanding of what attracts some students to mathematics and to physics post-16 and what drives others away. The research team, based at the Institute of Education, University of London, is using a mixed-method approach involving gathering data from questionnaires sent to schools across the country and undertaking interviews with 14- to 17-year-olds and first year university students. Interim results indicate the importance of psychological factors (such as motivation and feeling positive about mathematics and/or physics) on intention to study mathematics and/or physics post-16 and the role of school practice in increasing intention to participate generally and reducing gender bias in that intention. This project forms one of the five projects that make up the ESRC's Targeted Research Initiative on Science and Mathematics Education.

Teaching and learning – pedagogy (case studies 5-10)

An action research project undertaken by early years practitioners and researchers at the University of Winchester is presented in case study 5. This project involved researchers working with early years teachers to explore the potential for the use of curiosity and investigation in science learning in early years. The project consisted of individual action research projects brought together in an overarching framework. The practitioners worked together with those from other schools in small clusters and with the university staff. Individual developmental work around their own action research projects was then worked up in the form of case studies so that the whole team could together systemise learning. This work not only provided professional development for the teachers involved, but also provided insights into effective teaching of science in the foundation stage. One outcome has been the creation of a continuing professional development unit that disseminated relevant knowledge more broadly.

In case study 6 an international team with a partner at the University of East Anglia undertook a project that used an inter-country comparative approach to gain insights into mathematical misconceptions at primary level. This drew to the researchers' attention the importance of language in mathematics teaching and the potential for misunderstandings in the early learning years. By looking at mathematical misconceptions across classrooms in different countries, the project allowed the researchers to explore not only the role of language in early mathematical learning but also the different pedagogical approaches adopted in different countries and their relative effectiveness.

Case study 7 explored the use of talk and dialogue as teaching approaches in mathematics and science, while focusing on the primary phase and the use of exploratory talk in the teaching of arithmetic. The decision to research this area grew from a sense that arithmetic calculations early in primary school were, at that time, all too often being taught through the calculation strategies laid out in the National Numeracy Strategy with little interrogation and limited understanding being developed of the concepts underlying these strategies. If this were the case, pupils would be likely to become passive rather than active learners.

Case study 8 looks at developing effective pedagogy for use with interactive whiteboards (IWBs) in the teaching of mathematics. A team of researchers from Keele University undertook a series of projects in this area. They found that it is not surprising that the introduction of interactive whiteboards has been shown to have little effect on attainment, since whilst the technology has advanced, the pedagogy and teaching methods have not. Through video recording and direct observation, the researchers analysed the use of IWBs in order to determine strategies, pedagogies, resources and training that could lead to more effective use. There were numerous outcomes from this work including the development of a pedagogy to enhance mathematics teaching through using IWBs, development of professional development materials and a model for professional development.

Case study 9 describes research looking at science teaching in both the primary and secondary phases through 'dialogic teaching'. Dialogic teaching concerns the use of dialogue as a teaching approach. This project started from a point where dialogic teaching enabled meaningful learning, which is where connections were made between everyday and scientific meanings. The field work took place in five primary and three secondary schools. Data was mainly collected through video recordings, which were later used to analyse the interactions between teachers and students. The challenges to those working at primary level concerned limited practical resources. Also issues were identified regarding teachers being able to develop effective dialogues when working at the boundaries of their own scientific knowledge. In secondary schools, a key challenge was the lack of legitimacy accorded to the use of dialogic teaching. The project contributed to furthering knowledge and understanding of dialogic teaching and its relationship to meaningful learning in science. The work from this project directly impacted on the National Secondary Strategy through the development of lesson plans for dialogic science teaching at Key Stages 3 and 4. These materials were disseminated nationally in 2008 through the National Strategy's professional development programmes.

Collaborative Learning in Mathematics is the project presented in case study 10. The initial project was funded by the Esmée Fairbairn Charitable Foundation and was undertaken at the University of Nottingham. This research project grew from a concern regarding the large numbers of young people failing to achieve a grade C or above at GCSE level, often a minimum requirement for many careers and for access to higher education. Consequently, there are relatively high numbers of young people (16- to 19-year-olds) retaking GCSE mathematics in further education colleges. This context exacerbated an instrumental approach to taking the qualification. This, combined with low expectations on the part of the teachers and often the students themselves, led to teaching being largely transmission oriented. Innovative design-based research methodologies were used to investigate how to improve teaching and learning in these further education classrooms. Ofsted has endorsed the collaborative approaches developed in this project and there have been applications of the collaborative teaching and learning approaches advanced in this research beyond the principal target of the original work. For example, the then Department for Education and Skills (DfES) funded further developments of these approaches for all post-16 students through the initiative Success for All.

More broadly, design-based research, as illustrated in this case study, returns enquiry to the ultimate purpose of much education research, which is to improve the education experience. It addresses a key criticism of much education research by more directly connecting with practice and testing theories through iterative interventions in practice.

Teaching and learning – curriculum and resources (case studies 11 and 12)

Case study 11, Subject Leadership in Creativity in Design and Technology, set out to examine creativity in design and technology (D&T) classes in Key Stages 3 and 4 in schools in England through a research and intervention project. Being able to think creatively is important for individuals in terms of exhibiting the flexibility and innovation necessary in today's knowledge economy. But whilst the importance of creativity in education has been highlighted in policy and curriculum documents, there has been concern that real opportunities for creativity are not materialising in D&T. The aims of the project included understanding how current practice in secondary D&T teaching influences pupil creativity (preliminary phase) and developing ways to promote student creativity in the D&T classroom (intervention phase). The work involved working with 15 secondary schools with students aged 11-16, gathering data through semi-structured interviews with teachers and students, observations of lessons, surveys, document analysis and examining samples of pupil work. The researchers found a low level of creativity in the design ideas that the students put forward and also that, whilst they were frustrated that the students' ideas tended to be unoriginal, the teachers lacked the skills to facilitate more creative thinking. This project involved working with D&T teachers to develop ways in which the two policies of performativity and creativity can be mediated, thus enabling teachers to support and encourage more creativity in their classrooms.

The twelfth case study describes work at the University of Wolverhampton which plays an important role in the region in terms of school improvement. The University is working with Wrockwardine Wood Arts College (a National Challenge school) to provide curriculum-focused support designed to improve attainment through raising aspirations and motivation amongst students. One such project is the Maths Curriculum Coaches project, which has just completed its pilot phase. During the pilot phase, the Maths Curriculum Coaches spent one morning a week in the school supporting Year 10 maths classes, initially by providing learning support in the classroom and then by moving from supporting the whole class to focusing on 12 target students who needed additional support.

Teaching and learning – assessment (case study 13)

e-scape (e-solutions for creative assessment in portfolio environments) is a project led by a team at Goldsmiths, University of London. Initial phases of this project began in 2005 with an aim to develop a way of assessing creativity, innovation and teamwork in D&T as this was identified as a shortcoming in the National Curriculum framework and GCSE assessments. The project led to the development of a working prototype that involves a hand-held device for individual students to use to capture a range of data, along with a web-based portfolio assessment system.

These prototypes have since been developed in a further stage of the project to be transferable for use in different subjects and to be scaled up for potential use in national assessment. A second output of this work is the development of online technology that enables the simultaneous web-based assessment of portfolios with very high reliability.

Out-of-class support (case studies 14 and 15)

What happens outside of school has been demonstrated to have a significant impact on pupils' attainment and progress, particularly for younger children, and most obviously through the influence of parents or carers. The two final case studies illustrate the importance of these factors.

Case study 14, undertaken by researchers based at the University of Bristol, describes the numeracy strand of the Home-School Knowledge Exchange (HSKE) Partnership. This project involved analysing the impact of interventions in four primary schools compared to matched schools where no intervention took place. In each school a teacher was seconded to work part time on the project. Within each strand, home-school exchange activities were developed and trialled with a particular class in each school. The project shed light on the challenges of bridging home and school knowledge. It also elucidated the areas that needed to be addressed in order, on the one hand, for parents to confidently support their child's learning at home, and on the other, for teachers to build effectively on learning outside school. The work of the project has been written up in numerous papers and presented at many conferences, both academic and user-focused. The numeracy strand has also been written up as a book – *Improving Primary Mathematics: Linking Home and School* – that describes tried and tested examples of activities developed in the project that can bring the two worlds of home and school closer together to improve learning.

Case study 15 is an evaluation of after-school science and engineering clubs, funded by the then DCSF. The work was undertaken by researchers from Sheffield Hallam University. The research involved working with 174 of the 245 schools involved in the DCSF pilot. The team used a range of methods including a pupil survey, staff surveys, interviews, case studies and a survey of schools that had decided not to run clubs. The evaluation of the programme played an important role in demonstrating the impact that the clubs were having on the students as well as highlighting the elements and practices that seemed most effective. STEM Clubs have now been rolled out to 500 schools across England, with the ambition to establish a STEM Club in every secondary school and college in the country.

Recommendations

This report has identified a set of issues that lead to the following recommendations.

1   More work should be undertaken that aims to scale up and disseminate research findings in order to ensure that maximum value is achieved from projects. Follow-up grants are useful for knowledge transfer activities.

2   There is a need to explore more effective dissemination strategies and enhance the capacity of academics to deliver dissemination activities, both in terms of skills required and time available to undertake them.

3   A more diverse set of research methods should be mobilised as appropriate to the questions under study: for example, more use could be made of randomised controlled trials (RCTs) when this form of evaluation is most appropriate.

4   A thorough mapping of STEM education research taking place outside of education departments should be undertaken, in order to ensure that such research is not isolated from work undertaken in education departments.

5   Limited evidence was found of policy, historical and international work. More work in these areas would avoid the risk of parochialism and loss of previous acquired knowledge. However, this requires special interdisciplinary expertise that needs to be fostered.

6   Investment is needed in longitudinal studies, which would allow researchers to track individuals over time with the aim of teasing out causal links between input and output variables.

7   There is considerable potential for more projects to draw on a range of linked datasets, from large-scale national datasets (such as the National Pupil Database) along with more in-depth work undertaken with a subset of schools (or colleges) and/or students.

8   Better ways should be developed to capture work done by teachers, including action research projects and work undertaken at Master's and Doctoral level. This would enable teacher-researchers to build on existing knowledge and past experiences, as well as help make this type of research more widely accessible, for example in a national electronic database of theses and final reports.

9   Better coordination among projects is needed to ensure the research is cumulative and builds on the existing knowledge base, and there is not duplication of effort and funding. Reports such as this one should assist in this process.

1. Introduction

Globalisation and movement towards the knowledge economy has been much documented (see for example Brown *et al.*, 2008). The current and previous governments consider that for the UK to remain competitive in a knowledge economy, where innovation and technical expertise are highly valued, it must invest in developing a highly skilled workforce in order to remain at the forefront of the 'global skills race'. STEM subjects are a central plank in developing the UK's skills base. STEM is the acronym used in England for science, technology, engineering and mathematics. Specialist knowledge in these subjects not only underpins many high-tech sectors – such as IT and engineering – but is also important for creativity and developing new ideas. Future growth areas such as sustainable technologies rely on high-level STEM skills. Due to the perceived importance of STEM skills in terms of ensuring the UK's future competitiveness, governments have invested in improving the country's stock in STEM skills. These investments and policies are discussed in Section 3.

This report demonstrates the role of social science research, and specifically education research, in sustaining and developing the STEM skills base in England. Most commonly, in terms of schools and colleges, STEM translates into the subjects of science, design and technology, and mathematics with the traditional qualifications of GCSEs and A-levels in these subjects. There are, however, other qualifications in which STEM knowledge and skills are central, particularly some vocational and work-based qualifications, such as Key and Functional Skills, BTECs and the vocational pathways that are beginning to come on stream in Diplomas. Out of the fourteen Diplomas available, six are related to STEM subjects[1].

This report presents research that has taken place within education departments, schools and faculties (hereafter referred to as 'departments') in English higher education institutions. We do not have space to present a comprehensive mapping of all the research recently completed or currently underway. Rather we have attempted to present a range of research projects and their impacts, selected to give an indication of the breadth of work in different institutions, contexts and subject areas within STEM.

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1   In August 2011 there were fourteen Diploma subjects available: construction and the built environment; creative and media; engineering; information technology; society, health and development; environmental and land-based studies; business, administration and finance; manufacturing and product design; hospitality; hair and beauty studies; travel and tourism; public services; sport and active leisure; and retail business (see: http://www.direct.gov.uk/en/EducationAndLearning/QualificationsExplained/DG_070676) .

As relevant background, we also outline three recent major investments in research programmes of education – the Teaching and Learning Research Programme (TLRP: http://www.tlrp.org), its second Technology Enhanced Learning phase (TEL: http://www.tlrp.org/tel/), and the ESRC Targeted Initiative on Science and Mathematics Education (see ESRC, 2006), each of which includes STEM research, resulting in significant investment[2].

We hope this report demonstrates the importance of education research to the sustainability of the STEM field through its contribution to the development of the supply of young people with knowledge and skills in this area.

Where possible we outline the outcomes of the research projects that we have summarised and describe any impacts already documented. It is important to note that this report includes current or recently completed research projects and therefore much of the impact is yet to come. We make no judgements regarding the value of different types of research, the suitability of methods used or the significance of any impacts achieved; some projects might have significant impact on standards in a cluster of local schools whereas others might have impact at a national level through influencing national policy direction.

We acknowledge from the outset that there is a considerable volume of work happening between schools and various departments in higher education institutions that supports standards in STEM as well as more generally (Tough *et al.*, 2008). This includes:

- continuing professional development (CPD) for teachers in STEM areas

- curriculum enrichment through specific projects or use of facilities

- mentoring arrangements between university students and those at school or college

- widening participation activities such as summer schools

- activities specifically aimed at increasing participation in STEM subjects

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2   Total TLRP (not just STEM) investment is £31 million; of this just under £5 million was for STEM-related projects (for a list of these projects see Section 4.6). Of the £12 million for TEL, £2.5 million was allocated to projects with a specific focus on STEM (see Section 4.6). ESRC Targeted Initiative on Science and Mathematics Education is £3 million.

These activities may aim to increase attainment and participation in STEM subjects either through improving teaching and learning, or through increasing aspiration and engagement. Whilst such initiatives make important contributions to the Government's agenda for STEM subjects and to varying extents will involve some aspect of research activity, they are not the focus of this report, which takes research as its starting point. We take an inclusive definition of research as being any activity that involves a rigorous investigation aiming to make a valid contribution to knowledge. We have attempted to include a range of 'types' of research (though this is better considered as a spectrum of approaches rather than a distinct taxonomy), including applied, evaluative, action and developmental research. Section 3 describes the importance of STEM skills for the UK economy and thus government and policymakers. We then go on to look at how schools and education play a vital role in the supply chain of STEM skills, a role whose importance is enhanced given the rising demand for these skills. The problems of low attainment and low levels of participation in STEM subjects at aged 16 and beyond are outlined. Section 4 describes the contribution of education research in science and mathematics education in general and, in particular, in addressing challenges of participation and engagement. The case studies make up the main section of the report (Section 5). We do not attempt a comprehensive overview of research in STEM teaching and learning. The case studies have been chosen to indicate the broad range of creative, high-quality work and critical inquiry that underpins and supports science and mathematics education in schools and colleges. In the final section, we summarise the findings regarding the range of work we have reviewed and make some observations and recommendations regarding education research in science and mathematics education.

2. The contribution of schools and colleges to developing the STEM skills base

The importance of STEM skills

In 2001 Sir Gareth Roberts was tasked with reporting on the supply of science and engineering skills in the UK (Roberts, 2002). One of the problems identified by the review was the downward trend of those taking physics, mathematics, chemistry and engineering qualifications at university and Roberts concluded that these trends 'could undermine the Government's attempts to improve the UK's productivity and competitiveness' (Roberts, 2002: iii). Following that report the previous Government responded through numerous initiatives focused on schools and colleges in order to reverse this trend and to ensure that the country's future innovation and productivity is not constrained due to lack of appropriately skilled people. The Labour Government was committed to increasing:

- the flow of qualified people into the STEM workforce

- STEM literacy in the population (DfES, 2006)

Part of this commitment manifested itself in supporting the productivity agenda through the increased supply of highly-skilled knowledge workers. STEM skills are also important at the other end of the attainment range, particularly in terms of acquiring the basic levels of numeracy necessary to function adequately in society and when a grade C in GCSE maths is needed for a particular career or education pathway. Indeed, Nobel laureate Sir Harry Kroto asserts:

Scientific education is by far the best training for all walks of life, because it teaches us how to assess situations critically and react accordingly ... As well as trained engineers and scientists, we desperately need a scientifically literate general population, capable of thinking rationally – and that includes lawyers, businesspeople, farmers, politicians, journalists and athletes. This is vital if we are to secure a sustainable world for our grandchildren. (Kroto, 2007)

Equally, Professor Adrian Smith (who chaired an independent inquiry into post-14 mathematics education in 2004) highlights the importance of mathematical capability, and not just in terms of high-level employability: 'It also provides the individual citizen with empowering skills for the conduct of private and social life and with key skills required at virtually all levels of employment.' (Smith, 2004: 2)

Coyne and Goodfellow (2008) note that improved levels of mathematics are crucial not just because they underpin much STEM work but also because they are important across many subjects at university level. Smith also acknowledges that:

> *... mathematics occupies a rather special position. It is a major intellectual discipline in its own right, as well as providing the underpinning language for the rest of science and engineering and, increasingly, for other disciplines in the social and medical sciences. It underpins major sectors of modern business and industry, in particular, financial services and ICT.* (Smith, 2004: 2)

The centrality of mathematics and the importance of effective teaching are also highlighted by the *Independent Review of Mathematics Teaching in Early Years Settings and Primary Schools* undertaken by Sir Peter Williams and which reported in June 2008. The report made a range of important recommendations, the most significant of which was that there should be (in the long term) a mathematics specialist in every primary school (Williams, 2008).

