

Student attitudes, engagement and participation in STEM subjects

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Overview of the report

This report has been prepared as part of the work being undertaken by the Royal Society's Vision Project, which aims to set out a vision for how the UK might achieve inspiring, high-performing education systems which can deliver a radical shift in the population's understanding, engagement with and appreciation of mathematics and science by 2030.

This report addresses four questions:

1. What does the evidence say about student attitudes, engagement and participation in STEM subjects?
2. How can mathematics and science education be made most enjoyable, rewarding and effective?
3. What types of evidence need to be collected in future in order to assess more reliably students' choices and the reasons for these?
4. How should research and intervention strategies evolve to collect this evidence?

The report consists of two sections. The first is a review of the literature in the area. The second draws on the findings of the review to provide a commentary on possible future directions for work on student attitudes, engagement and participation in STEM subjects in the next 15-20 years, and implications for mathematics and science education.

Executive summary

Commentary on the future

General considerations

1. Countries seen as successful in STEM have initiated a strategic mix of policies and actions, and one outcome of this is that it can be difficult to identify the effects of individual actions.
2. Policies and practice from other countries provide a potentially informative perspective, rather than something for direct transfer. The art is in distilling out from what appears to be successful in other countries that which can be adapted and adopted in a different country.
3. There are considerable gaps in the research evidence base, and the most comprehensive evidence from the review focuses on describing what happens. There is considerably less evidence on explanations and causal factors.
4. Initiatives that might increase participation, and therefore be deemed to be successful at one level, may not necessarily increase engagement, thus failing at another level.

Systemic factors

5. Any major review of the structure of the education system and the curriculum in relation to mathematics and science provision in England should seek to develop alternative pathways for students from the age of fourteen onwards. These should take the form of academic pathways and vocational pathways, with both STEM and non-STEM routes in each pathway. There should be requirement to gain qualifications at a specified minimum level in mathematics and science. A review should also seek to develop an upper secondary level (post-16) curriculum that built on the preceding pathways to offer both breadth and depth of study. Such change would require the active support of a wide range of stakeholders, including government, policy-makers, professional societies, teaching bodies, employers, universities and parents.
6. There is no strong evidence to suggest that STEM-related subjects should have a higher priority than other subjects, as proposed, for example by supporters of a STEAM (STEM plus Arts) curriculum. Rather the subjects should form part of a balanced baccalaureate-type curriculum, irrespective of whether the emphasis is on STEM subjects or not.
7. An academic track in a baccalaureate-type curriculum might comprise of a core of English, mathematics, science, an arts/humanities subject, and an additional language, with other options available depending on interests. A vocational pathway would also comprise a core of subjects with options, but with an approach that is more applied in nature and more closely related to the world of work. In creating new pathways, it will be important to have more diversity, particularly at the post-16 level, such that there are attractive options for those who do not want to take academic A-levels or study STEM subjects at university level.

8. A number of systemic changes are desirable in relation to the provision of more and better careers education. Careers awareness should be fully embedded into the mathematics and science national curricula and supported by the development of a range of resources and provision being made for appropriate CPD. A co-ordinated programme of STEM careers awareness needs to extend beyond provision for students in schools in order to address imbalances the 'science capital' of students, particularly those currently under-represented groups in STEM. (Students with high science capital are normally from socially advantaged backgrounds where they have a close family member or friend with STEM qualifications and working in STEM-related areas, and science-related leisure interests.) Such a programme should include school-level strategies to involve families in mathematics and science, strategies such as mentoring and work placements to foster interaction between students and STEM role models, and enrichments programmes linking students to local projects related to STEM. Beyond school, awareness campaigns could be launched to improve public understanding of STEM-related career options.
9. It is highly desirable that a dedicated national STEM database is established to serve two functions. Firstly, it would pull together a range of STEM-related data, such as numbers taking mathematics and science subjects at various levels in the education system. Such a database would enable systematic monitoring and dissemination of data, and also form a basis for the setting of targets for participation in mathematics and science for a variety of different groups of young people. It would also provide an evidence base for incentives, such as, for example, scholarships and bursaries to support under-represented groups. Secondly, a STEM database would form a central repository for reports on STEM-related matters and STEM research. This would provide a very valuable resource for future work, and help address the challenge of identifying the large quantity of 'grey' literature on attitudes, engagement and participation in STEM subjects (i.e. literature produced by government, charities, academics, business and industry, but which is not controlled by commercial publishers). The existence of such a database would also assist with the identification of instruments to assess attitudes and engagement.
10. Consideration should be given to adopting some of the strategies that have been effective in other countries, including raising the minimum requirements for university entrance in mathematics and science; funding programmes that make it possible for people who have left the 'STEM pipeline' to re-enter it; and by implementing policies to improve the quality of STEM teaching and the career progression of STEM teachers.

School factors

11. The evidence indicates students are more likely to pursue post compulsory study of the physical sciences if they are taught in 11-18 schools, rather than in 11-16 schools. However, geographic and financial constraints suggest that it is not feasible to make all schools 11-18 schools, unless the school leaving age were to be raised to 18. This suggests that the way ahead lies in developing STEM focused targeted interventions to bridge the transition for students moving from 11-16 schools into further education establishments.

12. In the light of the evidence on gender effects and post-compulsory participation, co-educational secondary schools should be encouraged to teach mathematics and science in single-sex student groupings. Further research should also be conducted into the effects of teaching mathematics and science in single-sex groupings.
13. Schools should ensure that their science curriculum reflects ways in which science is used in everyday life and the world of work, and opportunities should be taken to link subject teaching to careers involving STEM.
14. Schools should take a number of actions in relation to their careers provision and guidance, and ensure STEM subject specialist teachers are involved in giving careers advice. Subject resources and careers resources should be examined to ensure that they reflect the range of careers open to people with STEM qualifications, and provide images that are likely to map onto the identities of a range of groups, particularly those who are currently under-represented and/or come from disadvantaged groups. Where feasible, parents as well as students should be involved in careers-related activities in order to help build 'science capital'.
15. Opportunities should be identified for students to engage with the world of work and find out more about the possibilities opened up by STEM qualifications. These could include developing mentoring programmes for students that involve local employers who would act as STEM ambassadors and provide illustrations of good role models.
16. More research is needed on factors affecting inter-school variations in levels of post-compulsory uptake of STEM subjects and factors that influence these variations.

Individual factors

17. More research is needed on the links between self-efficacy (i.e. students' confidence in their ability to cope with STEM subjects), performance, engagement and participation in science, drawing on the more extensive work that has already been undertaken in mathematics.
18. More research is needed on critical decision points in relation to subject choice, how these are shaped by attitudes, and at what point attitudes become well-established and resistant to change. Such research would, for example, help identify the age(s) when it is most useful to provide students with information on STEM-related careers.

External factors

19. A wide variety of external factors can influence students' attitudes, participation and engagement in STEM subjects but little exists in the way of systematic evaluation. The most feasible way ahead would seem to be to work with some of the larger groups offering such events to assess the feasibility of a more co-ordinated approach to assessing their effects.

Methodological considerations

20. The use of experimental methods and, in particular Randomised Controlled Trials (RCTs), has received considerable attention in recent years, with some groups viewing them as the only way

to gather evidence of 'what works'. However, large-scale systemic change is unlikely to lend itself to such experimental approaches. Rather, the approach is more akin to engineering, where decisions will be informed by a variety of evidence in order to implement what is hoped will be the optimal solution.