The previous Government laid out its commitment to developing the science, technology, engineering and mathematics skills base in their 10-year plan for science and innovation as part of the 2004 Comprehensive Spending Review – *Science & innovation investment framework 2004-2014* (HMT, 2004). The *Next Steps* report, published in 2006, outlined specific action in terms of how its ambitions were to be achieved through a focus on schools and colleges. The *Next Steps* ambitions were to:

- achieve year-on-year increases in the number of young people taking A-levels in physics, chemistry and mathematics

- continually improve the numbers of students getting at least level 6 at the end of Key Stage 3 (11- to 14-year-olds)

- continually improve the number of students achieving A*-B and A*-C grades in two science GCSEs

- step up recruitment, retraining and retention of physics, chemistry and mathematics specialist teachers (HMT, 2006: 3)

The importance of schools and colleges

In a recent report commissioned to look at university links with schools in STEM subjects, Coyne and Goodfellow note:

The current pattern and disposition of subjects within the STEM domain at university level requires a very clear set of competencies and prior attainment before entry. The route through which both discipline specific prior knowledge is obtained, allied to the need for a sound preparation in mathematics, means that there is a very clearly articulated route into STEM. This clarity of route also presents potential difficulties if vital steps in the process are broken.
(Coyne and Goodfellow, 2008: 16)

As is clear from the Government's focus on schools and colleges, there is an important link in the supply chain filled by these institutions and, as described in the quote above, in order to study STEM subjects at university, the available qualification pathways are currently relatively inflexible. Prior attainment and choices made, in terms of future study at ages 14 and 16, determine both the level of more general STEM skills in the population and also the numbers of students with the necessary skills to continue studying STEM subjects post-16 and at university level.

Figures 1 and 2 show the entries for sciences and mathematics A-level as a percentage of all A-level entries over the last 14 years. The general trend has been downwards, although there have been some increases in percentages of pupils choosing some subjects more recently. Nonetheless, with the exception of further mathematics, the proportion of students studying STEM subjects remains below that of 10 years ago.

Figure 1: Percentage of entries for science subjects at A-level
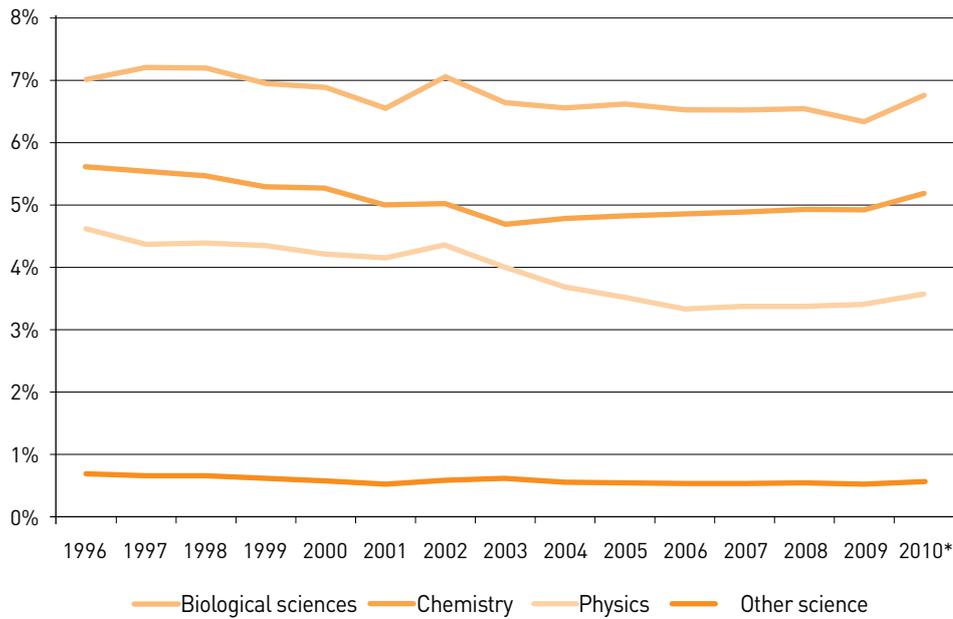
Note: *indicates provisional data
Data source: Table 9, DfE (2010)

Figure 2: Percentage of entries for mathematics and ICT at A-level
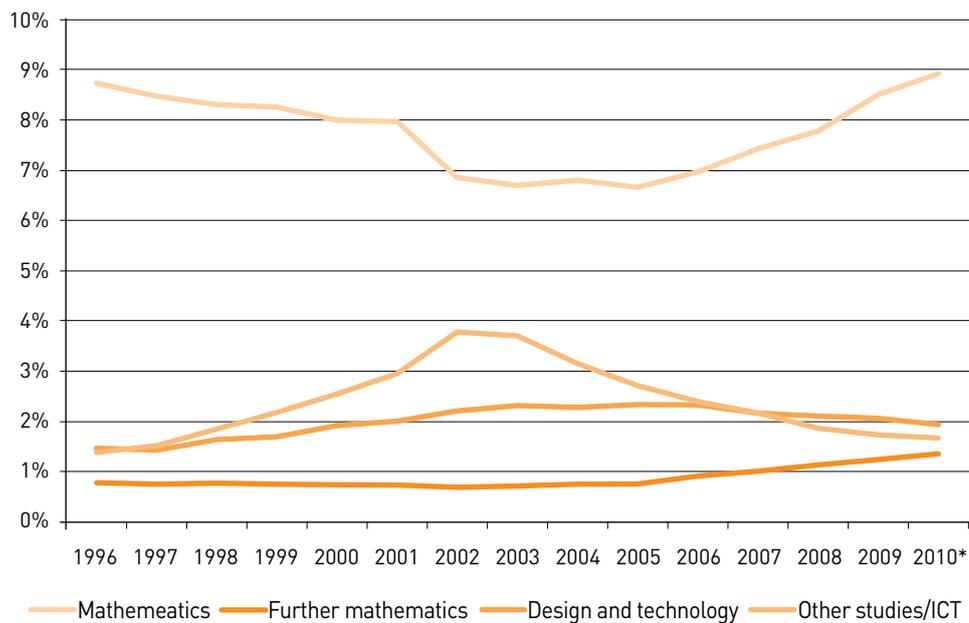
Note: *indicates provisional data
Data source: Table 9, DfE (2010)

In science, a key determinant of A-level subject is the choices students have made early in their education career. In mathematics, the story is rather different as students increasingly take mathematics for its general usefulness in future life and work. In 2007, 67 per cent of students took double science GCSE, 12 per cent took single science and eight per cent took three separate sciences (that is triple science) (Coyne and Goodfellow, 2008). Coyne and Goodfellow maintain that whilst there is a relatively high percentage taking double science, the 'necessary underpinning for "A-level" is more readily facilitated by those who take triple science' (2008: 16). Table 1 demonstrates that students who take triple science are nearly three times as likely to go on to take at least one science A-level than those who take double science, though most of this effect can be explained by the fact that students who take triple science at GCSE start (and finish) with substantially higher levels of attainment in science.

Table 1: Number of science A-levels studied by GCSE science route taken (% of students)

GCSE route taken	Number of science A-levels studied				
	0	1	2	3	At least 1
Single award	95.5%	3.4%	1.0%	0.1%	4.5%
Double award	88.9%	7.6%	3.1%	0.4%	11.1%
Triple award	69.3%	15.4%	13.1%	2.2%	30.7%

Note: The data used in this table refers to students in the south west region only although these are likely to reflect the national picture
Data source: National Pupil Database, 2007 A-level cohort
Source: SLIM (2009a: 70)

It is interesting to note that only 32 per cent of maintained mainstream non-selective secondary schools have students taking three separate sciences (triple science), compared to 73 per cent of grammar schools (Coyne and Goodfellow, 2008). The type of school or college appears likely to play a part in determining the options available and choices made in terms of future study. Gender is also an important factor in understanding future subject decisions. As shown in Figure 3 this is a particular problem in physics (this is discussed further in case study 3).

Figure 3: Number of students at different stages by gender
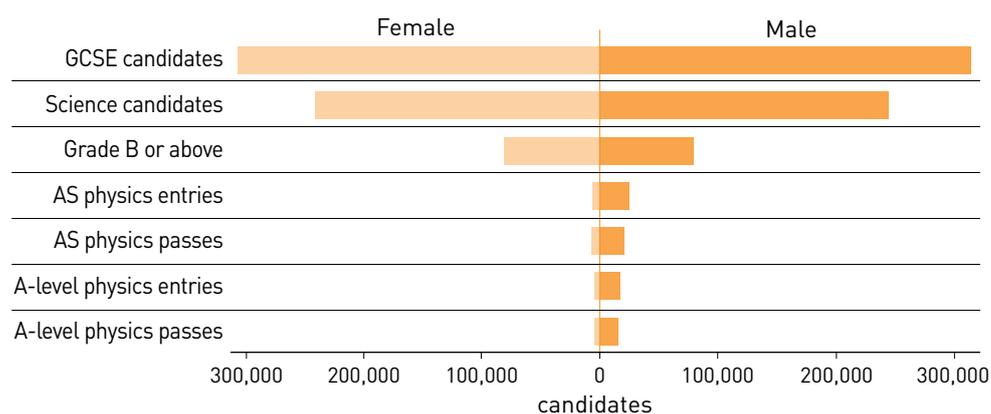
Data source: National Pupil Database, 2006 GCSE cohort
Source: Gill *et al.* (2009: 6)

The most recent Programme for International Student Assessment (PISA) survey (2006) that focused on science compared 15-year-olds' science ability in 30 Organisation for Economic Co-operation and Development (OECD) countries. The UK came ninth in the international rankings (though the confidence interval extends from eighth to 12th) with Finland, Canada, Japan, New Zealand, Australia and the Netherlands having higher mean scores (OECD, 2007). However, UK students reported a comparatively low level of motivation to use science in the future, with 34 per cent saying that they would like to work in a career involving science and only 13 per cent saying that they would like to spend their life doing advanced science (OECD average 21 per cent). Also, very few students reported regularly engaging in science-related activities such as watching TV programmes relating to science or attending a science club (OECD averages were 37 and 21 per cent respectively) (OECD, 2007).

In the 2007 Trends in International Mathematics and Science Study (TIMSS), where comparable assessments are made of pupils' abilities in maths and science in Years 5 and 9, England achieved high results internation-ally (Sturman *et al.*, 2008). In terms of the global competitiveness, the fact the countries that ranked higher than England were the Asian Pacific Rim countries is noteworthy (Chinese Taipei, South Korea, Singapore, Hong Kong, Japan). It is also worth noting that mathematics scores in Year 9 were significantly lower than the leaders in this area, suggesting that more could be done to ensure England is keeping up with the best in mathematical understanding in the lower secondary phase (Sturman *et al.*, 2008). This lower level is also reflected in students' enjoyment and confidence in mathematics in Year 9, with only 40 per cent stating that they enjoyed the subject (Sturman *et al.*, 2008).

In order to ensure the UK remains competitive in the knowledge economy and is not constrained in its productivity due to lack of skilled people, it is necessary for schools and colleges to work across the ability spectrum to ensure that increased numbers of the population have functional numeracy skills as well as high-level specialist STEM skills. In order to achieve this, the two key aims must be to increase attainment and participation in STEM subjects at all levels of compulsory and post-compulsory education. It has long been established that higher education institutions have a role to play in supporting schools in tackling these challenges. This support often takes the form of initiatives such as widening participation activities aimed at raising aspiration, subject support for students, school improvement support, continuing professional development, and gifted and talented provision (Coyne and Goodfellow, 2008). This report is about the contribution education departments within higher education institutions, through their research, make to supporting schools and colleges in increasing participation and attainment in STEM subjects.

3. The role of education research in STEM

England has a long history of internationally renowned education research in STEM subjects. In science education, much of this has been concerned with pedagogy. For example, the Children's Learning in Science Research Group at the University of Leeds in the 1980s and 1990s under Ros Driver undertook pioneering work into children's prior conceptions in science and the implications these have for teaching. At about the same time, Philip Adey and Michael Shayer at King's College London developed the CASE (Cognitive Acceleration through Science Education) project that was subsequently extended to mathematics in CAME (Cognitive Acceleration in Maths Education). Here the focus was on finding ways to improve the rate at which students could develop their thinking. Other research in science education has looked at the curriculum and there has been a long-running debate about the extent to which school science education should aim mainly to improve post-compulsory uptake of the subject or, more generally, to enhance scientific literacy.

Similarly, there has been considerable investment in internationally recognised research into mathematics education, starting in the 1980s with investigations of child methods in mathematics and misconceptions. Since that time there has been huge growth in research in terms of volume and also methodology, focus and scope. This includes in-depth studies of students' trajectories of learning in particular areas, such as in algebra, geometry and proof; detailed observation and interview research of the classroom and school context; and investigations of the impact of new initiatives, for example using digital technologies. Other work focuses on the curriculum, assessment, comparative classroom methods, motivation and expectations, home-school links and out-of-school mathematics, and the whole complex of socio-cultural factors that shape participation and engagement with the subject. The picture is made still more complex because of the interconnections and tensions between what is termed 'numeracy' and what is termed 'mathematics'.

Two important areas that are often missed in reports relating to higher education institutions' role in developing STEM skills are those of teacher training and research. This applies specifically to those institutions which have education departments[3]. Attracting and training high-quality science and mathematics teachers is clearly important. After years of shortages in these subjects (Royal Society, 2007) and following numerous initiatives aimed at making the profession more appealing to graduates (such as Golden Hellos and so on), a recent announcement from the Training and Development Agency for Schools (TDA) reports that recruitment targets are being met in these subjects (TDA, 2009). Education research has a potentially transformative role in addressing the challenges of both attainment and participation in STEM subjects at school and college, and thus at degree level as well.

In order to inform its Targeted Initiative on Science and Mathematics Education (see page 71), the ESRC commissioned a review of the evidence regarding pupil subject choice in schools (Morris, 2007). This report summarised what was known and what was not known regarding the factors influencing students' future educational choices. Morris identified four key areas that required further research:

- To develop approaches to teaching maths and science that:
  - *increase young people's confidence in engaging with complex issues*
  - *provide both support and challenge*
  - *as far as possible, focus on developing understanding rather than just transferring information*
- To promote a greater understanding of the role of science in everyday life ('science is not just for career scientists')

- To develop approaches to teaching maths that enable young people to use a variety of approaches to solving problems

- To consider and address any possible gender biases in outlines for tasks or projects (Morris, 2007: slide 57)

These areas are covered in many of the case studies in this report. A prominent focus of the research is that of pedagogic approaches which challenge and engage students but at the same time facilitate understanding of complex issues (see case studies 5 to 11). The issue of gender is addressed explicitly in case study 3, Girls in Physics.

3   Of the 107 higher education institutions in England, 65 have education departments.

4. Case studies

This section details different research projects recently completed or currently underway in education departments in English higher education institutions. Whilst not a comprehensive overview, the case studies were chosen to give a flavour of the broad range of creative, high-quality work and critical inquiry that underpins and supports science and mathematics education in schools and colleges.

We have looked to include a range of different types of research, from small-scale action research to national evaluation, and a range of methods both quantitative and qualitative, with many projects opting for a mixture as appropriate. There is also a range of different institutions represented, many working in partnership with other institutions and research organisations. The whole education journey up to 19 years of age is covered, with projects focusing on early years and further education settings as well as on the primary and secondary phases.

In an attempt to add some structure to what follows we have divided the case studies into five groups (Sections 4.1-4.5) relating to their main focus – although many of them clearly cover more than one issue. The first group, examined under the heading 'Understanding the problem', consists of projects that investigate regional, national and international challenges, with much of the work directed at policymakers. The majority of the education research currently being undertaken on STEM in institutions in England looks at teaching and learning (as one might hope). We have examined this in three areas: one focusing on pedagogy, one on curriculum and resources and one on assessment. These three areas interact, overlap and impact on each other and together underpin teaching and learning, and are therefore crucial to improving attainment and participation in STEM subjects. The fifth and final group covers research on learning outside of the classroom. Whilst not as central, perhaps, as areas directly looking at teaching and learning, learning outside of the classroom has an important role to play as research suggests that the impact of different schools accounts for a relatively small proportion of attainment variation between students (see for example Sammons, 2007). Consequently, any bridging to experiences beyond the classroom, such as experiences at home, has the potential to significantly impact attainment. Section 4.6 briefly summarises three substantial programmes of research which are either entirely focused on, or contain significant elements of, research supporting STEM teaching and learning.

4.1 Understanding the problem

There is a considerable amount of work that examines participation and attainment in STEM subjects at a policy level, which usually aims to influence and inform policymakers (regional or national) with regard to policy decisions and developments.

CASE STUDY 1: Demand and supply of STEM subjects in the south west

Funder	Principal investigator	Institution	Project team	Budget	Date
South West Regional Development Agency	Ben Neild	University of Exeter	Various researchers and consult-ants from SLIM and University of Exeter (see SLIM, 2009b: 3 for full list)	£70,000	April 2008-January 2009

Further information: http://www.swslim.org.uk/stem.asp

What

As well as being a national priority, it is also important for individual regions to have appropriate provision of STEM skills supply in order to address their current and future needs to sustain economic prosperity. In response to regional challenges, the South West Regional Skills Partnership (SWRSP) identified developing creativity and STEM skills as one of its four priorities for 2007-2010 (SWRSP, 2007). The region's response to this priority involved a three-pronged approach, one part of which was investing in research to understand STEM skills in the region.

A team from the University of Exeter (as part of the Skills and Learning Intelligence Module [SLIM – a module of the South West Regional Observatory]) was commissioned by the South West Regional Development Agency (SWRDA) to undertake research in order to gain a greater understanding of the demand and supply of STEM skills in the south west region. This included analysing trends in take-up and attainment from Key Stage 2 onwards as well as the demand for STEM skills by employers in the south west. The research objectives were to develop an understanding of:

- regional trends in STEM subject take-up and achievement from Key Stage 2 through to higher level degrees and first graduate occupations

- key leakages from the education system – whereby young people, either through choice or low levels of achievement, who study or achieve well at a given stage of their education do not go on to study STEM subjects at subsequent stages

- the current demand for STEM skills on the part of employers in the region

- evidence for skills gaps and evidence of unmet demand, particularly as expressed by Sector Skills Councils

- the future needs of employers for STEM skills

- the barriers faced by those in schools, further education and higher education institutions in delivering STEM qualifications

- practical measures that could be taken to improve take-up and achievement in STEM subjects in the future (SLIM, 2009b: 13)

How

The research team employed a combination of primary and secondary research (SLIM, 2009b). Evidence was collected in four areas: policy context, demand side, supply side and stakeholder views.