21. Targeted interventions should initially be introduced on a small scale to test 'proof-of-principle', with a view to testing on a larger scale if the initial evidence suggests the intervention may be having the desired effects. Such larger-scale testing should involve a mixed methods approach, which could involve the use of Randomised Controlled Trials (RCTs), supplemented by case studies of practice. In this context, large scale data sets such as the National Pupil Database offer considerable potential in providing a sampling frame for more rigorous research design.
22. A publicly-available bank of high quality, reliable and valid instruments with sound psychometric underpinning should be established to enhance the quality of the research evidence on attitudes and engagement in STEM subjects. Such a bank should contain a core of items to be used in the evaluation of interventions in order to facilitate comparisons between studies.

The evidence base from the literature review

General considerations

23. The key findings presented are those which have emerged from high quality studies and/or emerged consistently from a number of studies with a similar focus, thus enabling a good level of confidence to be placed in the findings. Studies have been judged to be 'high quality' if they are medium-to-large in scale (i.e. are not studies by one researcher in one location), and normally include sufficient information to make an assessment of the reliability and validity of both the methods employed and the analysis.
24. The evidence is presented under four main categories: systemic factors, school factors, individual factors, and external factors. These categories are not mutually exclusive. The most extensive work focuses on individual and school factors influencing engagement and participation. Rather less exists on the influence of systemic factors and external factors such as informal learning.

Systemic factors

25. Countries that are seen as successful in STEM (i.e. where there do not appear to be persistent concerns about participation in STEM subjects) share a number of common features. These include a clear national policy on STEM, supported by substantial investment, the perception of teaching as a high status profession, STEM teachers being fully trained in their main subject and only teaching this subject, clear bifurcation of provision into STEM and non-STEM tracks at around age 14, vocational and technical institutions running alongside academic institutions, more compulsion to study mathematics and science at upper secondary level, and the setting of STEM-specific requirements for entry into higher education.

26. The combination of early specialisation and lack of opportunities to re-enter the STEM 'pipeline' at a later stage exerts an influence on post-compulsory participation in the UK. Sweden has had success with government investment in post-compulsory STEM provision that allows participants not on a STEM track to move to a STEM track at a later stage in their education.
27. Although the notion of a STEAM (STEM plus Arts) curriculum has received attention, there is insufficient evidence at present to assess its impact.
28. Although Scotland has much higher levels of post-compulsory engagement in mathematics and science, there is a lack of detailed evidence explaining this pattern.

School factors

29. Private schools and schools that select on the basis of ability demonstrate higher uptake of STEM subjects than state schools. Higher levels of post-compulsory participation are associated with single-sex schools, particularly for girls, with subject specialist teaching, and schools that take students from age 11-18, rather than 11-16.
30. There is some evidence to suggest that curriculum diversity pre-16 in science provision (i.e. offering triple science, dual-award science and vocational courses) may have a more positive impact on post-compulsory participation than a single offer of triple science.
31. Context-based approaches for students aged 11-16 appear to improve engagement in science, but not in mathematics. The improvement in engagement in science does not translate in any substantial way to improved levels of post-compulsory participation. There is mixed evidence on improvements in levels of post-compulsory participation in science for students following a GCSE science course emphasising scientific literacy (*Twenty-first Century Science*).
32. There is evidence to suggest that post-compulsory participation in science is improved if schools set a higher entry requirement, i.e. GCSE grade B, rather than C, though explanations for this effect need further probing.
33. There is strong evidence to suggest that careers guidance exerts a major influence on levels of post-compulsory participation. As students often have clearly formulated, and non-STEM-related, ideas about future careers by the age of 11-12, several studies recommend that STEM careers advice should begin to be provided from a much earlier age, i.e. in primary school.
34. There is evidence to suggest that levels of post-compulsory participation are improved if subject specialist teachers have a leading role in offering guidance on post-compulsory subject choices in STEM subjects, and that advice to 'keep your options open' has a negative effect on levels of participation in the physical sciences.
35. There is evidence to suggest that carefully structured opportunities to engage with the world of work, such as work experience, improve levels of post-compulsory uptake in science subjects.

Individual factors

36. Students who aspire to study STEM subjects are more likely to come from families where there is a high level of 'science capital'. This background helps to create a sense in young people that science is what people like them do, and that careers involving STEM subjects are realistic and attainable ambitions. The 'disconnect' between interest and subject choice could be explained by students who report liking science, but not considering studying it, having less science capital at home.
37. With the exception of Chinese and Indian students, most minority ethnic groups are under-represented in post-compulsory study of STEM subjects compared with their white counterparts.
38. More boys than girls pursue the study of STEM subjects.
39. STEM subjects attract the more able students, particularly in mathematics.
40. There is mixed evidence on students' levels of interest in STEM subjects across the years of secondary schooling. A number of studies report declining interest, though more recent work suggests levels of interest are higher. However, even high levels of interest do not translate into post-compulsory study. By the age of 11-12, most students already see STEM subjects as something they personally are not going to study.
41. Enthusiastic and knowledgeable subject specialist teachers can exert a positive influence on attitude and post-compulsory participation.
42. There is strong evidence to suggest that attitudes to science outside school are more positive than attitudes to school science, as many students see 'science' as playing an important role in society, though not something they personally want to study.
43. Students in less developed countries place a higher value, and have more positive attitudes to science than students in more developed countries.
44. There is strong evidence to suggest that students perceive STEM subjects to be difficult, and analysis of examination results shows that that it is harder to obtain the higher grades in mathematics and science at GCSE and A-level.
45. In STEM subjects, studies of students' confidence in their ability to cope with STEM subjects (self-efficacy) suggests that there is a strong link between levels of self-efficacy, performance and, probably, levels of engagement and post-compulsory participation.

External factors

46. Evidence of the impact on engagement and participation of external factors such as visits to museums and science fairs is very limited, and poses considerable problems in undertaking much in the way of cohesive, systematic evaluation of effects.

Methodological considerations

47. The literature on attitudes, engagement and participation in STEM subjects is particularly extensive and appears in a wide variety of sources (with a very high proportion being 'grey' literature). It is characterised by huge diversity in the instruments used to gather data, weaknesses in instrument design, and a lack of replication studies. Taken together these characteristics pose a substantial challenge to producing a review of the literature.
48. The emphasis on survey methods in empirical studies leads to a weakness in the literature, in that much of it is descriptive, rather than explanatory, making it difficult to infer causality.
49. Additional constraints on the work include the difficulty of accessing data to enable cross-national comparisons and the difficulty of making such comparisons even when the data are available due to variations in the nature of data gathered and reported.
50. The review is limited to studies reported in English, thus containing a preponderance of publications from the UK, North America and Australia.
51. There is broad similarity in the findings from study to study, and over a period of time, pointing to the deep-rooted and persistent nature of the attitudes and their resistance to change.
52. Recent developments include work on self-efficacy in STEM, the conducting of more longitudinal studies, and the use of large datasets (such as the National Pupil Database, NPD), either as the focus of the study and/or to assist in the identification of a sample for more in-depth work.