Data gathering for the policy context involved desk research, including a substantial literature review of existing evidence and policy (SLIM, 2009c). To gain a picture of the demand side for STEM skills in the south west region, data from the National Employer Skills Survey (NESS) 2007 was used to provide an insight into skills shortages and skills gaps (SLIM, 2009d). Working Futures data was also used to forecast future demand for skills in particular sectors. The demand-side data analysis was complemented by a number of case studies developed from interviews with sector-based, employer-led bodies in the region.

The supply-side trends, including where the 'leaks' were in the system, were analysed using data from the National Pupil Database, the Higher Education

Statistics Agency and Universities and Colleges Admissions Service (UCAS). Multilevel modelling techniques were employed to assess the predictive value of a range of determinants affecting the attainment of STEM skills. These were then used to forecast future attainment levels (SLIM, 2009a).

The final component involved collecting stakeholder views in order to contextualise the quantitative data found in the previous work. The qualitative data, collected mainly from interviews with stakeholders responsible for delivery of STEM teaching, enabled researchers to 'validate, clarify and interpret the findings of the data review' (SLIM, 2009e: 12).

Many of the issues discussed in the interviews related to the choices made by students in determining their GCSE, A-level and higher education choices. Interviews took place with head teachers, heads of departments within schools, careers advisers, colleges, higher education institutions, education business links and organisations already delivering STEM support activities, including those in other regions. Consultation was via semi-structured telephone and face-to-face interviews. The research explored factors such as the availability of staff and equipment; teacher, parent and peer attitudes; and access to information, advice and guidance services. However, the focus was on identifying 'what is missing that would help' and the evidence for this. This then enabled the researchers to consider how to cost and ultimately fund appropriate actions in the final phase. The sampling included high- and low-performing schools in order to address the issue of divergences in performance and the factors that might account for them.

Outcomes and impact

The project reports and findings have been endorsed by the South West Regional Employment and Skills Partnership and have fed into the region's planning in this area. The director of the South West Regional Employment and Skills Partnership describes the impacts of the research below.

Through SLIM, the University of Exeter's research on the supply and demand of STEM skills in South West England has been valuable to the South West Regional Employment and Skills Partnership as it has contributed to STEM SW's thinking on the value of STEM skills; supported the identification of existing gaps and helped develop a greater understanding of the interventions needed to address them. Following earlier research by the University of Exeter and SLIM, and taking into consideration national priorities, the Regional Employment and Skills Partnership agreed that tackling STEM skills shortages should be a regional priority. This work will help in the development of our regional skills strategy and in the targeting of resources.

Jim Neilson
Director, South West Regional Employment and Skills Partnership

CASE STUDY 2: Identification and overview of research into mathematics education in countries with high mathematics attainment

International benchmarking studies (such as PISA and TIMSS) have become increasingly important for policymakers and politicians. The UK's performance on these tests, though good, has elements of variability (see page 21). There has been a tendency in government to look to successful policy examples in other countries but it is too simplistic to think that a seemingly successful approach or policy can simply be 'imported' into another country's systems and cultural and political context.

Funder	Principal investigator	Institution	Project team	Budget	Date
Nuffield Foundation	Mike Askew	King's College London	Mike Askew, Jeremy Hodgen, Sarmin Hossain, Nicola Bretscher	£30,204	January 2008-July 2009

Further information:
http://www.nuffieldfoundation.org/values-and-variables-mathematics-education-high-performing-countries

What

The Nuffield Foundation funded a team at King's College London (led by Professor Mike Askew) to review the research from countries with high levels of mathematics attainment (as measured by international benchmarking studies). For mathematics this includes many Asian Pacific Rim countries such as China, Japan, Hong Kong, Chinese Taipei, Singapore and South Korea (see page 21). Together with Finland, these were the main countries whose systems were considered. The questions that the research aimed to answer were:

- What is the range and type of research evidence from countries with high performance in mathematics that gives insights into the reasons for their relatively high position?

- What constitutes high performance in mathematics learning and what factors appear most powerfully to contribute to achieving it?

The second question involved examining countries that have made progress up the international performance tables (regardless of their starting position) in an attempt to disentangle factors that affect improvement and raise standards.

How

This secondary research project used systematic review research methodology (see EPPI-Centre website[4] for more on this approach). The team began with a search for relevant published research reports, which identified about 1,500 sources. These were categorised and a core body of approximately 500 items selected that met quality and significance criteria, and provided the substance of the review. A high-level seminar was held in June 2009 at the Royal Society in collaboration with the Joint Mathematics Council. The aim of the seminar was to discuss the emerging findings with stakeholders, peers and users in order to consider key messages and how best to present them in order to achieve maximum impact on policy, practice and future research (Nuffield Foundation, 2009).

Outcomes and impact

One output from this project is a detailed bibliography of relevant research concerning factors impacting on mathematics learning in countries where mathematical attainment is high. The final report – *Values and variables: Mathematics education in high-performing countries* (Askew *et al.*, 2010) – examines 14 themes identified from the literature by the research team. The themes included factors where there was significant evidence of impact from the literature and ones that were more relevant to England. These included teacher subject knowledge, parental expectation and confidence.

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4   http://eppi.ioe.ac.uk/

The report's main findings were as follows.

- England's performance in international rankings improved between 2003 and 2007. However, this does not necessarily mean an improvement in all areas of maths education. Year 9 performance in algebra is still below the international average.

- Use of textbooks for teaching maths in English schools is relatively low. English textbooks use routine examples and are less mathematically coherent than those used in other countries.

- Mathematics education outside school – shadow education – can contribute to high standards, but can also have an adverse effect on pupils' wider social development.

- There is no link between achievement and enjoyment in maths education. Pupils in countries that perform well in international surveys do not necessarily enjoy maths more than those from countries that perform less well.

- Pupils from high-performing countries often have low confidence in maths.

- Countries that perform well in maths have not reduced the difference in attainment between pupils from different socio-economic backgrounds.

- There is no evidence that pupils who participate in pre-school mathematics learning are likely to perform better at maths than those who don't.

- Differences in maths performance between countries do not necessarily reflect differences in standards of teaching. The degree to which the questions used in international surveys match the curriculum content of a particular country is a more significant factor than the standard of teaching.

(**Source**: http://www.nuffieldfoundation.org/values-and-variables-mathematics-education-high-performing-countries)

CASE STUDY 3: Girls in Physics

Funder	Principal investigator	Institution	Project team	Budget	Date
Institute of Physics	Patricia Murphy	The Open University	Patricia Murphy, Elizabeth Whitelegg, Martin Hollins and Bob Ponchaud	£12,000 (for initial research review)	2004-2006 plus follow-on dissemination and develop-mental work

Further information: http://www.iop.org/

What

As well as the overall decline in the proportions of young people choosing to continue studying science or mathematics after school-leaving age as described in previous sections, there is also a significant gender dimension. The Institute of Physics was concerned about falling post-16 participation rates and therefore commissioned two reviews to examine the issue. The first was a literature review that brought together existing literature concerning girls' participation in physics (Murphy and Whitelegg, 2006). The second investigated effective practice in schools that had high participation rates for girls post-16 (Ponchaud, 2006). The focus on gender was due to the underrepresentation of girls doing physics A-level compared to the other sciences (Murphy and Whitelegg, 2006).

How

The authors of the first report used practices developed by systematic reviewing to inform their review. Criteria for inclusion of reports and papers were chosen. These included: age of the students 11-16; UK-based research; published in the timeframe 1990-2005; clarity of purpose; clarity of data-collection tools; attention to the validity of the analysis and its interpretation (Murphy and Whitelegg, 2006). The review examined a range of different types of research and included 177 sources once the criteria were applied.

The second report by Bob Ponchaud (2006) was not published separately but fed into a guidance document which drew on the findings from both reports to develop *A Teachers' Guide for Action* (Hollins *et al.*, 2006). Ponchaud's report was an investigation into schools that had high proportions of girls taking physics A-level in order to see whether strategies taken in these schools may inform the practice in others.

Outcomes and impact

The first report presented findings in a range of areas: students, curriculum interventions, teacher and teacher effects, and assessment issues. A key and perhaps surprising finding was that there was a considerable lack of high-quality research looking explicitly at gender and physics. Other outputs included the teachers' guide (Hollins *et al.*, 2006) outlining effective strategies, and videos that can be used as a professional development resource in schools. The teachers' guide also included an exemplar questionnaire that could be used by teachers to increase their understanding regarding their students' view of science and how it was taught in their school.

There have been considerable developments following on from this project. The initial two reports (first two boxes in Figure 4) provided the foundation for an action research project. This was used as a method of disseminating the work. Engaging schools and teachers in this way is seen as much more effective, in terms of changing practice, than simply distributing reports (Daly *et al.*, 2009).

Girls in physics classroom (Institute of Physics)

Figure 4: Overview of project

Literature review	→	A Teachers' Guide for Action	→	Action research
Understanding the problem		Identifying good practice		Effecting change
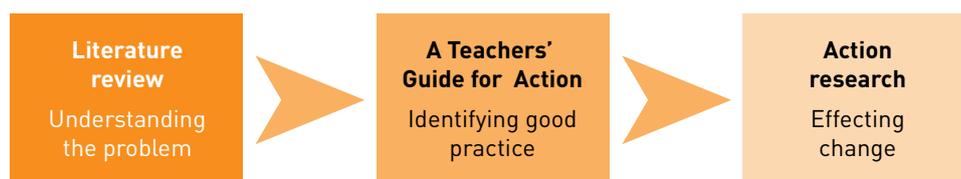
Source: Daly *et al.* (2009: iv)

The action research project had two phases. The initial phase involved piloting the work in three regions through the Science Learning Centres[5] (from 2006 to 2007). The then DCSF then funded a second phase in 2008 in which the action research project was initiated in 100 schools. An evaluation of this action research project was commissioned by the DCSF and completed in 2008 (Daly *et al.*, 2009).

> *The gender imbalance in physics post-16 has been a persistent problem. The Institute commissioned a research review to find out what was known about the issue. We discovered that, while there was no magic bullet, there were a number of promising approaches. Based on the research and some observations on best practice, we set up a number of action research projects, in collaboration with the (then) DfES and the Science Learning Centres. These have already engaged many enthusiastic teachers and made a real difference to classroom practice. The evidence from these projects has been published and forms the basis for our gender work within the national Stimulating Physics programme.*
>
> **Professor Peter Main**
> Director Education and Science, Institute of Physics

> *The way that I think about teaching physics has already changed – I try to plan lessons in a very different way now – thinking about how to link what we are learning to the students' lives and how to make concepts accessible without automatically throwing equations at them. So I'd say it is very sustainable because it has fundamentally changed the way that I plan and teach.*
>
> Teacher involved in the action research project which grew from the Girls in Physics reviews (source: Daly *et al.* [2009])

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5   The Science Learning Centres form a national network of regional centres which support science teachers through providing professional development. Regional Centres opened in 2004 with the National Centre following in 2005. For more information see the Science Learning Centres website: https://www.sciencelearningcentres.org.uk/

CASE STUDY 4: UPMAP: Understanding Participation rates in post-16 Mathematics And Physics

Funder	Principal investigator	Institution	Project team	Budget	Date
ESRC	Michael Reiss	Institute of Education, University of London	Celia Hoyles, Tamjid Mujtaba, Michael Reiss, Bijan Riazi-Farzad, Melissa Rodd, Anna Sfard, Shirley Simon and Fani Stylianidou	£721,433	April 2008-September 2011

Further information: http://www.ioe.ac.uk/study/departments/cpat/4814.html

What

The aim of this study was to deepen understanding of what attracts some students to mathematics and to physics and what drives others away. Knowing the factors that shape student engagement and choices will provide advice to policymakers to decide how to engage more students in these subjects by targeting interventions and new approaches to pedagogy. When students encounter school mathematics and physics, they respond to these discourses in a variety of ways. Understanding the reasons for these varied responses can help make sense of many of the ways in which different students (for example females and males) react differently to mathematics and physics and of the phenomenon, widely found in industrialised countries, in which many of those who do well at school in mathematics and the sciences subsequently take alternative education and career paths. This project aimed to identify, through research that uses a mixture of qualitative and quantitative methods, the range of factors (individual, school and out-of-school, including home), and their interactions, that influence post-16 participation in mathematics and physics in the UK and to assess their relative importance among different student populations. The research team aimed to gain the views of students and to examine the sources of these views through exploring the contexts, inside and outside of school, in which students experience barriers and opportunities, and form their identities in regard to post-16 participation in mathematics and physics.

How

This was a three and a half year project which started in April 2008 using mixed methods. Large numbers of statements (including many from existing published instruments) with which secondary school students are asked to agree or disagree were incorporated into questionnaires and distributed to 140 schools across the UK. Interviews with 14- to 17-year-olds in a selection of 12 of these schools were analysed using both thematic and discourse analyses, and the outcomes were complemented with comparisons from responses to the questionnaires. Lists of first year higher education institution students, who qualified to embark on degree courses in accountancy, mathematics, engineering or physics, were provided by institutions in order to select candidates for interview on the basis of whether or not the student's profile is such that an interview could reveal useful insights into factors that influence choices.

Outcomes and impact

The work is currently being written up. Interim results indicate that for school students, in the way they feel about mathematics and physics, their confidence in these subjects and extrinsic motivation are key psychological factors that have an independent influence on intention to take physics and mathematics post-16. The research team have also found that school policy plays an important role both in increasing the intention to participate in mathematics and physics post-16 and in reducing gender biases in intentions to take physics and mathematics post-16. Interviews with undergraduates who have chosen not to study STEM subjects at university despite having the A-levels or other qualifications to do so show the extent to which choosing not to study a STEM subject can be a defence against fear of failure and highlight the importance of significant older individuals in supporting students in their choice of STEM subjects.

To have the desired impact on policy and practice, effective dissemination will be crucial. Dissemination to a variety of audiences – academics, policymakers and teachers – is ongoing.

4.2 Teaching and learning – pedagogy

4.2.1 Early years and primary phase

A pupil's ability, or at least *perceived* ability, is related to their enjoyment of the subject and therefore to whether they choose to continue studying. Statistically, a young person's attainment at secondary school and their subsequent participation decisions are strongly influenced by their prior attainment, and this is true in STEM subjects as well as more generally (Gorard and See, 2009). It is therefore crucial that progress is made during early years and primary school in terms of knowledge and skills, particularly in terms of numeracy and literacy.

Three projects addressing the quality of teaching for younger pupils are described in this section. The first (case study 5) looks at science teaching in the foundation phase using an action research approach. The following two look at maths teaching in the primary phase. One is a small-scale intervention programme focusing on the importance of talk which develops activities and strategies with teachers in local schools (case study 6). The other is an international project that uses this dimension to draw out effective methods of dealing with common misconceptions, as well as the importance of language in mathematics teaching (case study 7).

CASE STUDY 5: Teachers and Young Children Exploring their Worlds Together

Whilst providing professional support for teachers is an important way in which higher education institutions support practitioners in improving teaching, it often is not described as research and therefore does not fall within the compass of this report. Some projects, such as the one presented here, fall into both areas: it provides professional development for those teachers directly involved and is an action research project which has given insights into effective teaching of science in the foundation stage and from which the creation of a continuing professional development unit has developed.

Funder	Principal investigator	Institution	Project team	Budget	Date
AstraZeneca Science Teaching Trust (AZSTT)	Lynda Fletcher and Helen Clarke	University of Winchester	Paula Moorse, Helen Clarke, Charly Ryan, Bridget Egan, Honor Houghton, Lynda Fletcher, Karen Phethean, plus teachers from schools in Wiltshire and Hampshire and local authority advisers	£80,000	July 2004- July 2006 for main project with ongoing dissemina- tion and development work

What

This project involved researchers working with early years teachers to explore the potential for the use of curiosity and investigation in science learning in early years. The project documented practice in foundation phase science and explored how practitioners can develop and encourage children's own ideas and curiosity to foster creativity and achievement. The project grew out of three areas of existing research: research around children's ideas (which had been developed in other settings but rarely in early years science), research around working with adults (in this case involving other school staff, governors, parents, local authority advisers and inspectors), and research around effective CPD.

How

This project involved university researchers working with the science coordinator and an early years practitioner from each of the 24 schools involved in the project.

The project consisted of individual action research projects brought together in an overarching framework. Action research involves teachers as researchers undertaking reflective practice. It describes an iterative process

in which professional researchers support and guide practitioners to design and evaluate practice in order to understand and develop improved teaching and learning. Action research challenges traditional academic approaches as it is practice-based rather than more abstract enquiry traditionally undertaken by research professionals. Individual projects featured a range of topics, including the use of stories as starting points for investigative activity and the development of suitable resources for children to access independently (Clarke *et al.*, 2006).

The practitioners worked together with those from other schools in small clusters and with the university staff. Individual developmental work around their own action research projects were then worked up into case studies so that the whole team could together systemise learning. Project funding bought teaching time (10 days per teacher in the first year, eight in the second) which allowed the teacher-researchers space 'for reflection on action and for the systemisation of this reflection in the form of case studies of practice' (Clarke *et al.*, 2006: 409). This process ensured the move from action project to research project. Four characteristics were used to describe the theoretical approach developed in order to systematise the findings of the action research projects (Clarke *et al.*, 2006):

- Creating space an important element both in terms of teachers involved and for children having space to explore their curiosity

- Appreciative inquiry – working with positive emerging objectives

- Action research as rhizomatic[6] growth – a non-linear model of action research

- Collaboration – working as communities of practice

Outcomes and impact

The project has had considerable positive impact not just on the teaching of those teachers directly involved in the project but through the sustained legacy of the work in the schools, through dissemination at practitioner and academic conferences, and the development of a continuing professional development unit enabling other early years practitioners to learn from this research and improve their practice. Teachers reported that both children's and staff's thinking was challenged to improve and extend science learning. They also noted an impact on girls' attitudes and attainment in science and technology.