PART 1 The literature review

1 Introduction

1.1 The nature of the problem

The uptake of Science, Technology, Engineering and Mathematics (STEM) subjects beyond the period of compulsory study has been the focus of considerable attention and concern in several industrialised countries for a number of years. There are a number of reasons for the concern. These include (a) a consensus that a country's economy and competitive strength suffers if there is a shortage of people with STEM skills and competencies, (b) predicted shortages of people electing to pursue careers in STEM-related areas¹, (c) a consensus that the pool from which future STEM specialists will emerge is restricted, with a lack of diversity in social and ethnic background and a notable under-representation of women, and (d) a desire by many countries to improve the overall scientific literacy of their population.

The concern has led to the close monitoring of post-compulsory uptake of STEM subjects, both cross-nationally by the Organisation for Economic Co-operation and Development (OECD, 2009) and in individual countries, for example: in Canada: Industry Canada (2007); in the USA: National Science Foundation (2010); in the UK: Roberts (2002); Sainsbury (2007); The Royal Society (2008). In tandem with these high level reviews, cross-national studies have also been undertaken to explore school students' attitudes to science. For example, the Programme for International Student Assessment (PISA) reports on attitudes to science in *Science Competencies for Tomorrow's World* (OECD, 2007) and notes that, whilst many young people are very positive about importance of science, substantially fewer feel that science is important to them personally, or that they want to pursue a career in science. In a similar vein, the Relevance of Science (ROSE) project shows that school students in many countries, particularly those with developed economies, do not feel very positive about their experiences of science (Sjøberg and Schreiner, 2010).

There are two dimensions to the problem. The first of these concerns levels of student *engagement* with science. Many teachers in schools, particularly secondary schools, report a lack of interest on the part of the majority of young people in what they encounter on a day-to-day basis in their mathematics and science lessons. This lack of engagement leads on to the second dimension of the problem, levels of *participation*. Once the period of compulsory study has ended and decisions are made over subject choices, physical science subjects and mathematics are not particularly popular choices. The percentage of A-level entries in England and Wales in the sciences and mathematics from 1990-2012 illustrates the problem, as shown in Table 1 (overleaf).

Cast positively, the data show there has been a steady improvement in the percentage of A-level entries in recent years. However, entries for chemistry, physics and mathematics A-level are still considerably lower than they were in 1990. A notable feature within these data is the particular decline of male students taking physics and chemistry (Smith, 2011).

¹ It should be noted that exact levels of demand for STEM skills are hard to assess, and therefore it is not possible to access hard data on predicted shortages.

Table 1: Percentage of A-level examination entries in biology, chemistry and physics, 1990-2013

Year	Biology	Chemistry	Physics	Mathematics
1990	6.8	6.8	6.2	12.8
1995	7.2	5.8	4.8	9.2
2000	7.1	5.2	4.1	8.0
2005	6.9	5.0	3.6	6.7
2010	6.8	5.2	3.6	9.0
2011	7.2	5.5	3.8	9.6
2012	7.3	5.7	4.0	9.9
2013	7.5	6.1	4.2	10.4

(Source: Joint Council for Qualifications, JCQ)

Table 2 shows the publicly available comparable data for the individual countries within the UK, confirming overall increases in entries over the period 2005-2012, with the exceptions of Biology in Wales and Chemistry in Northern Ireland. The substantially higher percentages for participation in Chemistry, Physics and Mathematics in Scotland are discussed in Section 3 of the report.

Table 2: Percentage A-level entries for England, Wales Northern Ireland, and Advanced Higher entries for Scotland, 2005-2013

	Year	Biology	Chemistry	Physics	Mathematics
<i>England</i>	2005	6.7	4.9	3.5	6.7
	2010	6.6	5.1	3.6	9.0
	2011	7.0	5.5	3.8	9.6
	2012	7.2	5.7	4.0	10.0
	2013	7.4	6.1	4.2	10.4
<i>Wales</i>	2005	7.9	5.8	3.8	7.3
	2010	7.3	5.7	3.9	9.0
	2011	7.7	6.2	3.8	8.9
	2012	7.8	6.2	4.0	9.8
	2013	7.9	6.5	4.2	10.4
<i>Northern Ireland</i>	2005	10.3	6.0	4.3	7.2
	2010	10.1	5.8	4.7	9.4
	2011	10.6	5.6	4.4	9.5
	2012	10.5	5.6	4.7	9.5
	2013	10.2	5.8	4.8	9.7
<i>Scotland</i>	2005	9.8	10.5	8.3	13.5
	2010	10.2	10.8	8.4	14.3
	2011	10.6	11.5	8.2	14.5
	2012	11.2	11.6	8.9	15.0
	2013	11.1	11.5	8.4	15.0

(Source: Joint Council for Qualifications, JCQ, and Scottish Qualifications Authority, SQA)

1.2 Why look at attitudes?

Attitudes are a key determinant of engagement and post-compulsory participation, and it is therefore not surprising that a very large volume of work exists on attitudes to STEM subjects, and to mathematics and science in particular. The literature on attitudes to science is particularly extensive, with a first peak of interest and activity in the 1970s and the first half of the 1980s. In the UK, this interest is often attributed to the 'swing from science' identified in the *Dainton Report* (Department of Education and Science, 1968). The comparative lack of work in the late 1980s and 1990s in England and Wales can be explained by the need to assess the effects of what was then the new National Curriculum, introduced in 1989, with the first national examinations for students at age 16 taking place in 1992. For the sciences, the National Curriculum represented a major structural change in school science provision, as it moved the age of compulsory study of all three sciences from 14 to 16, and made the study of science compulsory from the age of five. During the 1990s, it became apparent that the National Curriculum had failed to deliver any substantial increase in numbers taking physical science subjects beyond the compulsory period, resulting in an upsurge of interest in attitudes to science. The literature on attitudes to mathematics is also large, characterised by a steady output of publications expressing concern over levels of engagement from the 1970s onwards. The literature on technology and engineering is less extensive, and tends to focus on reports from groups with a particular interest in levels of participation, such as the Institution of Mechanical Engineering, and EngineeringUK (formerly the Engineering and Technology Board, ETB).

The work on attitudes to STEM subjects in the period up to 2000 is characterised by a number of methodological and substantive features. For science, persisting concerns were voiced over the quality of the work: there was a preponderance of small-scale, 'one-shot' studies, leading to a plethora of instruments for assessing attitudes, many with weaknesses in their reliability and validity, and an absence of psychometric underpinning, making comparisons between studies and meta-analysis very difficult (see, for example, Gardner, 1975; Scibecchi, 1984; Ramsden, 1988). Despite these shortcomings, a number of consistent messages emerged from the work. Many students were negatively disposed towards science and mathematics subjects, with attitudes declining over the period of secondary schooling, and female students being less positively disposed than male students towards mathematics and, in particular, science. In science, biological sciences were viewed more positively than physical sciences. Science and scientists were not viewed very positively, but the products of science and technology were valued. Attitudes to science beyond school were more positive than science within school. In a similar vein, concerns have also been raised about the quality of instruments used to assess attitudes to mathematics (see, for example, the reviews of Zan *et al.*, 2006 and Larsen, 2013). As with science, attitudes to mathematics were not very positive, though mathematics as a subject was seen as having high value as a qualification.