The work has also led to valuing open-endedness and the balance between planning and following emergent objectives in lessons. This is a challenge for teachers, researchers and teacher educators.

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6   The term 'rhizomatic' is attributed to Deleuze and Guattari (1987) and is used here to describe research that is non-hierarchical in its data interpretation, reflecting horizontal connections in knowledge building (for further detail see Amorim and Ryan, 2005).

The sustainability of the work in the school was a key aim for the second phase of the project (Year 2). In some schools the approach was used successfully across other subject areas and year groups, as the following quotes indicate. In all the schools involved in the project, the work had impacted on school planning through specific planning in science in the foundation stage or through the school's development plan. The evaluation of the project concluded that, 'the sustainability of the project, at least while current staff were in place, seemed highly likely' (Fletcher, 2006: 20).

The children's interaction with 'real life' experiences was considered to have stimulated their enjoyment and learning in science. One teacher reported, 'We are buzzing at the moment ... we are really harnessing the children's natural creativity' (Fletcher, 2006: 18). Head teachers agreed with teachers participating in the project that, 'More enthusiastic children enjoying sharing and building on own learning as they move up the schools' was a likely impact of the project in their schools (Fletcher, 2006: 5).

Exploring local pondlife (AstraZeneca Science Teaching Trust)

Although the main project ended in 2006, there are ongoing developments and outputs. A substantial output from the project is a CPD unit called Fostering Curiosity in Early Years Science which is free to download from the AstraZeneca Science Teaching Trust website (see: http://www.azteachscience.co.uk/resources/cpd/fostering-curiosity-in-early-years-science.aspx). This unit leads teachers through developing their own child-focused, open approach to teaching science in the early years phase, through using real life experiences. The project has also informed two new modules at the University of Winchester: Curiosity and Exploration in Learning for the BA in primary education and Research in the Early Years for the MA in professional enquiry.

Several teachers have presented their projects at our annual Science Coordinators Conference. All of these projects have been interesting and have added to our thinking but one project in particular has had a significant impact. The work on the role of exploratory, free play in science has far reaching implications about the importance of students developing ownership of their investigations. We have found that this is as important for adults as it is for children in reception. It is after all what motivates people to do science; finding things out for ourselves. This work has had a significant impact on the ability of teachers to provide meaningful science experiences for children.

Richard Aplin
County Adviser for Science in Hampshire

(**Source:** Fletcher *et al.* [2009])

As a result of these experiences in the Foundation Stage and making sure that this approach is built upon in subsequent years, we have evidence that the children have continued to perform highly on AT1 science skills. There is continued enthusiasm for bringing in items that have scientific interest.

This way of working has impacted on other subjects with children able to discuss each other's ideas, children having the ability to listen and value each other's opinions, more 'risk taking' in their ways of working.

Outside educational visitors have commented on the children's scientific knowledge when compared to other children of similar ages. Parents have also commented on the fact that their children 'stop and notice' their environment now.

Mrs LE Pugh
Head Teacher, Nomansland and Hamptworth Primary School

(**Source:** Fletcher *et al.* [2009])

CASE STUDY 6: Mathematical misconceptions: Opening the door to understanding in the primary school

Funder	Principal investigator	Institution	Project team	Budget	Date
British Academy	Anne Cockburn	University of East Anglia	Nine academics from the University of Parma, Tel Aviv University, Charles University (Prague) and Center for Educational Technology at Tel Aviv	£70,000	2006-2007

What

This project used an international comparative approach to gain insights into mathematical misconceptions. The project developed from the consideration of why 'zero' is a plural word in English – we say 'one dog' but 'zero dogs' (Cockburn and Littler, 2008: 2). This drew to the researchers' attention the importance of language in mathematics teaching and the potential for misunderstandings in the early learning years. By looking at mathematical misconceptions across classrooms in different countries, this project allowed the researchers to explore the role of language in early mathematical learning but also to take a broader look at different pedagogical approaches taken in different countries and explore their relative effectiveness.

How

This project involved a team of nine academics from four countries (UK, Italy, Czech Republic and Israel). The academics worked with primary school teachers (in more than 50 project classrooms) across the countries to look at mathematical misconceptions common in classrooms regardless of the country context.

Through observing classrooms in different comparator countries, and comparing and contrasting how specific topics were taught in different countries and what misconceptions were common, the researchers developed their understanding of how primary children learn mathematics. The researchers and teachers came together to discuss ideas at two international meetings over the course of the project. During the initial meeting, a series of arithmetic tasks were devised for use in the project classrooms. The data collected and existing research identified through literature review formed the basis for discussions at the second meeting.

Through looking at the misconceptions which occurred across countries, the importance of pedagogic approach, culture and language in terms of effective mathematics teaching could be explored. The research team went on to develop strategies which might diminish the occurrence of mathematical misconceptions.

Outcomes and impact

The analysis of the data led the researchers to a number of conclusions: that misconceptions can develop very early but may not be apparent for several years; that some misconceptions seem common across languages and cultures, suggesting that they are in fact difficult concepts (rather than ones which could be avoided by simply being taught differently); and that children's responses are often logical even though they may have arrived at an incorrect answer. The work also highlighted the importance of subject knowledge.

The key findings from the project have been published in a guide for primary teachers: *Mathematical Misconceptions: A Guide for Primary Teachers* (Cockburn and Littler, 2008). This is a practical teaching guide aimed at practitioners covering a range of strategies in tackling areas where younger children often get stuck. These include:

- the seemingly paradoxical number zero

- the concept of equality

- children's perceptions and misconceptions of adding, subtracting, multiplying and dividing

- the learning process

- the ways in which children acquire number concepts

As a secondary teacher of mathematics I've found this a remarkable insight into the student's thinking – giving me clear background information to help me think about my classes and their misconceptions and how I could help the children develop their thinking.

Association of Teachers of Mathematics (http://www.uk.sagepub.com/booksProdDesc.nav?prodId=Book232893)

CASE STUDY 7: Talking Counts: An intervention programme to investigate and develop the role of exploratory talk in young children's arithmetic

Funder	Principal investigator	Institution	Project team	Budget	Date
Esmée Fairbairn	Carol Murphy	University of Exeter	Ros Fisher, Rupert Wegerif, Tricia Nash plus Devon Learning and Partnership Development, local primary schools	£63,875	January 2009-April 2010

Further information: http://education.exeter.ac.uk/projects.php?id=490

What

The Williams review of early years and primary mathematics (see Section 2) highlighted some concerns with the quality of primary teachers' mathematical subject and pedagogical knowledge in primary schools (Williams, 2008). Williams recommended a 'renewed focus by practitioners on "oral and mental mathematics"' (2008: 60, recommendation 10). There has also been a growing interest in collaborative learning approaches in mathematics education in order to enable deeper understanding of mathematical concepts (see, for example, the work of Professor Malcolm Swan in case study 10). In the Key Stage 1 phase, research has found that with explicit teaching of strategies, even young primary children can use talk effectively (Kutnick *et al.*, 2008; Wegerif *et al.*, 2004). The decision to use exploratory talk in arithmetic in this project grew from a sense that arithmetic calculations early in primary school is an area that is likely to be taught through the calculation strategies laid out in the National Numeracy Strategy, with little interrogation – and therefore understanding – of the concepts underlying these strategies. This may result in pupils becoming passive rather than active learners.

How

This research took place in three phases. Phase 1 (developmental phase) was undertaken in the spring term of 2009 and involved developing collaborative group activities which combined instruction with talk focused on arithmetic with two Key Stage 1 teachers in local primary schools.

The second phase (extension phase – summer term 2009) involved extending the activities developed in phase 1 to 10 further Key Stage 1 teachers and evaluating the strategies used in doing so.

Data collected through video recordings were analysed. Diagnostic data was collected through clinical interviews to explore progress made in arithmetic over the course of the research. Baseline data was collected at the beginning and end of the phases and compared against national norms.

Outcomes and impact

The final phase of the project (phase 3) was based around dissemination and involved developing professional development resources. A teacher resource pack was created by the project team that can be downloaded from the project website (http://education.exeter.ac.uk/projects.php?id=490). These resources include an introduction to talk in the classroom at primary level as well as ideas for planning and activities for use in the classroom in order to encourage effective talk both in general and in maths. The following quotes are from teacher interviews which took place after phase 2 of the project.

> *It's certainly affected their learning, I think they've made a better progress, I think they have a better understanding of mathematical concepts.*
>
> **Lucy Herring**
> Countess Wear Community School

> *I think the idea of talk groups has helped to develop positive talk, discussion, listening and general manners across all areas of the curriculum.*
>
> *It's focused me in more on my assessments as well and the progress that they've made … I've got so much more evidence than I had before.*
>
> **Anna Langdon**
> Manor Primary School

4.2.2 Secondary and further education

Enthusiasm for and attainment in STEM-based thinking and exploration successfully fostered and developed in the early years and primary phases need to be maintained through the later phases of schooling. Challenges include maintaining interest in STEM subjects which can begin to seem abstract, difficult and irrelevant to some students as they move through secondary school. Therefore, approaches that increase engagement in these subjects and aid deeper understanding are important. As well as encouraging participation in science subjects at GCSE level and then converting this into continued study in STEM subjects post-16, it is important to build knowledge and understanding across the ability range.

CASE STUDY 8: Enabling enhanced mathematics teaching with interactive whiteboards

Funder	Principal investigator	Institution	Project team	Budget	Date
National Centre for Excellence in the Teaching of Mathematics (NCETM)	Dave Miller	Keele University	Dave Miller, Derek Glover and Doug Averis, plus 10 teachers	£24,978	September 2006- September 2008

Further information: http://www.keele.ac.uk/education/research/interactivewhiteboard/

What

This project is the latest in a series of projects undertaken by the Keele Interactive Whiteboard Research Group led by Dave Miller. Previous projects undertaken by the team on interactive whiteboards (IWBs) provided the foundation for this work and demonstrate the team's expertise in this area. These projects included ones funded by the Nuffield Foundation (Miller *et al.*, 2004), Becta (Miller *et al.*, 2005), the TDA (Miller *et al.*, 2006) and the Secondary National Strategy (Miller and Glover, 2006) (for more information see: http://www.keele.ac.uk/education/research/interactivewhiteboard/).

There has been a large increase in the numbers of IWBs in schools in recent years. The Becta Harnessing Technology survey found there has been an increase in the proportion of all teachers regularly using IWBs in lessons from 42 per cent in 2006 to 73 per cent in 2008 (Becta, 2008).

Despite the increase in the number of IWBs in classrooms, research has found that although the use of IWBs does make a difference in the classroom there is limited evidence of positive impact on attainment outcomes (Moss *et al.*, 2007). This project took this as its starting point and looked to explore how IWBs were being used in order to determine strategies, pedagogies, resources and training that could lead to more effective use of IWBs in mathematics classrooms.

How

This developmental study used direct observation and video recording of 10 secondary mathematics teachers. The team also built on their considerable knowledge and past research in this area (that is, reanalysing video evidence from previous projects).

The teachers and researchers worked together using an approach called Developmental Work Research (Engestrom, 2001). The structure of the project was based around seven one-day team meetings where approaches, materials and experiences were discussed, with tasks set between the meetings.

The project was supplemented by an additional project which involved providing IWB development courses for the Secondary National Strategy consultants. This enabled the team members to test out their resources and ideas with the consultants, building in another iterative feedback loop.

Outcomes and impact

This research involved gaining deeper understanding of the use of IWBs in secondary mathematics classrooms. Through this project and through previous projects and experience, the project team arrived at a range of outcomes – some involve high-level, policy-related recommendations and others the development of practical tools for teachers, mathematics departments and teacher trainers.

An independent evaluation of the project was undertaken by Dr Jenny Piggott from the University of Cambridge (Piggott, 2008). The outcomes from the project identified by the team and by Piggott included the following:

A. Development of a pedagogy to enhance mathematics teaching using an IWB

The team found through their observations that even those teachers who were more experienced in IWB use asked relatively low-level questions and used the IWB for didactic or presentational (for example displaying a PowerPoint presentation) purposes rather than interactive teaching methods. The team drew from proven methods of mathematics teaching such as Swan's work (see case study 10) and their own experience to develop an effective pedagogy which incorporates effective use of IWBs – 'at the board, on the desk, in the head' (see: http://www.ncetm.org.uk/mathemapedia/BoardDeskHead).

B. Development of materials for professional development and for use in the classroom

The project included developing materials that could be used for professional development purposes as well as resources for teachers to use in the classroom. This included setting up a new website which acts as a database for resources for IWBs (see: http://www.iwbmathstraining.co.uk). This includes versions of lessons and resources for use on an IWB based on *Improving Learning in Mathematics* (Swan, 2005, and see case study 10).

C. Model of professional development

The team found in this project, as with other similar ones in the past, that often there is a huge financial investment in the IWB hardware and software but little or no resource given over to training and professional development of the teachers. They raise this as a likely contributory factor as to why 'too often teachers used them [IWBs] simply for PowerPoint presentations with no interaction by the pupils' (Ofsted, 2008: 27), stating that 'the level of support needed to enable mathematics teachers to develop an appropriate mathematics pedagogy has been greatly under-estimated' (Miller *et al.*, 2008: 4). The team proposed a solution in a professional development framework called SPORE (skills, pedagogy, opportunity, reflection, evolution).

Other materials developed included a diagnostic questionnaire for teachers designed to get teachers thinking about interactivity in their classrooms, and a list of resources, equipment, features and software needed for an effective mathematics classroom.

The project evaluation also noted that a considerable impact was the positive effect of the project on the professional development of those individuals involved. It therefore suggested that thought should be given to innovative approaches to dissemination to enable some of these impacts to be felt by a greater number of secondary mathematics teachers.

Impacts have reached beyond those directly involved in the research. Through what was learned by the team several resources were developed to be used by teachers, departments and teacher trainers nationally and beyond, such as the diagnostic questionnaire to enable teachers to consider how interactive their lessons are. There are several recommendations made by the research team highlighting how curriculum agencies, schools and school resource producers can support more effective IWB use in mathematics classrooms.

These include improved virtual learning environment structures in schools, more thought given to the IWB application of resources by agencies, and improved access to professional development around IWB use. This research built on other current applied research looking at pedagogical approaches in effective mathematics teaching (see for example case study 10) to develop pedagogies and resources aimed at improving the teaching (and thereby students' learning and attainment).

The project delivered successfully in all areas of its proposal. The focus of the project leader on identifying key products of the project (such as the CDs and development days) helped to maintain a momentum throughout the project. One of the most valuable aspects for the NCETM was the ability of the project leader to draw in resources from other areas to support and extend the project in related and mutually supportive ways.

For teachers and HEI colleagues directly involved in the project development, a most valued aspect of the project was being given time to work with other teachers with a range of expertise.

The University worked as a hub for this project and potential to make connections with research and educational developments more generally. This was seen as a very valuable aspect of the project by all. From the point of view of colleagues within the HEI, the role of teachers was felt to be crucial in making outcomes realistic and based on classroom experiences.

The project was managed to a very high standard and was excellent value for money.

Dr Jenny Piggott
University of Cambridge (external evaluator)

(**Source:** Piggott [2008])

It (the research) has made me think more in depth about every lesson I teach; how the board could be used more efficiently, how learning could be improved, what resources would bring the lesson alive, what activities could pupils get involved with at the board to reinforce mathematical ideas and discussion.

Teacher

(**Source:** Wilson and Miller [2008: 3])

CASE STUDY 9: Dialogic inquiry in science teaching

Funder	Principal investigator	Institution	Project team	Budget	Date
ESRC (follow up EU Framework 7)	Phil Scott and Neil Mercer	University of Leeds, University of Cambridge	Neil Mercer, Judith Kleine Staarman (University of Cambridge), Phil Scott, Jaume Ametller (University of Leeds), Lyn Dawes (University of Northampton)	£136,256 (ESRC phase)	March 2005-June 2007 (plus follow on dissemination and developmental work started summer 2009)

Further information: http://www.esrc.ac.uk/my-esrc/grants/RES-000-23-0939-A/read

What

This research was concerned with the quality of teaching in science classrooms, at both primary and secondary level. 'Dialogic teaching' describes the use of dialogue as a teaching approach. This project started from a point where dialogic teaching enabled meaningful learning (where connections are made between everyday meaning and scientific meaning rather than rote learning). By using video footage of lessons the team were able to uncover some of the links between dialogic teaching and meaningful learning through analysis of individual learners' pathways of understanding. The video footage was also used to study the interactions and dialogues between teachers and students. Through this, the research identified four characteristics of dialogic teaching in science:

- Working on knowledge: including making links between common-sense and scientific points of view

- Shifts in communicative approach: between authoritative and dialogic ways of working

- Teacher actions: including being responsive to students' understandings

- Student engagement: in articulating their own points of view and raising questions (Mercer, 2007)

Through working in both primary and secondary classrooms, the project allowed comparison between approaches and challenges to dialogic teaching in both settings. The challenges to those working at primary level concerned limited practical resources and issues regarding ability to develop effective dialogues when working at the boundaries of their scientific knowledge. In secondary schools a key challenge was the unfamiliarity of teachers with a dialogic teaching approach (Mercer, 2007; Mercer *et al.*, 2009; Scott, 2008; Loxley *et al.*, 2010).

How

The approach taken was one of multiple case studies. The field work took place between 2005 and 2007 in five primary and three secondary schools (with a total of six primary and six secondary teachers). Video recording was used (120 hours in total) to capture the interactions between teachers and students in classrooms. Other than discussing the lesson topic with the teachers involved and outlining their interest in dialogic approaches, the researchers made no interventions in the lessons. Teachers' different strategies were analysed and researchers sought to identify successful approaches.

Outcomes and impact

The project advanced knowledge and understanding of dialogic teaching and its relationship with meaningful learning in science.

The work from this original project directly impacted on the National Secondary Strategy through the development of lesson plans for 'dialogic' science teaching at Key Stage 3 and 4 and on the National Primary Strategy through input to QCA/DfE national working groups. Materials were disseminated nationally in 2008 through the National Strategy professional development programmes (Mercer, 2007). Members of the team have also provided numerous workshops and seminars about dialogic teaching of science for teacher training institutions, local authorities, schools and international conferences.

A follow up phase of the work, carried out by Leeds members of the team (Scott and Ametller), started in summer 2009 and was funded through an EU Framework 7 grant[7]. This phase involved using a multiple case study approach to design and evaluate the impact of CPD on teaching and learning. As part of this, the research team created a training package for collaborative work with science teachers in primary and secondary schools. Through collaborative networks of teachers and researchers, examples of 'effective practice' teaching sequences, based on dialogic inquiry as well as pupil motivation, have been developed and disseminated. A DVD was also created for teacher development purposes.

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7   This project is part of the S-TEAM project (Science-Teacher Education Advanced Methods) (see: https://www.ntnu.no/wiki/display/steam/About+S-TEAM)

CASE STUDY 10: Collaborative Learning in Mathematics

Funder	Principal investigator	Institution	Project team	Budget	Date
Esmée Fairbairn Charitable Foundation (follow up projects funded by LSDA, DfES Standards Unit, NRDC)	Malcolm Swan	University of Nottingham	Malcolm Swan (for initial study)	£50,000 (for initial study)	1995-1997 (follow up projects from 2000-2007)

What

This research project grew from a concern regarding the large numbers of young people failing to achieve a grade C or above at GCSE level – a minimum requirement for many careers and for access to higher education (Swan, 2006). Consequently there are relatively high numbers of young people (16- to 19-year-olds) retaking GCSE mathematics in further education colleges. This context exacerbates the instrumental nature of the qualification and this, combined with low expectations on the part of both the teachers and often the students themselves, the teaching is transmission-oriented in the main. The approach to teaching has been shown to be ineffective in terms of enhancing students' learning and understanding.

Research regarding the effectiveness of collaborative learning is established but work was needed to take this research to the next stage in terms of implementing it in real classrooms and dealing with the challenges in this.

How

Swan used design-based research methodologies to investigate approaches to improve teaching and learning in further education classrooms. Design-based research is an emerging paradigm 'for engaging in theoretical research in realistic learning settings' (DBRC website, no date). Design-based research returns to the ultimate purpose of much education research in terms of aiming to improve the education experience. It addresses a key criticism of much education research through connecting with practice and testing theories through iterative interventions in practice.

The key characteristics of design-based research are (i) the development of local theory, (ii) interventions in real-world learning environments, (iii) the destructive testing of emerging theories, (iv) iterative design and (v) pragmatism (theoretical accountability) (Cobb *et al.*, 2003).

The initial research project involved four further education GCSE retake classrooms. The research team used findings from theoretical and small-scale empirical work to inform effective lesson design principles. Initiatives and lesson plans cannot be made 'teacher proof', and after initial sharing with the four teachers in the developmental study it was clear that the interpretation and corresponding approach to the lesson depend on the teachers' beliefs. Based on this initial phase, a professional development programme was developed along with revised classroom activities. This revised package was then introduced into 44 further education colleges across England and the impacts recorded and evaluated.

Whilst learning gains were modest, they were associated with the number of activities used and the level of student-centred teaching. Where teachers used a significant of number of activities, some of them reported changes to their belief and practices.

Outcomes and impact

An important dimension of the impact of this work was the contribution to design research methodology as well as the considerable contributions to mathematics education specifically.

While the original project was undertaken in further education colleges with students doing GCSE mathematics retakes, the approach and design principles can and have been more broadly applied to other settings and phases. The research demonstrates the potential of using collaborative approaches to tackle conceptual challenges. In the current target-driven culture which incentivises an instrumental approach, this research provides practitioners with a welcome process and approach to enable deeper mathematical understanding.

As well as recognising the increased use of collaborative learning in the classroom, Ofsted endorses the approach explored in Swan's work, concluding in a 2006 report that one of 'the factors which made the most significant contributions to high achievement in 14-19 mathematics ... [was]: Teaching that focuses on developing students' understanding of mathematical concepts and enhances their critical thinking and reasoning, together with a spirit of collaborative enquiry that promotes mathematical discussion and debate' (Ofsted, 2006: 2).

There have been applications of the collaborative teaching and learning approaches advanced in the research beyond the principal target of the original work. The then Department for Education and Skills (DfES) funded further developments of these approaches for all post-16 students through the initiative *Success for All* (DfES, 2005). Copies of the resources developed in this phase (Swan, 2005; Swan and Wall, 2005) were sent to all further education colleges by the DfES and to all secondary schools by the National Centre for Excellence in the Teaching of Mathematics. The Qualifications and Curriculum Authority commissioned work exploring the potential of collaborative learning for 11- to 16-year-olds for learning algebra (QCA, 2004) and the National Research and Development Centre for adult literacy and numeracy (NRDC) are taking this forward for adult learners through their *Maths4Life* project and the *Thinking Through Mathematics* project.

This ... shows how powerful teaching methods can be developed, in conjunction with teachers, which alter the life chances of students who might otherwise fail to get a mathematics qualification. This is a major contribution to mathematics education literature, providing an outstanding example of design research.

Dr Anne Watson
University of Oxford

(**Source:** Swan [2006])

The good thing about this was, instead of like working out of your textbook, you had to use your brain before you could go anywhere else with it. You had to actually sit down and think about it ... After I did it I found that I used a lot of brain power, but I felt dead clever. Do you know that when you have actually done something and you actually put all your effort into something ... it makes you feel dead clever. I've told all my friends that I have actually done a bit of work in maths. 'Cause I never thought I was any good at maths, but I was all right with that.

Further education student

(**Source:** Swan [2006])

4.3 Teaching and learning – curriculum and resources

There is an integral relationship between pedagogy, curriculum and assessment which means that research focusing on a particular strand will inevitably affect the other two. This is demonstrated in the case studies which explored pedagogy but also had implications for the development of curriculum resources. The dialogic teaching approaches developed in case study 9 are also related to some aspects of assessment for learning or formative assessment. The case studies which follow have a focus on curriculum development; however, there are also considerable links to issues around pedagogy and assessment.

CASE STUDY 11: Subject Leadership in Creativity in Design and Technology

Funder	Principal investigator	Institution	Project team	Budget	Date
Gatsby Technical Education Projects (The Gatsby Charitable Foundation)	Bill Nicholl	University of Cambridge	Bill Nicholl, Ros McLellan	£329,000	2005-2010

Further information: http://www.educ.cam.ac.uk/people/staff/nicholl/Research-Project-Details.pdf

What

Professor Ken Robinson highlighted the importance of creative education for young people in his 1999 report (Robinson, 1999). An ability to think creatively is an important skill both for the individual in terms of exhibiting the flexibility and innovation necessary in today's knowledge economy and for the economy in order for the UK to remain at the forefront of design and innovation. 'Creativity and critical thinking' is one of seven 'whole curriculum dimensions' that form the 'overarching themes which have a significance for individuals and society' (QCA, 2008). Creativity is important for many subjects at school and college but one where it is central is design and technology (D&T). Creativity is one of the four key concepts which underpin the study of D&T (QCA, 2007). Whilst the importance of creativity in education has been highlighted in the policy and curriculum documents from government and curriculum agencies, there has been concern that real opportunities for creativity are not materialising – specifically in D&T (Kimbell *et al.*, 2004). Nicholl reports that 'both Kimbell and Barlex referred to creativity as being in "crisis" (Barlex, 2003; Kimbell, 2000a, 2000b) and government inspection reports in the UK have continually referred to the lack of design opportunities, particularly for students aged between 11 and 14 years (Ofsted, 2003)' (2007: 34).

This project, led by Bill Nicholl at the University of Cambridge, set out to examine creativity in D&T classes in Key Stages 3 and 4 in schools in England through a research and intervention project. Aims of the project included to understand how 'current practice in secondary design & technology teaching influences pupil creativity' (Nicholl and McLellan, 2007: 37) (preliminary phase) and to develop ways to 'promote student creativity in the D&T classroom' (Nicholl and McLellan, 2008: 588) (intervention phase).

How

The work involved working with 15 secondary schools with students aged 11-16. During the first (preliminary) phase data was gathered from these schools through semi-structured interviews with teachers and students, observations of lessons, surveys, document analysis (such as inspection reports, schemes of work, classroom resources and so on) and samples of pupil work.

Table 2: Overview of data sources

Data source	Sample	Phase
Interviews with D&T teachers	14 teachers across 6 schools	Preliminary
Interviews with students	126 students across 6 schools	Preliminary
Teacher survey	69 teachers across 11 schools	Intervention
Student survey	4,996 students across 11 schools	Intervention

Source: McLellan and Nicholl (2008: 4)

The data was used to gain a deeper understanding of how D&T was taught in this phase, with a particular focus on creativity. The project has explored what happens in D&T classrooms more generally (Nicholl and McLellan, 2009) as well as how students generate creative ideas and how the current policies and practices played out in D&T classrooms impact on creative activity.

Outcomes and impact

The research team found that there was a low level of creativity in terms of the design ideas that students were coming up with. They found that students often produced stereotypical designs such as love hearts and sports logos but that this was not due to a lack of creative ability (Nicholl and McLellan, 2007). Nicholl and McLellan use the construct fixation (Jansson and Smith, 1991) to explain how this is a natural response by young people. Fixation 'refers to a blind, and sometimes counterproductive, adherence to a limited set of ideas in the design process' (Jansson and Smith, 1991: 4 quoted in Nicholl and McLellan, 2007). Nicholl and McLellan also draw on the work of Ward (1995) to develop the theory around how the development relates to existing knowledge: when people use their imagination to think of new ideas their imagination is 'structured' in predictable ways due to their past experiences and knowledge and they often draw on the knowledge and experiences most readily available to them to fuel their ideas (the 'path-of-least-resistance model') (Ward, 1995 cited in Nicholl and McLellan, 2007).

A second dimension of the work explored the role of the teaching in supporting creativity inside the D&T classroom. The researchers found a low level of creativity in the design ideas that the students put forward and also that, whilst they were frustrated that the students' ideas tended to be unoriginal, the teachers lacked the skills to facilitate more creative thinking. Whilst the students' stereotypical designs are predictable as people's imaginations often default to 'what they know', this is not fixed. The researchers believed that teachers have an important role to play in overcoming fixation and thereby enabling creativity. The researchers found, however, that current pedagogical approaches are contributing to fixation. Awareness and understanding of the problem of fixation is the first step in developing strategies which will enable students to display creativity.

A key tension which D&T teachers are working against is the emphasis on performativity in the current national accountability framework (epitomised by the emphasis on creativity in national policy but lack of reference to it in assessment criteria and attainment targets – see for example Kimbell *et al.*, 2004). As Nicholl and McLellan describe:

> This creates a tension, or as Ball puts it, a 'splitting' between teacher judgements of good practice and the demands of performativity (Ball, 2004). On the one hand, teachers personally value creativity but on the other hand, they need their students to get results, which are not contingent on being creative. (2008: 596)

This project involved working with D&T teachers to develop ways in which the two policies of performativity and creativity can be mediated, thus enabling teachers to support and encourage more creativity in their classrooms (Nicholl and McLellan, 2008).

CASE STUDY 12: Maths Curriculum Coaches project

Funder	Principal investigator	Institution	Project team	Budget	Date
University of Wolver-hampton	Henriette Harnisch	University of Wolver-hampton	Godfrey Blunt, Dr Jane Tinker	£580	Summer term 2009

What

The Curriculum Innovation and Development (CID) Department is part of Education Partnerships at the University of Wolverhampton. The University of Wolverhampton plays an important role in the region in terms of school improvement. The CID Department works collaboratively with schools and further education colleges in the local area to provide curriculum-based support and activities for teachers and students. The projects are routed in developing 'innovative, relevant progression routes for young people' (CID, no date).

The University of Wolverhampton worked with Wrockwardine Wood Arts College (WWAC – a National Challenge school) to provide curriculum-focused support designed to improve attainment through raising aspirations and motivation amongst students. One such project was the Maths Curriculum Coaches project, which completed its pilot phase in 2009.

How

During the pilot phase, the Maths Curriculum Coaches spent one morning a week in the school supporting Year 10 maths classes, initially through providing learning support in the classroom and then moving from supporting the whole class to focus on 12 target students who needed additional support.

For the future, WWAC would like to continue the project but deploy coaches building on the initial pilot. Two possible ways forward were identified:

(a) 'Deep' coaching which deploys coaches over a longer time period (start in late autumn term) and on a whole-day basis on the school's 'Collapsed Timetable' days, which are more flexible than normal school timetable days. This should ideally be supported by e-communication so that students get more flexible support. WWAC also hopes to run an Easter revision course in maths which could involve coaches.

(b) Extra-curricular and cross-curricular work in which coaches run an after-school club in maths and/or Sunday maths groups, plus support the Year 7 'Explore Days' which tackle issues in a cross-curriculum way. Maths could be involved in any of a wide range of issues explored on these days.

In either situation WWAC plans to involve and inform parents more.

Maths coaches working with students (University of Wolverhampton)

Outcomes and impact

The coaches received positive feedback from the maths teacher in the school and the students, as the quotes below demonstrate. The school found that the coaches were committed and highly driven and were able to work with the teacher intuitively.

The University reports on the benefits it received:

From the university's point of view, we view these curriculum focused collaborative projects as hugely valuable. By developing in-depth relationships that are driven through curriculum need we gain invaluable insights into specific issues that affect the 14-19 sector in particular. This, in turn, is then fed into strategically important initiatives the university is engaged in, such as curriculum progression planning and the First Year Experience, to name but two. (Dr Henriette Harnisch, CID Director)

The coaches were a useful extra pairs of hands to support the whole class. We were very happy with the quality of support and the coaches' preparation and commitment. They were able to work with the teacher intuitively and the pupils were well occupied.

Dr Jane Tinker
Assistant Head teacher, Wrockwardine Wood Arts College

The university's students are a huge resource for supporting activities with our local schools and college. I'm constantly awed by their level of commitment. This pilot has helped us identify how we can best tap this resource and use it to support the development of learners.

Godfrey Blunt
Curriculum Innovation & Development Officer, Education Partnerships, University of Wolverhampton

4.4 Teaching and learning – assessment

Assessment is the third plank of teaching and learning and is therefore vital in the learning process. As described in Section 4.3 the three elements – pedagogy, curriculum and assessment – interact with each other. One of the findings from Bill Nicholl's work in case study 11 is how the national assessment system and performativity pressures impact on creativity in the D&T curriculum as well as how it is taught.

The importance of assessment as a learning tool (assessment for learning) has been widely reported and acknowledged in recent years since Black and William quantified the progress made when teachers used effective formative assessment (1998). The case study below focuses on assessment. It builds on some of the findings from case study 11 and looks at how assessment can support creativity and innovation rather than work against it (as witnessed in case study 11).

CASE STUDY 13: E-scape: e-solutions for creative assessment in portfolio environments

Funder	Principal investigator	Institution	Project team	Budget	Date
Phase 1: DfES, QCA **Phase 2:** DfES, QCA, Edexcel, AQA **Phase 3:** DCSF, Becta, Edexcel, OCR **Additional:** Various including AZSTT	Richard Kimbell/ Dan Davies	Goldsmiths, University of London	Colleagues from Bath Spa University and Sheffield Hallam University	**Phase 1:** £300,000 **Phase 2:** £600,000 **Phase 3:** £1.3 million	**Phase 1:** January -October 2005 **Phase 2:** November 2005- January 2007 **Phase 3:** September 2007-March 2009 **Additional work:** ongoing

Further information: http://www.gold.ac.uk/teru/projectinfo/

What

The project began as a Qualifications and Curriculum Authority (QCA)-DfES project to develop a way of assessing creativity, innovation and teamwork in design and technology as this was identified as a shortcoming in the national curriculum framework and GCSE assessments (see case study 11). The initial research and development work in D&T highlighted the potential of using ICT to enhance assessment activity[8].

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8   High stakes assessment (such as GCSE) can have considerable impact on pedagogy and the curriculum through a potential overemphasis on 'getting the grade' at the expense of deeper understanding (by all levels in the system – the Government, the local authority, the school, the teacher and the pupil) in a high stakes system (Brooks and Tough, 2006). Assessment processes are therefore central in delivering the most effective education experience for pupils.

The main *e-scape* (*e-solutions for creative assessment in portfolio environments*) project took place in three phases but additional projects are also underway in a range of areas building on the main *e-scape* project. One of these additional projects was funded by the AstraZeneca Science Teaching Trust and used the research and technology developed in the previous phases (which focused on secondary school) to enhance science learning at primary school (Davies, 2011). Other work has taken place piloting the use of the assessment tools by Awarding Bodies in the new diplomas.

How

Phase 1 of the *e-scape* project involved finding evidence for 'proof of concept' through a series of small-scale trials in schools. Once this was accepted, the next phase (Phase 2) involved developing a working prototype with technology partners for use in assessment of D&T. The prototype system included developing a hand-held device for individual students to use to capture a range of data, and a web-based portfolio assessment system was also developed.

Phase 3 ended in March 2009 and involved two main strands: scaling up the tool for use in a national assessment system (scalability) and transferring the tool to other subjects – namely geography and science (transferability) (Kimbell *et al.*, 2009). This involved running a national pilot in summer 2008 to test and inform the scalability of the assessment tool and process.