2 The scope, methods and structure of the literature review

2.1 The scope of the review

The literature review covers the evidence from publications reporting the findings of studies in the period 2000-2013 that have explored aspects of students' attitudes, engagement and participation in STEM subjects. Restricting the review to studies undertaken since 2000 means that it focuses on the most recent and relevant work. The studies included are summarised in the Appendix to this review.

2.2 The review methods employed and criteria for inclusion of empirical studies

The review draws on the methodology of the Evidence, Policy and Practice Initiative (EPPI) systematic reviews (see, for example, Bennett *et al.*, 2005). Studies have been selected for the review on the basis of the size of the sample and the quality of the work. Thus the studies are medium-to-large in scale (i.e. are not studies by one researcher in one location), and normally include sufficient information to make an assessment of the reliability and validity of both the methods employed and the analysis. The studies selected have either been published in peer-reviewed journals, or are reports commissioned by a variety of key bodies and organisations including the Government, research councils, charitable trusts and prestigious organisations, such as the Department for Education, The Royal Society, the Institute of Physics, the Royal Society of Chemistry, the Institution of Mechanical Engineers, the Nuffield Foundation, the Wellcome Trust, the Organisation for Economic Co-operation and Development (OECD), and the Programme for International Student Assessment (PISA).

The review focuses on the evidence from studies of learners aged 5-19, with the bulk of studies undertaken with learners in the 11-19 age-range, as this is seen as the particularly problematic age in relation to attitudes to STEM subjects. The majority of the work included in the review has been undertaken in England, but is informed by data from other UK countries and international studies where this is available. Much of the research funding in the UK goes to institutions in England, which comprises 84% of the UK population, and studies therefore frequently have a focus on provision in England. As mathematics and science are the two compulsory STEM subjects throughout the school curriculum, it is inevitable that the majority of studies focus on these two subjects. Within this, levels of concern are higher for the physical sciences than for biology. Thus the emphasis of the literature is on work in the physical sciences.

2.3 The structure of the review

The literature review synthesises the evidence in four main areas: systemic factors, school factors, individual factors, and external factors.

Systemic factors include the structures of education systems, points of subject choice and subject specialisation. Exploration of systemic factors can help identify pathways, whether academic or vocational, that best encourage engagement and participation in STEM education.

School factors include the nature of the school and composition of the student intake (selective or all ability, single-sex or co-educational), school ethos, school management, the science curriculum on offer, teacher effects, and careers advice offered to students. Exploration of school factors can help identify the characteristics of particular types of schools that influence uptake and achievement in STEM subjects in the post-compulsory period. Depending on the nature of the education system, exploration of systemic or school factors can also yield information of the effects of particular curriculum interventions (such as, for example, the use of material with an emphasis on context-based approaches, or on scientific literacy) on engagement and participation in STEM subjects.

Individual factors influencing subject choice have been explored in a wide range of studies which have focused on aspects such as gender, socio-economic status, ethnicity, age, personality factors, ability, prior attainment, subject enjoyment, perception of subject usefulness for further study and/or career purposes. Exploration of individual factors can help shed light on why students are, or are not, choosing to study STEM subjects.

External factors that may influence subject choice include formal and informal activities that can shape responses to STEM subjects. Formal experiences include activities such as visits to museums, participation in science fairs and similar events, and visits to workplaces involving scientists and science-related activity. Informal activities include interaction with science in the media and leisure activities with a science focus. Exploration of external factors allows evidence to be gathered on how 'informal learning' in STEM subjects might support wider recognition of the value and importance of STEM education to society.

3 Evidence from the literature review

3.1 Systemic factors

As a preface to this section, it is important to note that making comparisons between education systems is complex. There are substantial variations from country to country in government policies, job markets and economies, social views, traditions, education systems and the cultural and political values in which they are embedded, methods of subject choice, ability groupings and examination systems. Countries also collect and report data in different ways, and statistics therefore rarely lend themselves to direct comparison. These complexities are reflected in the way that comparative studies are undertaken, typically drawing on document studies and input from experts or expert groups within countries.

3.1.1 International comparisons

In a comparative study of tertiary uptake of STEM courses across several industrialised nations (The Netherlands, Sweden, United States, and United Kingdom), Van Langen and Dekker (2005) explored systemic factors that influenced uptake. The countries were selected on the basis of the very different levels of uptake of STEM subjects at the tertiary level (i.e. further or higher education), with levels of take-up being Sweden (28.1%), the UK (22.21%), The Netherlands (14.6%) and the US (12%). All four countries report concern over declining interest in STEM subjects, under-representation of girls and women, current and/or predicted shortfalls in the labour market, and aspirations for stronger economic growth. The

study took the form of a document analysis and in-depth interviews with five or six experts in each country.

Van Langen and Dekker identify three systemic factors of particular influence. First, they found that the percentage of tertiary students taking STEM-based programmes is significantly higher in education systems that provide for multiple entry points, for example through STEM foundation programmes or horizontal transfer from humanity subjects. Second, they conclude that the association between the cost of studying and the drop-out risk influences uptake, with the lowest uptake for courses with a high cost combined with a high risk of drop-out. Lastly, they found that early specialisation in STEM courses, as opposed to more broad-based programmes, has a negative impact on uptake.

Van Langen and Dekker looked at the impact of these factors on the 'STEM pipeline', i.e. the process by which students move through the system towards a career in a STEM-related subject, and are either retained or lost depending on their choice of subjects at key decision points. Sweden, which has the highest STEM tertiary participation rate, has several initiatives to allow points at which students not on a STEM track can move back in to the 'pipeline'. These include government-funded adult education programmes provided by secondary schools to prepare for STEM entry at tertiary level, and preparatory years offered by universities and polytechnics with lower admissions rates and no limit to recruitment. In contrast, the education system in the UK provides comparatively few entry points into the STEM pipeline, with comparatively early exit points. In England these occur at age 16 (GCSE), 17 (after AS-level) and 18 (after A-level). The UK also has early and quite specific specialisation both before and during tertiary STEM programmes.

In a review of STEM provision in twenty-two countries (including the UK²) undertaken for the Australian Council of Learned Academies, and drawing on a series of commissioned expert reviews in each country, Marginson *et al.* (2013) identified a number of commonalities between countries that are seen to be performing strongly in STEM education (i.e. where there do not appear to be persistent concerns about levels of participation), such as Finland, China and South Korea. The teaching of STEM subjects is set within some form of national policy on STEM, supported by substantial investment. Teaching is seen as a well-paid and high status career, and, in STEM subjects, the expectation is that teachers will be fully qualified in the subject they teach, and will only teach their main subject. Other features of interest in countries seen as strong in STEM provision noted in the review include the bifurcation into clear STEM and non-STEM tracks in the later years of secondary education, development of 'STEM-heavy' technical and vocational schools and tertiary institutes running alongside the academic track, more compulsion to study mathematics and science at upper secondary level, and the setting of STEM-specific requirements for entry into higher education.

One of the reports commissioned for the above review was from South Korea (Jon and Chung, 2013), and one section within the review focuses on their government-funded STEAM (STEM plus Arts) initiative, aimed at fostering students' creativity through the inclusion of arts subjects in a STEM-focused curriculum. Such a move has also received support in the USA, and a recent report from the OECD (Winner *et al.*, 2013) has explored the

² Work reported from the UK was limited to provision in England and Wales.

value of arts education in fostering reflection, critical thinking and creativity. This latter report concludes that more empirical research is needed on the effects of arts education and the transferability of skills that might be developed. There is currently insufficient research in these areas to reach any firm conclusion about the effects of a STEAM curriculum on engagement and participation in STEM subjects.