One additional project involved expanding the approach to primary science assessments (Davies, 2011). Research has shown that current national assessment arrangements have a negative 'backwash' into the curriculum with teachers 'teaching to the test' as they feel under pressure to have improving results year-on-year (Harlen, 2008). The *e-scape* tool for primary school science was designed to help combat the negative effects of Key Stage tests in science. The research involved working with 16 teachers from 8 primary schools and their 263 pupils (aged 9-11). The teachers were supported in designing and trialling science assessment tasks using the *e-scape* approach. The aim of the project was to explore how effective the *e-scape* tools could be for primary science assessment. This included exploring how stimulating the pupils found undertaking the tasks and analysing how valid and reliable the assessments were (Davies, 2011). Conclusions from the project suggest that *e-scape* could provide an authentic and reliable tool for science assessment at primary level but further research is needed to fully examine the impact of the tool on pedagogy (Davies, 2011).

Teachers training to use the pairs engine (Goldsmiths, University of London)

Outcomes and impact

The central output of the *e-scape* project is the technology which enables and facilitates two main innovations: first the development of a hand-held tool which collects real-time data on students' activity, enabling the production of web portfolios; and second the development of the online technology which enables assessment of the portfolios. This online assessment technology is founded on a 'Thurstone pairs' model of comparative assessment[9] and enables simultaneous web-based assessment of portfolios with very high reliability (0.95) (Kimbell *et al.*, 2009).

The third phase of the project developed the product into a more generic tool with much broader usability. The work allowed the teachers to design their own assessment tasks (rather than having to work with activities designed by the project team) and run their own assessments in schools without the involvement of project team members. While the scope for piloting the tools developed through the *e-scape* project is currently limited in the UK, the work is being taken up in other countries including Israel, Singapore and Australia.

9   Thurstone pairs is a model of assessment which uses comparative judgement originally developed by Thurstone (1927) and developed by Polllit and Crisp (2004). Here the approach is developed into a 'pair engine'. Two portfolios are compared by a judge who makes an overall holistic judgement about which is better. Initially the engine considers all portfolios to be of equal quality so a judge may be presented with two of very different quality. As the process goes on, however, the portfolios presented for comparison will become closer in quality and judgements harder to make. The end result is a complete rank order with high inter-judge comparability (Kimbell *et al.*, 2009).

I suppose the most testing question would be, 'would I do it again?' ... to which I can only answer 'YES PLEASE!' Do I see e-scape as an effective way of assessing creativity and innovation in design work? ... Without a doubt! If Design and Technology is to continue to appeal to students, examiners, universities and employers it has to move on. To keep its credibility D&T has to look to challenging students to not only produce products using tried and tested processes but to show flair and imagination. It's time to start to think about new ways of gathering evidence, assessing what really matters in D&T and to move on. For me e-scape has done this.

Dave White
Subject Coordinator for D&T, Clevedon School. D&T Advanced Skills Teacher, North Somerset (source: Kimbell *et al.* [2009: 161])

From a personal view I think that the principle of having focused innovation challenges as a regular part of pupils' D&T experience is one that all schools should consider. In my view too many schools offer an 'engineered success' D&T experience to their students and rarely offer anything in the way of opportunities for them to show innovation or genuine creativity with an element of risk, where real success or failure can happen. The advantages of a fixed timeframe innovation challenge include the greater pace that all pupils work at, the 'walled garden' opportunity to design and make within constraints of the available time, resources, materials, and a lack of a long term investment in a project. This gives the pupils a greater freedom to take risk and to experiment with their designing and making.

The schools were enthusiastic about taking part in this project, trying out (in a D&T context) things which were innovative and focused on encouraging pupils themselves to be innovative. Whether this enthusiasm by teachers and pupils would be maintained if the process was repeated (with different design challenges) would be interesting to see. One hopeful outcome would be that pupils simply got better at being innovative and being prepared to be challenged. Some schools that I am aware of (BSF) are reviewing their whole school ICT provision and are considering a more widespread adoption of this technology in many curriculum areas.

I observed a well-managed project which was delivered equally well in schools with differing circumstances. I consider the outcome of these trials was that pupils' creativity was given an opportunity to flourish within a limited timeframe and that all pupils were better motivated, more involved and produced more original ideas than in any comparable designing situation.

Paul Clewes
West Midlands Regional Coordinator (source: Kimbell *et al.* [2009: 66-67])

4 .5 Out-of-class support

What happens outside of school – most obviously through the influence of parents or carers – has been demonstrated to have a significant impact on pupils' attainment and progress, particularly for younger children (Sylva *et al.*, 2008). The two final case studies illustrate the importance of these factors. The first (case study 14) examines the mathematical learning that happens outside the classroom (primarily at home) and how this can be built on in the classroom and visa versa. The second (case study 15) looks at the role science and engineering clubs play in increasing enjoyment, motivation and attainment in science.

CASE STUDY 14: The Home-School Knowledge Exchange project

Funder	Principal investigator	Institution	Project team	Budget	Date
ESRC/TLRP	Martin Hughes	University of Bristol	Martin Hughes, Andrew Pollard, Jane Andrews, Anthony Feiler, Pamela Greenhough, David Johnson, Elizabeth McNess, Marilyn Osborn, Leida Salway, Mary Scanlan, Vicki Stinchcombe, Jan Winter, Wan Ching Yee, Guy Claxton	£964,939	March 2001– September 2005

Further information:
http://www.esrcsocietytoday.ac.uk/esrcinfocentre/viewawardpage.aspx?awardnumber=L139251078
http://www.tlrp.org/proj/phase11/phase2e.html
www.home-school-learning.org.uk

What

Whilst parents and out-of-school learning had been considered important and were often referred to in policy texts (for example Every Child Matters), the evidence that school engagement with parents will raise attainment is unclear. One review (Dyson and Robson, 1999) of research on home-school working found that existing work in the UK involved uncoordinated small-scale projects, many of which operate 'as a form of cultural imperialism, devaluing the practices and values of families who may already be marginalised' (Dyson and Robson, 1999 cited in Hughes, 2006). The Home-School Knowledge Exchange (HSKE) project aimed to go some way in filling this gap.

The HSKE project was part of phase II of the ESRC Teaching and Learning Research Programme (see pages 74-75) and involved three strands of work around home-school relationships: literacy in Key Stage 1, numeracy in Key Stage 2, and the primary-secondary transfer. The numeracy strand is reported here.

How

The interventions took place in four primary schools – two in Cardiff, two in Bristol – as well as four secondary schools when addressing the transfer strand. The schools were picked to have approximately the same ethnic composition as the city they were in. In each city one more advantaged and one more disadvantaged school was chosen. A group of matched comparison schools were also recruited in order to compare outcomes between these schools and the schools where the intervention took place. The numeracy strand took place with Year 4 and 5 pupils in the four schools.

The researchers drew from the concept of 'funds of knowledge' (Moll and Greenberg, 1992; Moll *et al.*, 1993) as a way of understanding and valuing the knowledge and learning which took place outside of the classroom (usually but not always through parents) in order to avoid Dyson and Robson's charge of 'cultural imperialism'. The term 'funds of knowledge' refers to the 'information, skills and strategies which families and households acquire and use to maximise their well-being and life-chances' (Hughes, 2006: 2).

In each school a teacher was seconded to work part time on the project. Within each strand home-school exchange activities were developed and trialled with a particular class in each school. The children's progress in numeracy was assessed using the Performance Indicators in Primary Schools (PIPS) tests, as well as through other assessment processes, throughout the project providing quantitative data on any progress made (Hughes, 2006).

In each action class further data was collected from six children (three girls, three boys; two higher attaining, two medium attaining and two lower attaining children) and their families. The data was mainly qualitative and was collected through interviews, videos, photographs and observation. The data was collected in order to give the researchers deeper understanding of the funds of knowledge demonstrated by the teachers and the parents and to understand how the parents and teachers responded to the HSKE activities.

The HSKE activities were developed involving home-to-school activities and school-to-home activities. School-home activities included class newsletters detailing what topics will be covered over the next half term and videos made by the children showing what methods they were using at school. Home-school activities included an Everyday Maths project where pupils took photos of out-of-school activities that involved maths in some way, and a Family Maths Trail which involved parents and children working together to follow a trail around the school (Hughes, 2006).

Outcomes and impact

Initial assessments of the different numeracy-related practices that happened outside schools showed that whilst there was a range of different activities involving numeracy skills (eg games, and activities such as shopping), these were often undertaken using a different mathematical language or method to that used at school. Parents were often not confident in their mathematical abilities and often did not want to confuse the child by doing something a different way (Hughes, 2006). The project shed light on the challenges of bridging home and school knowledge. It also elucidated the areas that needed to be addressed in order, on the one hand, for parents to confidently support their child's learning at home, and on the other, for teachers to build effectively on learning outside school.

The parents of children involved in the project reported greater awareness of their children's mathematics and appreciated more information about the mathematics their child did at school. Progress made by children in the action schools was greater than that made in the matched schools, but this difference was not statistically significant.

The work of the project has been written up in numerous papers and presented at many conferences – both academic and user-focused. The numeracy strand has also been written up as a book – *Improving Primary Mathematics: Linking home and school* (Winter *et al.*, 2009) – which describes tried and tested examples of activities developed in the HSKE project which can bring the two worlds of home and school closer together to improve learning.

The impact review of the funder (Hughes, 2006) describes how the project team played a central role in the Teaching and Learning Research Programme (TLRP) Initiative on Personalised Learning in 2004, which included a presentation at the DfES and a contribution to the TLRP Commentary (Hughes, 2004). The need for a 'strong partnership between home and school' is one of the five components of personalised learning in the DfES's own subsequent commentary, *A National Conversation about Personalised Learning* (DfES, 2004).

The project team noted that 'the project has a high profile in Wales' (Hughes, 2006) and that it is specifically mentioned in the Welsh Assembly's key document *The Learning Country* (WAG, 2001). The findings from the HSKE project also provide evidence for the Williams review of mathematics in early years and primary school (Williams, 2008: 70), which discusses the importance of parental involvement in a child's learning.

Professor Hughes has been able to build on the work undertaken in this project through an ESRC Professorial Research Fellowship to do further work on learning out of school.

CASE STUDY 15: After-school science and engineering clubs evaluation

As part of the previous Government's commitment to improve the supply of STEM skills (HMT, 2004), the then DfES set up the After School Science and Engineering Clubs (ASSECs) programme in March 2006. Initially 250 schools were funded to run ASSECs over two years (2007-2009). The evaluation of the programme undertaken by academics at Sheffield Hallam University played an important role in demonstrating the impact the clubs were having on the students as well as highlighting the elements and practices that seem most effective. Following a successful pilot of ASSECs in 500 schools across England, it is expected that 2,500 schools will be affiliated to the STEM Clubs Network by the end of March 2012 (STEMNET).

Evaluations of education interventions are often undertaken within the education departments of higher education institutions; however, this is also an area that is often characterised by a high proportion of private sector or not-for-profit research consultancies operating. Examples in the area of STEM include the evaluation of after-school science and engineering clubs discussed below and the national evaluation of the previous Government's *Every Child Counts* (ECC) initiative which has recently been completed and was led by academics at the University of York (Torgerson *et al.*, 2011). The ECC evaluation is an example of a randomised trial which is still relatively uncommon in the English context.

Funder	Principal investigator	Institution	Project team	Budget	Date
DCSF	Ken Mannion, Mike Coldwell	Sheffield Hallam University	Ken Mannion, Mike Coldwell and colleagues from the Centre for Science Education and the Centre for Education and Inclusion (both based at Sheffield Hallam University)	£85,995	October 2007-October 2008

Further info: http://www.dcsf.gov.uk/research/data/uploadfiles/DCSF-RW071.pdf

http://www.stemnet.org.uk/a fter_school_clubs.cfm

What

As part of the previous Government's agenda to improve the supply of skills in STEM areas, in 2006 the Treasury announced funding (£5 million) to pilot 250 After School Science and Engineering Clubs (ASSECs) over two years from 2007 (Mannion and Coldwell, 2008). The aims of the clubs were to:

- enrich, enhance and extend the Key Stage 3 curriculum

- improve attainment in, interactions with and experiences of science among those students already showing interest and ability in these subjects

- improve collaboration between schools, and between schools and industry and the research base

- encourage students to continue their education in STEM beyond GCSE level (BSA, 2008: 3)

The research team explored how the *enabling* aims (aims 1 and 3 above) could lead to the *impact* aims (2 and 4).

As well as the impact of the clubs on attainment and attitudes to participation, the project was commissioned to shed some light on the challenges faced by schools in setting up a club and to offer insights into best practice.

How

The research team worked in 174 of the 245 schools (71 per cent) taking place in the pilot. The evaluation team used multiple methods in order to gain an understanding of the impact of ASSECs. The methods included a pupil survey, two staff surveys (club leaders and staff not involved in the clubs), telephone interviews, case studies, and a survey of schools deciding not to run clubs (Mannion and Coldwell, 2008).

Outcomes and impact

Pat Langford, Director of Programmes at STEMNET describes the impacts of the evaluation in the box below. The evaluation provided the evidence of positive impacts necessary in order to roll out science and engineering clubs to every school as well as providing important feedback in terms of engaging girls in the clubs.

Lord Sainsbury's 'Race to the Top' report recommended that, subject to a positive evaluation of the After School Science and Engineering Club pilot there should be a STEM Club in every secondary school within the next five years. STEMNET and DCSF agreed that the evaluation had supported this expansion because of the evidence of very many positive impacts and outcomes in the pilot.

However, evidence in the evaluation did also highlight that a growing tendency in some clubs to pursue schemes and activities around cars, robots and rocket themes could be seen as unappealing for girls and this was reflected in falling numbers of girls regularly participating in Clubs. We have fed this information back into club schools when carrying out support visits and have suggested activity ideas with more universal appeal. We have also been able to focus on the language used to promote club activities and how this can be adjusted to appeal to both genders. This has been particularly useful, especially where club leaders hadn't given this aspect of engaging the participants much consideration.

Pat Langford
Director – Programmes, STEMNET

4.6 STEM research programmes

Alongside the individual projects described above, there are three education research programmes funded in the main by the Economic and Social Research Council (ESRC) which include a considerable amount of work in the area of STEM. These three programmes are outlined below. We have included these programmes as they represent a significant monetary investment in the area of STEM education research totalling some £10 million, highlighting the importance of this area for the funding council and ultimately government.

ESRC Targeted Initiative on Science and Mathematics Education

This targeted initiative worth almost £3 million was announced in 2006 to address key challenges in science and mathematics education in the UK. The ESRC, in collaboration with other Research Councils UK partners and the Institute of Physics, was particularly interested in research that had the potential to lead to improvements in attainment and participation:

The overall aims of the initiative are to support the development of research-informed policy and practice with the potential to make a significant contribution to ensuring that future generations have the mathematical and scientific skills required by the UK as a competitive knowledge economy, that there is a flow of highly skilled graduates for future research, teaching, business and other careers requiring such skills, and that future citizens have the capacity to engage more fully in debates about, and to benefit from, science and technology. (ESRC, 2006: 1)

The five projects which make up this targeted initiative are briefly described below:

A) ASPIRES (Science Aspirations and Career Choice: Age 10-14) – King's College London

This project, led by Professor Louise Archer at King's College London, is a five-year longitudinal project which has three parts. Using questionnaires, focus groups and classroom intervention methods, this project analyses the impact of teaching about science-related careers at Key Stage 3 on later educational choices made. The first part will analyse what factors (for example peers, parents and schools) influence subject choices during the Key Stage 3 phase (age 10-14) and whether these interact differently depending on gender, class and ethnicity. The second part looks at how science-related careers are demonstrated during this age range. This part of the project will involve working with teachers to develop effective strategies for teaching about these careers. The final phase will build on the previous two phases to explore whether and how educational and career aspirations are affected by interventions based around teaching about science-based careers. (Professor Louise Archer, Dr Jennifer DeWitt, Professor Justin Dillon, Professor Jonathan Osborne, Billy Wong)

B) ICCAMS (Increasing Competence and Confidence in Algebra and Multiplicative Structures) – King's College London

Also based at King's College London, this project will develop ways of increasing engagement and attainment in the areas of algebra and multiplicative structures at Key Stage 3. The project, led by Dr Jeremy Hodgen, has two main parts.

Part one involved a large scale survey on attainment and attitudes (and what factors affect these) of students in Key Stage 3 and then data analysis of the results collected. Using questions first used in a survey in the 1970s will allow comparisons of standards and abilities to be made over time. Initial findings from this phase show that while there has been an increase in the attainment in national assessment exams over the period since 1976, this does not appear to be related to improvements in mathematical understanding (Hodgen *et al.*, 2009).

Part two will be informed by the survey undertaken in part one of the project (such as where it highlighted areas of misunderstanding and difficulty). With a small group of eight teacher-researchers a design research approach will be taken (see case study 11 above for more on this methodology). The teams will explore the potential of using formative and diagnostic assessment to enhance enjoyment and attainment in algebra and multiplicative reasoning at Key Stage 3, as well as investigating how teachers can engage with research to improve their practice in these areas. The wider applicability of these approaches will be tested in a wider range of schools. (Dr Jeremy Hodgen, Professor Margaret Brown, Dr Robert Coe, Dr Dietmar Küchemann)

C) EISER (Enactment and Impact of Science Education Reform) – University of Leeds

Led by Dr Jim Ryder at the University of Leeds, this project (part funded by the Gatsby Charitable Foundation) considers the changing nature of the science curriculum for 14- to 16-year-olds and how teachers are responding to this in schools. The project is a three-year longitudinal study which explores the impacts of the science curriculum changes in 2006 (Banner *et al.*, 2009). The work combines quantitative analysis of the National Pupil Database with 19 in-depth case studies (including interviewing children and teachers) to investigate the impact of curriculum changes on pupil attainment, attitudes and participation rates in post-16 science courses. (Dr Jim Ryder, Helen Morris, Professor James Donnelly, Dr Matt Homer, Dr Indira Banner)

D) epiSTEMe (Effecting Principled Improvement in STEM Education: Student Engagement and Learning in Early Secondary-School Physical Science and Mathematics) – University of Cambridge

The aim of this project is to develop a new approach to teaching in the physical sciences (physics and chemistry) and mathematics. The project is being led by Professor Kenneth Ruthven (University of Cambridge) and will develop an intervention which will enable deeper understanding and engagement in these subjects. The design of the intervention will draw on a range of different approaches (concerned with conceptual growth, identity formation, classroom dialogue, collaborative learning, and relations between everyday and formal understanding) and will provide a tried and tested resource for teachers. The three phases of the project involve working with teacher-researchers to develop and pilot the intervention (phase 1), implementing and revising the intervention (phase 2), and evaluating the revised implementation with the original teacher-researchers alongside initial implementation with a new teacher-researcher group (phase 3). (Professor Kenneth Ruthven, Professor Christine Howe, Professor Neil Mercer, Dr Keith Taber, Dr Riikka Hofmann, Dr Stefanie Luthman, Fran Riga)

E) UPMAP (Understanding participation rates in post-16 Mathematics And Physics) – Institute of Education, University of London

This project is led by Professor Michael Reiss at the Institute of Education, University of London and aims to uncover which factors influence post-16 participation in mathematics and physics. This project is described in more detail on pages 35 and 36 as case study 4. (Professor Michael Reiss, Professor Celia Hoyles, Tamjid Mujtaba, Dr Bijan Riazi-Farzad, Dr Melissa Rodd, Professor Anna Sfard, Professor Shirley Simon, Dr Fani Stylianidou)

Teaching and Learning Research Programme

The **Teaching and Learning Research Programme** (TLRP) was the largest education research programme in the UK. A generic portfolio of projects looking at education across the lifecourse ran from 2000 to 2009. Dissemination and impact work took place across the entire period. The cumulative programme budget totalled some £31 million, with major contributions from the Higher Education Funding Council for England, government education departments in England, Northern Ireland, Scotland and Wales, Research Councils UK and the Joint Information Systems Committee (JISC). TLRP was managed by the Economic and Social Research Council. TLRP aims to improve outcomes for learners of all ages in teaching and learning contexts across the UK, which includes both the acquisition of skill, understanding, knowledge and qualifications and the development of attitudes, values and identities relevant to a learning society. The programme is committed to working in partnership with other relevant organisations and to enhancing capacity for all forms of research on teaching and learning, and for research-informed policy and practice.

Below are listed the TLRP projects that have researched issues relating to the STEM agenda and so are relevant to this review. More information regarding the projects listed below can be found via the TLRP website (www.tlrp.org).

TLRP projects relating to STEM
(note that Scottish and Welsh institutions are included in this list)

Learning Scientific Concepts in Classrooms Groups at Key Stage 1 – Stephen Hodgkinson, University of Brighton

5-14 Mathematics in Scotland: The Relevance of Intensive Quantities – Professor Christine Howe, University of Cambridge (Professor Christine Howe, Professor Terezinha Nunes, Professor Peter Bryant)

Understanding the System: Techno-Mathematical Literacies in the Workplace – Professor Celia Hoyles, Institute of Education, University of London (Professor Celia Hoyles, Professor Richard Noss, Dr Phillip Kent, Dr Arthur Bakker, Chand Binder)

Home-School Knowledge Exchange in Primary Education – Professor Martin Hughes, University of Bristol (see case study 14 above) (Professor Martin Hughes, Professor Andrew Pollard, Professor Guy Claxton, Professor David Johnson, Jan Winter, Jane Andrews, Anthony Feiler, Pamela Greenhough, Elizabeth McNess, Marilyn Osborn, Leida Salway, Mary Scanlan, Vicki Stinchcombe, Wan Ching Yee)

The Use of ICT to Improve Learning and Attainment through Interactive Teaching – Dr Steve Kennewell, Swansea Metropolitan University (Dr Steve Kennewell, Dr Gerran Thomas, Dr Richard Thorpe, Dr John Parkinson, Dr Gary Beauchamp, Dr Howard Tanner, Sonia Jones, Nigel Norman, Dr Alex Morgan, Lynne Meiring, Sarah Duncan)

Towards Evidence-Based Practice in Science Education – Professor Robin Millar, University of York (Professor Robin Millar, Professor John Leach, Professor Jonathan Osborne, Dr Mary Ratcliffe)

Role of Awareness in the Teaching and Learning of Literacy and Numeracy in Key Stage 2 – Professor Terezinha Nunes, University of Oxford (Professor Terezinha Nunes, Professor Peter Bryant, Dr Jane Hurry)

INTERPLAY: Play, Learning and ICT in Pre-School Education – Dr Lydia Plowman, University of Stirling (Dr Lydia Plowman, Dr Christine Stephen)

InterActive Education: Teaching and Learning in the Information Age – Professor Rosamund Sutherland, University of Bristol (Professor Rosamund Sutherland, Dr Susan Robertson, Dr Peter John)

Keeping Open the Door to Mathematically-Demanding FE&HE Programmes – Professor Julian Williams, University of Manchester (Professor Julian Williams, Dr Pauline Davis, Geoff Wake, Su Nicholson, Dr Graeme Hutcheson, Dr Laura Black, Dr Maria Pampaka, Dr Paul Hernandez-Martinez)

Enhancing 'Skills for Life': Adult Basic Skills and Workplace Learning – Professor Alison Wolf, King's College London (Professor Alison Wolf, Professor Karen Evans, Professor John Bynner, Tom Jupp)

Technology Enhanced Learning

The Teaching and Learning Research Programme (TLRP) has entered a new phase – **Technology Enhanced Learning** (TEL) – providing funding of about £12 million for eight interdisciplinary projects running from 2007-2011. TLRP-TEL is jointly managed by ESRC and the Engineering and Physical Sciences Research Council. The aim of TEL research is to improve the quality of formal and informal learning, and to make accessible forms of knowledge that were simply inaccessible before. But research does not translate easily into practice, at school, in higher education or in the workplace. The forms of pedagogy that characterise learning in these settings have remained more or less invariant even when radical technologies have been introduced.

Education is now coming to terms with the importance of supporting individuals in developing the capability to produce their own knowledge, rather than merely consume the knowledge of others. There is a nascent attempt to develop learners' skills of enquiry, analysis, synthesis, knowledge construction and collaboration. These kinds of learning – and these kinds of new knowledge – are difficult, and sometimes impossible to address broadly with traditional technologies. Only in informal settings are such novel strategies and knowledge commonplace, risking a widening of the gap between what is actually required by citizens and employees, and what formal educational systems offer. Technology, suitably designed and deployed, can help to close that gap. This is the key challenge of TEL research.

TEL projects that relate specifically to STEM

Though all the projects are to some extent STEM related given their technology focus, two specifically concern science and mathematics in school:

MiGen: Intelligent Support for Mathematical Generalisation – Professor Richard Noss, Institute of Education, University of London (Professor Richard Noss, Professor Alexandra Poulovassilis, Professor Celia Hoyles, Dr George Magoulas, Dr Niall Winters, Dr Ken Kahn)

Personal Inquiry (PI): Designing for Evidence-Based Enquiry across Formal and Informal Settings of Learning – Professor Mike Sharples, University of Nottingham (Professor Mike Sharples, Professor Eileen Scanlon, Dr Shaaron Ainsworth, Professor Steve Benford, Professor Grainne Conole, Dr Charles Crook, Dr Ann Jones, Professor Karen Littleton, Professor Claire O'Malley, Dr Paul Mulholland)

5. Summary and recommendations

The examples detailed in the previous section demonstrate the broad range of research based in education departments in higher education institutions which underpins improvements in STEM teaching and learning in England's schools and colleges. This section summarises the education research in science, mathematics and technology education uncovered by our research and outline recommendations as to where we feel, based on the evidence in this report, further progress might be made.

A range of methodologies and approaches are adopted in STEM research, reflecting the diversity of goals. Many studies used mixed methods employing both quantitative and qualitative techniques. An example is case study 1 that looked at the demand and supply of STEM subjects in the south west of England. This project used quantitative analysis of large datasets to explore where the 'leaks' were in the supply of STEM skills during students' school and college careers. It went on to contextualise the emerging themes through interviews with teachers in order to 'validate, clarify and interpret' the findings from the data (SLIM, 2009e: 12).

Methods used in the case studies presented in this report also include systematic reviewing, developmental work, action research and evaluation. Systematic reviewing (such as that used in case studies 2 and 3) is crucial in securing the knowledge base and ensuring future work builds on what is already known. Case study 13 involved developmental work which applied research findings to develop innovative products and resources – in this case, a tool enabling more effective assessment strategies. Action research projects and evaluations are discussed further overleaf.

There is also evidence of innovative methodological developments, such as the use of design-based research. Design-based research moves theory to practice. It takes as a starting point robust findings from previous research (for example, as to what might be the most effective way to teach or assess) and then sets out to design a curriculum or tool to enhance learning based on these principles. The cycle of design, develop and test is iterative, with new designs altered according to feedback from appropriate users.

Research concerning the whole age range of learners has been reported. Engagement early on in the school career is critically important for future participation in STEM. It is therefore good to find high-quality research in the case studies aimed at increasing understanding of teaching and learning, and ultimately at improving attainment, at primary school (in case studies 6 and 7), and even in the early years (as in case study 5).

There is quite a lot of research in the area of design and technology but it is often based outside of education departments and is not as visible as a part of the broader education research community. Much of the work in design and technology is focused on practice. This may be symptomatic of funding streams as this research tends to be funded by foundations and government agencies, rather than research councils.

Whilst the focus of this work was to look at research rather than at continuing professional development (CPD), there is a considerable amount of action research taking place in schools and higher education institutions which has elements of both CPD and research. Often these projects involve researchers and practitioners working together to reflect on practice so as to develop teaching approaches and advance pedagogy. Action research projects can also be based around curriculum enhancement as in case study 12. As reflected in the quotes included in the case studies, teachers directly involved in this type of project often report significant positive impacts on their practice. In recent years there has been a growing emphasis on evidence-informed practice and in engaging practitioners with the existing knowledge base, as well as supporting them to undertake their own research projects. The forthcoming Master's in Teaching and Learning is an important development with regard to this. Having more teachers engaged with research could also lead to more bottom-up work (that proposed by teachers) taking place, which would help ensure that research is tightly linked to addressing the correct challenges.

In action research projects, the impacts reported by practitioners directly involved in projects are obviously important in their own right. But in order to maximise the full potential of work undertaken it is also important for teacher-researchers and institution-researchers to have time to reflect on the potential relevance of their findings beyond their own classrooms. One example of this is the research project led by academics at the University of Winchester (case study 5) which provided a framework for several action research projects undertaken with teachers in early years settings. The findings from these projects were then developed into a CPD training unit – Fostering Curiosity in Early Years Science – which is free to download from the AstraZeneca Science Teaching Trust website.

Many of the case studies include good examples of significant research findings being followed up and disseminated effectively. Dissemination strategies obviously differ depending on the focus of the research but examples used in the case studies include engaging with policymakers through seminars and undertaking follow-up work in terms of developing resources. This may involve the development of a CPD unit which can be used as a training resource in schools, such as in case study 5. The project funded by the National Centre for Excellence in the Teaching of Mathematics (NCETM) on using interactive whiteboards (case study 8) was required to disseminate its findings through the NCETM as well as more broadly – through, for example, developing an online database used as a central resource for teachers of mathematics and through presentations at national and regional events. The findings from the Girls in Physics project (case study 3) were disseminated to 100 schools through a large-scale action research project coordinated by the then DCSF.

This approach to dissemination is perhaps likely to be more effective than more traditional strategies (such as presenting findings at practitioner conferences) in terms of effecting change in the classroom.

The recent developments with regard to valuing research impact in the Research Excellence Framework (REF) should provide stronger incentives for academics to engage in more knowledge transfer activity.

Evaluation is a growing area in education research as government departments and related agencies are increasingly required to evaluate initiatives in order to justify their investment decisions. One effective method of determining impact is using randomised controlled trials (RCTs); however, there are not many of these currently taking place in England. One notable exception is the Every Child Counts evaluation recently completed by a team led by academics at the University of York (Torgerson *et al.*, 2011). RCTs are not an appropriate methodology for evaluating all initiatives but in some instances they are the best way of determining the impact of an intervention. RCTs are also very expensive, but then so are some initiatives and it is therefore still cost effective to determine the likely impact before rolling out.

There is a considerable amount of work taking place in departments examining pedagogy and ways of improving teaching and learning. This is reassuring given the importance of teacher (and teaching) quality in affecting student outcomes. Many projects looking at pedagogy are working in related areas (as demonstrated in the case studies), for example the use of dialogue and using collaborative approaches to embed deeper learning. This is positive as it demonstrates that knowledge is cumulative and that projects are building on past work.

Recommendations

This report has identified a set of issues that lead to the following recommendations.

1   More work should be undertaken that aims to scale up and disseminate research findings in order to ensure that maximum value is achieved from projects. Follow-up grants are useful for knowledge transfer activities.

2   There is a need to explore more effective dissemination strategies and enhance the capacity of academics to deliver dissemination activities, both in terms of skills required and time available to undertake them.

3   A more diverse set of research methods should be mobilised as appropriate to the questions under study: for example, more use could be made of randomised controlled trials (RCTs) when this form of evaluation is most appropriate.

4   A thorough mapping of STEM education research taking place outside of education departments should be undertaken, in order to ensure that such research is not isolated from work undertaken in education departments.

5   Limited evidence was found of policy, historical and international work. More work in these areas would avoid the risk of parochialism and loss of previous acquired knowledge. However, this requires special interdisciplinary expertise that needs to be fostered.

6   Investment is needed in longitudinal studies, which would allow researchers to track individuals over time with the aim of teasing out causal links between input and output variables.

7   There is considerable potential for more projects to draw on a range of linked datasets, from large-scale national datasets (such as the National Pupil Database) along with more in-depth work undertaken with a subset of schools (or colleges) and/or students.

8   Better ways should be developed to capture work done by teachers, including action research projects and work undertaken at Master's and doctoral level. This would enable teacher-researchers to build on existing knowledge and past experiences, as well as help make this type of research more widely accessible, for example in a national electronic database of theses and final reports.

9   Better coordination among projects is needed to ensure the research is cumulative and builds on the existing knowledge base, and there is not duplication of effort and funding. Reports such as this one should assist in this process.

6. References

Amorim AC, Ryan C (2005) 'Deleuze, action research and rhizomatic growth' *Educational Action Research* 13(4) pp. 581-594

Askew M, Hodgen J, Hossain S, Bretscher N (2010) *Values and variables: Mathematics education in high-performing countries.* London: Nuffield Foundation. Online at: http://www.nuffieldfoundation.org/values-and-variables-mathematics-education-high-performing-countries

Ball SJ (2004) 'Performativities and fabrications in the education economy' in Ball SJ (ed) *The RoutledgeFalmer reader in sociology of education.* London: RoutledgeFalmer pp. 143-155

Banner I, Ryder J, Donnelly J (2009) *The role of teachers' priorities for science education in the enactment of science curriculum reform.* A paper presented at the European Science Education Research Association conference, Istanbul, September 2009

Barlex D (2003) *Creativity in Crisis? Design and Technology at KS3 and KS4.* A report from a joint invitation seminar held 10 September 2002 by Nuffield Design and Technology in conjunction with the Design and Technology Association

Becta (2008) *Harnessing Technology Review 2008: The role of technology and its impact on education – Full report.* Coventry: Becta. Online at: http://publications.becta.org.uk/download.cfm?resID=38751

Department for Business, Innovation and Skills (2009) *Higher Ambitions.* London: BIS. Online at: http://www.bis.gov.uk/policies/higher-ambitions

Black P, Wiliam D (1998) 'Assessment and classroom learning' *Assessment in Education* 5(1) pp. 7-74

British Science Association (2008) *Science and Engineering Club Handbook.* Online at: http://www.britishscienceassociation.org/forms/download/Clubs/080612_Clubs_handbook_PUBLIC.pdf

Brooks R, Tough S (2006) *Assessment and Testing: Making space for teaching and learning.* London: ippr. Online at: http://www.ippr.org/publications/55/1554/assessment-and-testingmaking-space-for-teaching-and-learning?siteid=ippr

Brown P, Lauder H, Ashton D (2008) *Education, globalisation and the knowledge economy: A Commentary by the Teaching and Learning Research Programme.* London: TLRP. Online at: http://www.tlrp.org/proj/phase111/assoc_brown.html

Curriculum, Innovation and Development (no date) 'About Curriculum Innovation and Development' University of Wolverhampton website: http://www.wlv.ac.uk/default.aspx?page=15702

Clark H, Egan B, Fletcher L, Ryan, C (2006) 'Creating case studies of practice through Appreciative Inquiry' *Educational Action Research* 14(3) pp. 407-422

Cobb P, Confrey J, diSessa A, Lehrer R, Schauble L (2003) 'Design Experiments in Educational Research' *Educational Researcher* 32(1) pp. 9-13

Cockburn A, Littler G (2008) *Mathematical Misconceptions: a Guide for Primary Teachers.* London: Sage Publications Ltd

Coyne J, Goodfellow JM (2008) *Report to the Secretary of State, DIUS, on universities' links with schools in STEM subjects.* Online at: http://www.bis.gov.uk/policies/higher-education-debate

Daly A, Grant L, Bultitude K (2009) *Girls Into Physics: Action Research.* Ormskirk: Edge Hill University. Online at: http://www.dcsf.gov.uk/research/data/uploadfiles/DCSF-RR103(R).pdf

Davies D (2011) *Using pupil-generated e-portfolios to assess scientific enquiry skills at age 11,* A paper presented at European Science Education Research Association conference, Lyon, France, September 2011

Design Based Research Collective (n.d.) 'What is design-based research?' DBRC website: http://www.designbasedresearch.org/dbr.html

Department for Education (2010) GCE/Applied GCE A/AS and Equivalent Examination Results in England, 2009/10 (Provisional). Statistical First Release SFR31/2010. Online at: http://www.education.gov.uk/rsgateway/DB/SFR/s000964/index.shtml