In the UK, the Nuffield Foundation has also commissioned two reports focusing specifically on mathematics provision. The first of these (Hogden *et al.*, 2010) was an international comparison of provision and participation at upper secondary (students aged 16-19) mathematics in 24 countries, including those in the UK, with the second (Hogden *et al.*, 2013) looking in more detail at provision in seven countries (England, Germany, Hong Kong, New Zealand, Scotland, Singapore and the USA). The first review revealed that England, Wales and Northern Ireland have the lowest levels of participation in upper secondary mathematics, and are the only countries in which fewer than 20% of upper secondary students study mathematics, compared with a minimum of 50% of students taking the subject in most other countries. Although levels of participation in Scotland are higher, with just under half of upper secondary students studying mathematics, they are still below average. Of the twenty-four countries surveyed, only six do not require compulsory participation in mathematics at upper secondary level, with the four countries in the UK being in this group. The countries with the highest levels of participation were Japan, South Korea, New Zealand, Singapore and Taiwan. The reviews also note that, where mathematics was compulsory, this normally goes hand-in-hand with compulsory study of the first language, a second language, and science. The reviews conclude that the key drivers for take-up of mathematics at upper secondary level are compulsion and entry requirements for higher education. Other proposals for England made in the review include development of different models of post-16 mathematics, drawing on the successful mathematics programme in New Zealand that focuses on statistics as part of mathematical application and fluency, and the provision of a simple system of vocational qualifications.

3.1.2 *National comparisons within the UK*

Looking within the UK, it is apparent from the data in Table 2 that levels of post-compulsory participation in the physical sciences and mathematics are substantially higher in Scotland than in other UK countries. The Scottish system parallels the system in other UK countries in that students typically take Higher grade subjects at age 16-17, which are comparable with AS-levels, and Advanced Highers at age 17-18, which are comparable with A-levels. Academic students normally take five Highers and three Advanced Highers, but it is also possible to study a mix of Intermediate and Higher grade subjects at age 16-17, and a mix of Higher and Advanced Higher grade subjects at age 17-18. Explanations tend to attribute the difference in participation to this flexibility, to a curriculum that allows breadth and depth of study, to lower student to teacher ratios, and a higher proportion of teachers teaching their specialist science subject. However, it has not been possible to identify any detailed studies of explanations for the higher levels of post-compulsory participation in Scotland.

3.2 **School factors**

School factors that may influence uptake include the type of school and the student intake (selective or all ability, single-sex or co-educational), the ethos of the school, the school management, the curriculum on offer, teacher effects, and careers advice offered to students.

3.2.1 *Type of school (selection on the basis of ability, gender, size, and age range)*

Analyses of national data sets in England have indicated that private schools and selective schools, where selection is based on ability, have consistently demonstrated a higher uptake of post-16 chemistry and physics than in maintained all-ability (comprehensive) schools (e.g. Smithers and Robinson, 2007; Vidal Rodeiro; 2007; Gorard and See, 2009).

The type of school attended appears to make more difference for girls than boys, particularly in physics. For example, girls are four times more likely to choose A-level physics if attending an independent or grammar school, compared with twice as many boys. Girls at maintained schools are almost two-and-a-half times more likely to go on to do A-level physics if they attend an all-girls school, rather than a co-educational school, compared with boys being one-and-a-half times more likely. In 2011, no girls went on to study A-level physics in 49% of maintained co-educational schools (Institute of Physics, 2011), compared with 12% for boys. In the same year, 7.7% of girls in girls-only sixth forms take up physics at A-level compared with 3.6% for the whole population (Gill and Bell, 2013).

The particular success of female students in single-sex schools in achieving good grades in science subjects has resulted in some schools experimenting with single-sex groupings in science teaching at all levels, though there has been relatively little systematic research into its effectiveness (Murphy and Whitelegg, 2006).

School size does not appear to be an influence on engagement and participation (Hampden-Thompson and Bennett, 2011), but the age range of students in schools does make a difference, with fewer students going on to study physical science subjects in 11-16 schools than 11-18 schools.

3.2.2 *School ethos, leadership and management*

A number of studies have looked at aspects of schools that appear more successful in encouraging post-compulsory participation in science subjects, particularly the physical sciences (Smithers and Robinson, 2007; Department for Children, Schools and Families [DCSF], 2009; Institute of Physics, 2011; Bennett *et al.*, 2013).

School ethos plays a major role, with leadership and management features playing out in interesting ways. Strong school leadership associated with a high degree of subject teacher autonomy improves levels of post-compulsory participation, as strong subject leadership by science staff is often associated with active and direct recruitment into post-compulsory study by school science staff. However, strong school leadership that includes a high degree of involvement of senior staff in giving subject advice results in lower post-compulsory uptake. This is because senior staff need to appear even-handed, and not favouring

particular subjects, or taking action that might have a negative impact on some curriculum areas. Equally, senior staff are likely to encourage students to 'keep their options open' when choosing subjects. As will be seen in the later section on careers advice, this militates against post-compulsory participation in the physical sciences (Bennett *et al.* 2013).

3.2.3 Curriculum effects

A number of aspects of the curriculum offered by schools have an impact on engagement and participation. These include the structure of the curriculum, the nature of the curriculum, and experiences provided for students in lessons.

There is mixed evidence on the effects on post-compulsory participation of offering different science curricula at GCSE level. Gill *et al.* (2009), Gill and Bell (2013) and the National Audit Office (2010) suggest that, where a school offers separate sciences at GCSE level, the uptake of post-16 chemistry and physics is more likely to be higher, even when taking into account attainment at GCSE. However, Bennett *et al.* (2013) suggest that the provision of a triple science option did not, in itself, appear to have a universally positive effect. Rather, higher levels of post-compulsory uptake were characterised by a diversity of science curriculum offerings at GCSE, including vocational curricula and academic curricula, and dual and triple science. This permitted more homogeneous teaching groups which, in turn, appeared to influence students positively towards choosing chemistry or physics. This aspect of curriculum provision would benefit from further exploration.

Students have differing views of the level of demand made on them by the science curriculum. In the early years of secondary school, some students report being alienated by the repetition of material covered in their primary schools (Institution of Mechanical Engineers, 2010). This reported alienation is most noticeable amongst higher ability students. In the later years of secondary education, students perceive the science curriculum in England to be over-full and overladen with facts, resulting in a feeling of not being in control of their learning (Osborne and Collins, 2001; Cerini *et al.* 2004; Van Langen and Dekker, 2005). These studies also report students feeling that there is insufficient time for discussion of scientific issues, though Jenkins and Nelson (2005) did not find particularly strong support for the inclusion of such matters in the science curriculum.