Deleuze G, Guattari F (1987) *A Thousand Plateaus: Capitalism and schizophrenia.* London: Athlone

Department for Education and Skills (2004) *A National Conversation about Personalised Learning.* London: DfES. Online at: http://nationalstrategies.standards.dcsf.gov.uk/downloader/77d889a11f57f07a95375a2f622e6d48.pdf

DfES (2006) *The Science, Technology, Engineering and Mathematics (STEM) Programme Report.* London: DfES. Online at: http://webarchive.nation-alarchives.gov.uk/20100210151716/http://www.dcsf.gov.uk/hegateway/hereform/stem/programmereport.cfm

Dyson A, Robson E (1999) *School, family, community: Mapping school inclusion in the UK.* Leicester: Youth Work Press

Engestrom Y (2001) 'Expansive learning at work: towards and activity theoretical reconceptualisation' *Journal of Education and Work* 14(1) pp. 133-156

Economics and Social Research Council (2006) *Targeted Research Initiative on Science and Mathematics Education: Call for outline research proposals.* Swindon: ESRC

Fletcher L (2006) Final Report to the AZSTT Trustees: Teachers and Young Children Exploring their Worlds Together

Gill T, Vidal Rodeiro CL, Bell JF (2009) *The Complexities Surrounding the Uptake of A-level Physics.* A paper presented at the British Educational Research Association conference, University of Manchester, September 2009. Cambridge Assessment: Cambridge

Gorard S, See B (2009) 'The impact of socio-economic status on participation and attainment in science' *Studies in Science Education* 45(1) pp. 93-129

Harlen W (2008) 'Science as a key component of the primary curriculum: a rationale with policy implications' *Perspectives on Education 1 (Primary Science): 4–18.* Online at: www.wellcome.ac.uk/perspectives

Hodgen J, Küchemann D, Brown M, Coe R (2009) Secondary students' understanding of mathematics 30 years on. A paper presented at the British Educational Research Association conference, University of Manchester, September 2009

Hollins M, Murphy P, Ponchaud B, Whitelegg E (2006) *Girls in the Physics Classroom: A Teachers' Guide for Action.* London: Institute of Physics. Online at: www.iop.org

HMT (2004) *Science & innovation investment framework 2004-2014.* London: HM Treasury. Online at: http://www.hm-treasury.gov.uk/spending_sr04_science.htm

HMT (2006) *Science & innovation investment framework 2004-2014: Next steps.* London: HM Treasury

Hughes M (2004) 'Home-School Knowledge Exchange' in Pollard A, James M (eds) *Personalised Learning: A commentary by the Teaching and Learning Research Programme* Swindon: Economic and Social Research Council

Hughes M (2006) Home-School Knowledge Exchange and Transformation in Primary Education. ESRC End of Award Report, L139251078. Swindon: ESRC. Online at: www.esrcsocietytoday.ac.uk

Hughes M, Greenhough P, Yee WC, Andrews J, Winter J, Salway L (2007) 'Linking children's home and school mathematics' *Educational and Child Psychology* 24(2) pp. 137-145

Jansson, DG, Smith SM (1991) 'Design fixation' *Design Studies* 12(1) pp. 3-11

Kimbell R (2000a) 'Creativity in crisis' *Journal of Design and Technology Education* 5(3) pp. 206-211

Kimbell R (2000b) 'Creativity, risk and the curriculum' *Journal of Design and Technology Education* 5(1) pp. 3-4

Kimbell R, Miller S, Bain J, Wright R, Wheeler T, Stables, K (2004) *Assessing Design Innovation: Final report* London: Goldsmiths, University of London. Online at: http://www.gold.ac.uk/static/teru/pdf/assessingDesignInnovation.pdf

Kimbell R, Wheeler T, Stables K, Shepard T, Martin F, Davies D, Pollitt A, Whitehouse G (2009) *e-scape portfolio assessment: a research & development project for the Department of Children & Family Services – phase 3 report.* London: Technology Education Research Unit, Goldsmiths, University of London. Online at: http://www.gold.ac.uk/media/e-scape_phase3_report.pdf

Kroto H (2007) 'The wrecking of British science' *The Guardian*, 22 May 2007. Online at: http://www.guardian.co.uk/science/2007/may/22/highereducation.education

Kutnick P, Ota C, Berdondini, L (2008) 'Improving the effects of group working in classrooms with young school-aged children: facilitating attainment, interaction and classroom activity' *Learning and Instruction* 18(1) pp. 83-95

Loxley P, Dawes L, Nicholls L, Dore B (2010) *Teaching Primary Science: Promoting Enjoyment and Developing Understanding.* Essex: Pearson Education

Mannion K, Coldwell M (2008) After-school Science and Engineering Clubs Evaluation. Research Report DCSF-RW071. London: DCSF

McLellan R, Nicholl B (2008) *Creativity in crisis in D&T: Are classroom climates conducive for creativity in English secondary schools?* A Paper presented at the British Educational Research Association conference, Heriot-Watt University, Edinburgh, 3-6 September 2008

Mercer N (2007) Dialogic teaching in science classrooms: Non-Technical Summary (Research Summary). ESRC End of Award Report, RES-000-23-0939-A. Swindon: ESRC

Mercer N, Dawes L, Staarman JK (2009) 'Dialogic teaching in the primary science classroom' *Language and Education* 23(4) pp. 353-369

Miller D, Glover D, Averis D (2004) Enhancing Mathematics Teaching through New Technology: The use of the interactive whiteboard. Summary of a report made to the Nuffield Foundation on completion of a funded two year project (April 2002-March 2004). Keele: Department of Education, University of Keele. Online at: http://www.keele.ac.uk/education/research/interactive-whiteboard/

Miller D, Averis D, Door V, Glover D (2005) *From Technology to Professional Development: How can the use of an interactive whiteboard enhance the nature of teaching and learning in secondary mathematics and modern foreign languages? ICT Research Bursary 2003-04 – Final Report.* Coventry: Becta. Online at: https://content.ncetm.org.uk/itt/sec/KeelePGCEMaths2006/InteractiveWhiteboard&DataProj/Research/BectaReportMiller&co.pdf

Miller D, Glover D (2006) *Interactive whiteboard evaluation for the Secondary National Strategy: Developing the use of Interactive Whiteboards in Mathematics. Final Report.* Online at: http://nationalstrategies.standards.dcsf.gov.uk/node/96272

Miller D, Glover D, Averis D, Door V (2006) *From technology to professional development: How can the use of an interactive whiteboard in initial teacher Education change the nature of teaching and learning in secondary Mathematics and modern languages?* Keele: Department of Education, University of Keele. Online at: http://www.keele.ac.uk/education/research/interactivewhiteboard/

Miller D, Glover D, Averis D (2008) *Enabling enhanced mathematics teaching with interactive whiteboards: Final report for the National Centre for Excellence in the Teaching of Mathematics.* Keele: Department of Education, University of Keele. Online at: http://www.keele.ac.uk/education/research/interactivewhiteboard/

Moll L, Greenberg J (1992) 'Creating zones of possibilities: Combining social contest for instruction' in Moll L (ed) *Vygotsky and Education* Cambridge: Cambridge University Press, pp. 319-348

Moll L, Tapia J, Whitmore K (1993) 'Living knowledge: The social distribution of cultural resources for thinking' in Salomon G (ed) *Distributed Cognitions* Cambridge: Cambridge University Press

Morris M (2007) *Pupil subject choice in schools:* ESRC Commissioned Briefing for Policy Makers. Swindon: Economic and Social Research Council

Moss G, Jewitt C, Levačić R, Armstrong V, Cardini A, Castle F (2007) *The Interactive Whiteboards, Pedagogy and Pupil Performance Evaluation: An Evaluation of the Schools Whiteboard Expansion (SWE) Project: London Challenge DfES Research Report RR816.* Online at: http://www.dcsf.gov.uk/research/data/uploadfiles/RR816.pdf

Murphy C, Fisher R, Wegerif R, Nash T (2010) *Talking Counts: Resource Pack for Talk and Maths at KS1.* Exeter: Graduate School of Education, University of Exeter. Online at: http://education.exeter.ac.uk/projects.php?id=490

Murphy P, Whitelegg E (2006) *Girls in the Physics Classroom: A Review of the Research on the Participation of Girls in Physics.* London: Institute of Physics. Online at: www.iop.org

Nicholl B, McLellan R (2007) '"Oh yeah, yeah you get a lot of love hearts. The Year 9s are notorious for love hearts. Everything is love hearts." Fixation in Pupils' Design and Technology Work (11-16 years)' *Design and Technology Education: An International Journal* 12(1) pp. 34-44

Nicholl B, McLellan R (2008) '"We're all in this game whether we like it or not to get a number of As to Cs." Design and technology teachers' struggles to implement creativity and performativity policies' *British Educational Research Journal* 34(5) pp. 585-600

Nicholl B, McLellan R (2009) '"This isn't my project [work]. It's ... just do it ... you just do research" What student voice reveals about the nature of design and technology lessons in English schools, and the implications this has on their motivation and learning of complex tasks', in Jones A and de Vries M (eds) *International handbook of research and development in technology education.* Rotterdam: Sense Publishers pp. 223-232

Nuffield Foundation (2009) *Mathematics education in countries with high mathematics attainment.* Summary of seminar held on 11 June 2009

Organisation for Economic Co-operation and Development (2007) *PISA 2006: Science Competencies for Tomorrow's World: OECD briefing note for the United Kingdom.* Online at: http://www.oecd.org/dataoecd/16/30/39722183.pdf

Ofsted (2003) *Design and technology in secondary schools: Ofsted subject reports series 2001/02, HMI 815* London: Ofsted. Online at: http://www.ofsted.gov.uk/Ofsted-home/Publications-and-research/Browse-all-by/Education/Curriculum/Annual-Report-2001-02-Ofsted-subject-reports-secondary

Ofsted (2006) *Evaluating mathematics provision for 14-19-year-olds HMI: 2611* London: Ofsted. Online at: http://www.ofsted.gov.uk/content/download/1789/12062/file/Evaluating%20mathematics%20provision%20for%2014-19-year-olds%20(PDF%20format).pdf

Ofsted (2008) *Mathematics: understanding the score – messages from inspection evidence* Reference no: 070063. London: Ofsted. Online at: http://www.ofsted.gov.uk/Ofsted-home/Publications-and-research/Browse-all-by/Documents-by-type/Thematic-reports/Mathematics-understanding-the-score

Piggott J (2008) 'Evaluation Report for the NCETM Funded Interactive Whiteboard Project in Collaboration with Keele University' in Miller *et al.* (2008) *Enabling enhanced mathematics teaching with interactive whiteboards: Final report for the National Centre for Excellence in the Teaching of Mathematics*

Pollitt A, Crisp V (2004) *Could Comparative Judgements Of Script Quality Replace Traditional Marking And Improve The Validity Of Exam Questions?* A paper presented at the British Educational Research Association conference, UMIST, Manchester, September 2004

Ponchaud B (2006) *Yes she can* Report commissioned by the Institute of Physics about girls' engagement with physics. An investigation into schools that are successful at attracting girls to study A-level physics and how this might inform other schools. [*Yes She Can* has not been published but it forms the basis for section 1 of Hollins *et al.* (2006).]

Qualifications and Curriculum Authority (2004) *Developing reasoning through algebra and geometry.* London: QCA

QCA (2007) *Design and technology: Programme of study for key stage 3 and attainment target.* London: QCA. Online at: http://curriculum.qcda.gov.uk/uploads/QCA-07-3331-pDesignTech3_tcm8-398.pdf?return=/key-stages-3-and-4/subjects/design-and-technology/index.aspx%23page2_p

QCA (2008) *A big picture of the curriculum.* London: QCA. Online at: http://nationalstrategies.standards.dcsf.gov.uk/node/258427?uc=force_uj

Roberts G (2002) *SET for Success: The supply of people with science, technology, engineering and mathematics skills.* Online at: http://www.hm-treasury.gov.uk/ent_res_roberts.htm

Robinson K (1999) *All Our Futures: Creativity, Culture and Education* Report to the Secretary of State for Education and Employment and the Secretary of State for Culture, Media and Sport. London: National Advisory Committee on Creative and Cultural Education. Online at: http://www.cypni.org.uk/downloads/alloutfutures.pdf

Royal Society (2007) *The UK's Science and Mathematics Teaching Workforce.* London: Royal Society. Online at: http://royalsociety.org/Education-Policy/Reports/

Sammons P (2007) *School Effectiveness and Equity: Making Connections. A review of school effectiveness and improvement research – its implications for practitioners and policy makers.* Reading: CfBT Education Trust. Online at: http://www.cfbt.com/evidenceforeducation

Scott P (2008) 'Talking a way to understanding in science classrooms' in Mercer N, Hodgkinson S (eds) *Exploring Talk in School.* London: Sage pp. 17-36

SLIM [Skills and Learning Intelligence Module] (2009a) *STEM: Demand and Supply of Skills in the South West Evidence Report 3: Supply of STEM Skills in the South West.* Exeter: SLIM. Online at: http://www.swslim.org.uk/

SLIM (2009b) *STEM: Demand and Supply of Skills in the South West: Key Findings and Recommendations.* Exeter: SLIM. Online at: http://www.swslim.org.uk/

SLIM (2009c) *STEM: Demand and Supply of Skills in the South West Evidence Report 1: Policy Context.* Exeter: SLIM. Online at: http://www.swslim.org.uk/

SLIM (2009d) *STEM: Demand and Supply of Skills in the South West Evidence Report 2: Employer Demand for STEM Skills.* Exeter: SLIM. Online at: http://www.swslim.org.uk/

SLIM (2009e) *STEM: Demand and Supply of Skills in the South West Evidence Report 4: Stakeholder Views.* Exeter: SLIM. Online at: http://www.swslim.org.uk/

Smith A (2004) *Making Mathematics Count: The report of Professor Adrian Smith's Inquiry into Post-14 Mathematics Education.* Online at: http://www.mathsinquiry.org.uk/report/MathsInquiryFinalReport.pdf

Sturman L, Ruddock G, Burge B, Styles B, Lin Y, Vappula H (2008) *England's Achievement in TIMSS 2007: National Report for England.* Slough: NFER. Online at: http://www.nfer.ac.uk/publications/TMO01/

South West Regional Skills Partnership (2007) *South West Regional Skills Partnership: Statement of Priorities 2007-2010.* West Monkton, Somerset: SWRSP. Online at: http://library.swresb.co.uk/library/detail.php?id=279&orderBy=&fieldName=&catID=50&page=2

Swan M (2005) *Improving Learning in Mathematics: Challenges and Strategies.* London: Department for Education and Skills Standards Unit. Online at: https://www.ncetm.org.uk/files/224/improving_learning_in_mathematicsi.pdf

Swan M (2006) *Collaborative Learning in Mathematics: A challenge to our beliefs and practices.* London: NRDC and NIACE.

Swan M, Wall S (2005) *Improving Learning in Mathematics* (multimedia publication – DVD, teaching materials, professional development materials etc). London: Department for Education and Skills Standards Unit. Online at: http://www.nationalstemcentre.org.uk/elibrary/collection/282/improving-learning-in-mathematics

Sylva K, Melhuish E, Sammons P, Siraj-Blatchford I, Taggart B with Hunt S, Jelicic H, Barreau S, Grabbe Y, Smees R, Welcomme W (2008) *Final Report from the Primary Phase: Pre-School, School and Family Influences on Children's Development during Key Stage 2 (Age 7-11), DCSF-RB061.* Online at: http://www.dcsf.gov.uk/research/data/uploadfiles/DCSF-RB061.pdf

Training and Development Agency for Schools (2009) '"Bumper year" for numbers of new trainee teachers helps drive up quality'. TDA press release, 18 November 2009. Online at: http://www.epolitix.com/members/member-press/member-press-details/newsarticle/bumper-year-for-numbers-of-new-trainee-teachers-helps-drive-up-quality///sites/training-and-development-agency-for-schools/

Thurstone LL (1927) 'A law of Comparative judgement' *Psychological Review 34*, pp. 273-286

Torgerson CJ, Wiggins A, Torgerson DJ, Ainsworth H, Barmby P, Hewitt C, Jones K, Hendry V, Askew M, Bland M, Coe R, Higgins S, Hodgen J, Hulme C, Tymms P (2011) *Every Child Counts: the independent evaluation executive summary*, DFE-RBX-10-07. Online at: https://www.education.gov.uk/publications/RSG/publicationDetail/Page1/DFE-RBX-10-07

Tough S with Sasia A, Whitty G (2008) *Productive Partnerships? An examination of schools' links with higher education.* Online at: http://www.suttontrust.com/research/productive-partnerships/

Ward TB (1995) 'What's old about new ideas?' in Smith SM, Ward TB, Finke RA (eds) *The creative cognition approach* Cambridge, Massachusetts: MIT Press pp. 157-178

Wegerif R, Littleton K, Dawes L, Mercer N, Rowe D (2004) 'Widening access to educational opportunities through teaching children how to reason together' *Westminster Studies in Education* 27(2) pp. 143-156

Welsh Assembly Government (2001) *The Learning Country, A paving document: A comprehensive education and lifelong learning programme to 2010 in Wales.* Online at: http://wales.gov.uk/topics/educationandskills/publications/guidance/learningcountry/?lang=en

Williams P (2008) *Independent Review of Mathematics Teaching in Early Years Settings and Primary Schools: Final Report.* Online at: http://publications.teachernet.gov.uk/eOrderingDownload/Williams%20Mathematics.pdf

Wilson F, Miller D (2008) *Enabling enhanced Mathematics teaching with interactive whiteboards.* National Teacher Research Panel – Conference Summary.

Winter J, Salway L, Yee WC, Hughes L (2004) 'Linking Home and School Mathematics: The Home School Knowledge Exchange Project' *Research In Mathematics Education* 6 pp. 59-75

Winter J, Andrews J, Greenhough P, Hughes M, Salway L, Yee WC (2008) *Improving Primary Mathematics: Linking home and school.* London: Routledge