A systematic review of the effects of context-based approaches to the teaching of science approaches (Bennett *et al.*, 2007) has shown that, whilst students are more engaged with their experiences in science lessons, there is relatively little evidence to suggest that this is translated into increased participation in the post-compulsory period of study on a substantial scale. Thus increasing the emphasis on everyday applications appears to offer only a partial solution to increasing post-compulsory levels of participation. There is mixed evidence on the effects on post-compulsory participation of a GCSE science course with a substantial emphasis on scientific literacy, *Twenty First Century Science (21CS)*. Bennett and Hogarth (2006) found that almost three-quarters of students taking the course felt everyone should study science subjects up to the age of 16, compared with only half of students taking other GCSE courses. A survey of schools in England who started the course in 2006 suggests that this increased value placed on science might be translated into increased participation,

as there were substantial increases in the number of students starting AS-level courses in the sciences in 2008: 30% in biology, 24% in chemistry and 38% in physics (Millar, 2010). However, data on subsequent cohorts of students (Homer and Ryder, 2012) suggest the picture is more mixed. Students following dual-award *21CS* are more likely to progress to A-level biology than non-*21CS* students, and students following triple-award *21CS* are less likely to progress to physics A-level than non-*21CS* students. There is also a noticeable gender effect: boys taking both dual-award and triple-award *21CS* are less likely than non-*21CS* students to go on to A-level in any science, but girls taking dual-award *21CS* are more likely to go on to study A-level biology and chemistry, and girls taking triple-award science more likely to go on to study A-level biology. Overall, once corrections are made for prior attainment and other school-level factors, students taking *21CS* are slightly less likely to progress to A-level biology and chemistry, with the difference being more appreciable for physics.

Hampden-Thompson and Bennett (2011) analysed the PISA 2006 data for 12,000 students aged 15 in the UK to explore the effects of particular kinds of lesson activities on engagement in science. The students reported higher levels of engagement, future orientation and motivations towards science when they regularly experienced lessons characterised by interaction (students explaining their ideas, and expressing their opinions), hands-on activity (practical work, designing investigations) and an emphasis on the relevance and applications of what is being studied.

There is strong evidence to suggest that experiences in lessons have a negative impact on attitudes to mathematics (Nardi and Steward, 2003; Mathews and Pepper, 2005.) Students report feeling isolated, and teaching being associated with a high reliance on dull repetition and rote learning. These feelings are exacerbated by a dependence on applying techniques that are not understood, but give the right answer. In contrast to science, there is also some evidence that students have negative attitudes to contextualised learning activities in mathematics. Despite the good intentions of such approaches, they are perceived by students to be irrelevant (Nardi and Steward, 2003; Kounine *et al.*, 2008). These appear to be important messages for curriculum interventions in mathematics: an emphasis on personalised learning may result in feelings of isolation on the part of students, and contexts that might appear to be 'real-life' to those developing materials may not be seen as such by students.

Concerns over the mathematics curriculum have resulted in a potential substantial change to the GCSE mathematics curriculum being piloted. This is the mathematics linked-pair (MLP), originally proposed in the report *Making Mathematics Count* (Smith, 2004). The MLP consists of two GCSEs, one focusing on applications of mathematics, and the other on methods in mathematics. The preliminary findings of the evaluation (Smith *et al.*, 2013) suggest that there have been slight increases in post compulsory uptake of mathematics, and that students report mathematics as more useful, and sometimes more enjoyable, when it is based on real-life scenarios.

3.2.4 *A-level entry requirements*

A Government report (DCSF, 2009) into progression to post-16 science suggests students with GCSEs at grade B needed further investigation, as school A-level entry policy varies,

and grade B student often miss out. Bennett *et al.* (2013) indicate that there are higher rates of post-compulsory participation in chemistry and physics at schools with higher entry qualifications, with schools who allowed students with grade Cs to progress having lower uptake of chemistry and physics. Interviews with teachers suggested that teachers felt the higher entry grades gave a sense of status to the subjects, but this aspect needs further probing to establish likely explanations.

3.2.5 *Careers advice and guidance*

Careers advice has been the focus of considerable attention as an area of potential influence on post-compulsory study. The National Audit Office (2010) reports careers guidance as being very patchy, with considerable differences between schools, and a number of reports argue for the need for more, and different, careers advice (e.g. The Institution of Mechanical Engineering, 2010; Osborne and Dillon, 2008; Walport, 2010).

In the ASPIRES project, a longitudinal study of the career aspirations of students aged 10-14, Archer *et al.*, (2013) found that, even before entering secondary school, over 80% of students indicate that they have decided a career in science is not for them. Careers advice is criticised for being too little, too late. Other groups have also argued that careers advice on STEM subjects needs to be provided in primary schools as well as secondary schools (e.g. The Institution of Mechanical Engineering, 2010; Walport, 2010). Walport also notes the dearth of advice on technical and vocational careers in STEM, recommending a broadening of careers advice, with the different pathways into STEM careers being clearly defined and laid out within schools, and young people receiving planned systematic information, advice and guidance on STEM careers from age eight onwards. Similarly, Hutchinson and Bentley (2011) established that, whilst most students are aware of academic pathways involving STEM subjects, fewer than one-third had any knowledge of vocational pathways. Osborne and Dillon (2008) argue for the need to improve the human and physical resources available to schools for informing students about careers *in* science and careers *from* science, i.e. the extensive range of potential careers afforded by the study of science.

Bennett *et al.* (2013) found that schools with a high level of post-compulsory participation were characterised by careers advice being provided by science specialist staff who are proactive in recruiting students to their subjects. In contrast, students in schools with low post-compulsory uptake are provided with general careers advice. This emphasises the importance of keeping options open by going for breadth of study, resulting in students choosing just one science subject, often biology. Bennett *et al.* (2013) also found that work experience that involved science, and was undertaken early in Year 10 (students aged 14-15) has a positive impact on participation.

Fitzgibbon (1999) showed that there were significant inter-school variations in numbers of students electing to study subjects beyond the compulsory period. Her study primarily focused on mathematics and what she termed the “pulling power” of different mathematics departments in schools, but she also suggested that there might be similarities with science departments in factors underlying student choice.

There is mixed evidence on the extent to which students are influenced by school and home experiences. Hutchinson and Bentley (2011) found sources of careers information are most

likely to be parents and family members, not school, with students also reporting the internet as a good source of information. Archer *et al.* (2013) report that around a quarter of lower secondary age students say that school is an influence on their choice of career, but fewer than 0.5% are influenced by their school's careers education. Lyons and Quinn (2010) found that students aged 15-16 felt that teachers have more influence than parents on their subject choices and career choices.

3.2.6 *Enrichment activities*

Studies of the effects of enrichment activities in schools (such as science trips, science clubs, maths clubs) generally indicate positive effects on engagement and participation (DCSF, 2009; Hutchinson and Bentley, 2011; Gorard *et al.*, 2012; Bennett *et al.* 2013), though the analysis of the PISA data by Hampden-Thompson and Bennett (2011) found no statistical difference in levels of engagement between schools with higher and lower level of extra-curricular activities.

3.2.7 *Teacher specialism*

The impact of specialist subject teaching has received particular attention, partly due to the shortage of physics teachers in secondary schools. The DCSF (2009) reported that schools with higher levels of post-compulsory participation are characterised by enthusiastic teaching from specialist teachers. Bennett *et al.* (2013) found that low post-compulsory uptake of physical sciences is associated with non-specialist teaching. Reid and Skryabina (2002) attribute the substantially higher level of post-compulsory uptake of physics in Scotland to it being taught mainly by qualified physics teachers.

3.3 **Individual factors**

The largest volume of work on engagement and participation focuses on attempts to identify individual factors influencing responses to STEM subjects. These studies usually take the form of analysis of national data sets and/or studies of groups of students in school. Much of the work in the latter area takes the form of self-report data by students, most often based on attitudinal surveys. The analysis of large-scale datasets has identified a range of factors that exert an influence, including socio-economic status, ethnicity, gender and prior achievement in GCSE mathematics and science. Studies of students in schools also reveal a range of influences, including experiences of STEM subjects within and beyond school, aspirations for further study and careers, teacher influences, perceptions of subject difficulty, and confidence in abilities (self-efficacy).

3.3.1 *Socioeconomic effects*

International data from the PISA 2006 survey (OECD, 2007) found that students from more advantaged socio-economic backgrounds are more likely to be interested in science, and that students with a parent in a science-related career are more likely to see their own career involving science. In the UK, Hampden-Thompson and Bennett (2011) analysed PISA data and report that levels of student engagement and future orientation towards science increase with the number of years for which their parents have been educated, and higher occupational status.

Gorard and See (2009) note that participation in higher education has continued, over decades, to be stratified in terms of social class, ethnicity and region. They suggest that data on widening participation in STEM are ambiguous as they show that whole numbers entering higher education have increased overall, but these increases have been very small for the physical sciences and mathematics. Thus, as a proportion of total uptake, participation in STEM subjects has declined. They conclude that relative overall cost is one of the most significant and important factors determining higher education participation. This may have implications for the longer degree courses (e.g. MChem, MPhys) that have been introduced in the last decade.

3.3.2 *Ethnic background effects*

There are substantial variations in subject choice for students of different ethnic background (Springate *et al.* 2008; Gill and Bell, 2013). Chinese and Indian students show a strong preference for A-level chemistry and physics, but are under-represented at degree level. Pakistani and Bangladeshi students are under-represented at degree level, compared with their numbers at A-level. Black Caribbean students are under-represented at both levels. Ethnic minority students are less likely to study for a PhD in chemistry or physics than their white peers.

In their systematic review of twelve studies on factors influencing choice of STEM subjects, Tripney *et al.* (2010) report that young people described as Asian are more likely than those from other ethnic groups to choose mathematics and science beyond the compulsory period of study. They do, however, sound a note of caution, as they also found that studies tended to treat this group as if homogenous, whereas it contains people from different socio-cultural and ethnic backgrounds. Archer *et al.* (2013) report a similar pattern of uptake for students they describe as 'South Asians'. Further research is necessary to establish the explanations for the variation of such patterns of participation.

3.3.3 *Gender effects*

Gender effects in STEM subjects have been the focus of numerous research studies, with the principal area of concern being the comparatively low numbers of girls choosing mathematics and the physical science subjects, particularly physics.

Looking at the most recent work, the PISA 2006 data reports gender difference in attitudes to science as being most prominent in Germany, Iceland, Japan, South Korea, the Netherlands and the UK, where males are more positive than females (OECD, 2007; Hampden-Thompson and Bennett, 2011). Tripney *et al.* (2010) found that boys are more likely than girls to choose separate sciences at age 14. Archer *et al.* (2013) identify two groups of girls who engage with science: 'bluestocking scientists', who are not 'girly', are often Asian or white, and seen as seen as good girls by their parents, and 'feminine scientists' who like science but have more 'girly' identity, being more sociable and fashionable.

Male students are more likely to take physics and mathematics than female students, but about equal numbers take chemistry (Stokking, 2000; Murphy and Whitelegg, 2006; Vidal Rodeiro, 2007). Multi-level analysis indicates that the gender difference cannot be explained

by gender patterns in achievement, as marginally more girls than boys obtain A-C grades in the sciences and mathematics at age 16. Gill and Bell (2013) explored the association between performance and participation. They found that performance at GCSE at grade B or above is the same for both genders but uptake rates for females are much lower, particularly in physics. Males in co-educational schools are more likely to take up physics than their peers in single-sex schools, whereas a larger proportion of females from all-girls schools, rather than co-educational schools, opt for A-level physics.

Mujtaba and Reiss (in press) found that girls are less likely than boys to be encouraged to study physics post-16 by teachers, family and friends. Compared with girls who do not intend to study physics beyond the compulsory period, the small sub-set of girls who are planning to take physics are characterised by higher levels of extrinsic motivation to physics and more positive perceptions of physics teachers and lessons.

In mathematics, a clear picture emerges of female students typically being far less confident in their abilities in mathematics and therefore viewing the subject less positively than their male counterparts (Nardi and Steward, 2003; Kyriacou and Goulding, 2006; Brown *et al.*, 2007). Both Boaler (1997) and Mendick (2006) comment on the ways in which schools unwittingly make it more difficult for girls to believe they are succeeding at mathematics even when all the evidence suggests that they are.

3.3.4 *Family effects*

Data suggest that family effects can exert a substantial impact on students' career aspirations. For example, Archer *et al.* (2013) report that 47% of students aged 12-13 say that their family is the main source of influence, compared with 33% citing hobbies and out of school interests, and 25% citing school as the main influence. Students who aspire to study STEM subjects are more likely to come from families where there is a high level of 'science capital' (Archer *et al.*, 2013) i.e. from socially advantaged backgrounds where they have a close family member or friend with STEM qualifications and working in STEM-related areas, and science-related leisure interests. This background helps to create a sense in young people that science is what people like them do, and that careers involving STEM subjects are realistic and attainable ambitions.

3.3.5 *Age effects*

Positive attitudes to science decrease between ages 11 and 16, with the sharpest decline taking place between ages 11 to 14 (Bennett and Hogarth, 2009). Within this, physics consistently receives the fewest positive responses, but the decline in interest is sharpest for chemistry, a feature that also emerged in the study by Osborne and Collins (2001). Galton *et al.* (2003) demonstrated that attitudes to science and school science, when compared with mathematics and English, decline most noticeably in the early years of secondary education. Hutchinson and Bentley (2011) report ease and enjoyment of mathematics and science declining from age 11-12 to age 13-14, with mathematics showing the biggest decline of any school subject. These findings point to the early years of secondary education as being particularly crucial in shaping attitudes.

3.3.6 *Ability effects*

Tripney *et al.* (2010) report that young people with higher prior levels of attainment are more likely than those with lower levels of prior attainment to choose mathematics and science. Vidal Rodeiro (2007) established that more able students are more likely to take physical science subjects post-16, a finding confirmed by Gill and Bell (2013) who found that students were more likely to choose to take physics if they achieve their best GCSE marks in physics and mathematics.

A particular phenomenon that appears to be unique to mathematics is the group termed by Matthews and Pepper (2005) as the elite 'clever core', whose existence tends to polarise attitudes to mathematics. The majority of students do not feel they are good enough at mathematics to study it beyond the compulsory period. In contrast, students in the 'clever core' see themselves as capable mathematicians and do not see mathematics as irrelevant or difficult; rather they enjoy the subject and appreciate its logic and ability to solve problems. The notion of the clever core has its parallels in the work of Brown *et al.* (2008), where many students' attitudes were influenced by their perception of mathematics as a subject with a 'fixed ceiling' of understanding beyond which it was not possible for them to progress. Matthews and Pepper (2005), and Brown *et al.* (2008) recommend exploring the introduction of two-tier provision post-16, with one of the tiers targeting students at the level below the clever core.

3.3.7 Responses to STEM subjects as experienced in school

There is little doubt that, despite a range of initiatives over a period of several decades, mathematics and science as taught in schools continue to lack sufficient appeal for many young people to the point that they choose to study the subjects beyond the compulsory period.

The evidence on levels of interest is mixed. The most positive responses are reported in the recent Wellcome Trust Monitor surveys (Butt *et al.*, 2013; Clemence *et al.*, 2013), in which 80% of young people report finding science lessons fairly interesting or very interesting, and over half report finding science lessons more interesting than English or mathematics lessons. Similarly, the National Audit Office (2008) report the majority of students aged 12-13 to be positive about mathematics and find their mathematics lessons enjoyable. However, a later study by the National Audit Office (2010) notes young people's enjoyment, interest and motivation to pursue the study of mathematics and science in the UK has declined in international comparisons undertaken between 2003 and 2007. Straw and MacLeod (2013) also note that interest appears to decline across the period of secondary schooling. The Relevance of Science Education (ROSE) international study (Sjøberg and Schreiner, 2010) reports that school science is seen by students as less interesting than most other subjects, not pointing in the direction of exciting jobs and careers, not increasing curiosity, and not making students feel that science and technology play an important role in everyday life. Similar findings emerged from a UK study by Mansell (2011). Sjøberg and Schreiner (2010) also report that the higher the level of development in a country, the lower the levels of interest in school science. Much large-scale survey data are limited in that they only describes a situation, rather than revealing why, so it is not possible to explain why there are conflicting results from surveys. However, the levels of post-compulsory participation in STEM subjects suggest that, whatever levels of interest are declared by young people, this is

not translated in any substantial way into decisions to study STEM subject once the point of choice is reached.

A number of studies suggest that science is seen by students as important, and an important subject in the school curriculum, with the majority of students believing everyone should study science at school (Cerini *et al.*, 2004; Jenkins and Nelson, 2005; Bennett and Hogarth, 2009). However, the value placed on science appears to derive more from perceptions of possible career benefits than its ability to engage and interest students (Osborne and Collins, 2001; Jenkins and Nelson, 2005).

In a multi-nation study of students' responses to science, Lyons (2006) found that attitudes improve when the curriculum deals with contemporary issues, when the teaching style is less didactic and allows for the student voice, and when conscious efforts are made to make the science less difficult. However, even those students who report finding the physical sciences interesting and important do not extend this into a science-based career choice, a finding that also emerges very clearly in the ASPIRES project (Archer *et al.*, 2013). It appears that there is some form of disconnect between personal views of science and personal choices about studying science. Stokking (2000) and Lyons (2006) found that, regardless of students' views about their school science experiences, the main reasons for uptake of post-compulsory chemistry and physics studies are instrumental, i.e. as a strategic positioning for desirable tertiary courses or desirable careers. Archer *et al.* (2013) suggest that the disconnect can be attributed to 'science capital' (see Section 3.3.4), and that students who report liking science but not considering studying it have less science capital at home.

As with science, mathematics is seen by students as an important subject in the school curriculum, with, for example, almost three-quarters of students aged sixteen believing that mathematics is important and useful in everyday life (Blenkinsop *et al.*, 2006). Attitudes to school mathematics appear to be less positive, with Nardi and Steward (2003) noting the 'quiet disaffection' of many students at age 14 who, whilst recognising the value of a mathematics qualification and feeling obliged to participate, demonstrate little real engagement in lessons. A particularly noticeable feature of the work was the link between enjoyment of mathematics and feeling confident with the subject (Matthews and Pepper, 2005; Kyriacou and Goulding, 2006; Brown *et al.*, 2007). There is strong evidence to suggest that negative attitudes to school mathematics are associated with students' views of their experiences in lessons as isolating, over-individualised, involving a high reliance on dull repetition and rote learning, exacerbated by dependence on applying techniques that were not understood, but gave the right answer (Nardi and Steward, 2003; Mathews and Pepper, 2005.) In contrast to school science, there is also some evidence that students have negative attitudes to contextualised learning activities (Nardi and Steward, 2003). These appear to be important messages for curriculum interventions in mathematics: the emphasis on personalised learning may result in feelings of isolation on the part of students, and contexts that might appear to be 'real-life' to those developing materials may not be seen as such by students.

3.3.8 Responses to STEM subjects as experienced beyond school

Studies of responses to mathematics have largely focused on factors relating to experience of mathematics in school. Some of the studies on responses to science in school have also

focused on science beyond school, demonstrating that, whilst many young people appear generally positive towards science and believe it benefits society, they are much less positive about their experiences of school science (Osborne and Collins, 2001; Jenkins and Nelson, 2005; Bennett and Hogarth, 2009; Sjøberg and Schreiner, 2010; Archer *et al.* 2013). This view poses one of the biggest challenges to increasing participation in science.

The evidence on perception of scientists and the work they do is mixed. The stereotypical image of the white-coated, male 'mad scientist' that emerged in earlier studies has changed, with a broader interpretation of scientists and their work, though with physical scientists still being seen as predominantly male (Haste, 2004). Though the work of scientists appears to be valued and seen to make a positive contribution to the world, negative images of scientists persist, and contribute to a lack of desire on the part of many young people to pursue careers in science (Haste, 2004; OCR Examination Board, 2005; Jenkins and Nelson, 2005; Bennett and Hogarth, 2009). Jenkins and Nelson (2005) also note that students in developing countries place a much higher value on jobs involving science, suggesting that there are factors beyond the school system that influence attitudes.

The portrayal of STEM subjects and people working in STEM areas in the media has a strong negative effect on students, particularly female students. For example, Van Langen and Dekker (2005) report that, in addition to the stereotypical male 'geeky', 'nerdy' image of people working in STEM areas, STEM careers are also typically portrayed in the media as unappealing, unglamorous and too difficult for women.

3.3.9 Career and further study aspirations

The ROSE study (Sjøberg and Schreiner, 2010) reports that, across a number of countries, few young people, and very few girls want to become scientists, or work in the fields of science and technology. PISA data (OECD, 2012) report the proportion of students planning a career in engineering or computing. This varies widely among countries, ranging from relatively high proportions in Chile, Mexico, Poland and Slovenia to very low numbers in Finland and the Netherlands, with the UK ranking 49th from 55 countries (compared with, for example, the USA 39th, Sweden 37th, The Netherlands 53rd) and the UK having the second lowest percentage (2%) of girls indicating this as a choice. There is no obvious pattern linking responses to geographic location.

Career intentions appear to be much more influential in decision-making for mathematics and science than in other subjects, in that mathematics and science are far less likely to be chosen by students who have yet to formulate their career plans (Vidal Rodeiro, 2007; Bennett *et al.*, 2013).

Students who do elect to study physical sciences beyond the compulsory period cite a number of reasons for doing so. Bennett *et al.* (2013) identify four categories of strategies that can influence subject choice: aspirational (linked to further study and/or career purposes), prior experience (subjects they have enjoyed, subjects where they have done well, teachers they liked, subjects with which they feel they have identified), or tactical (reducing risk, keeping options open, subjects that go well together), or external factors, such as parental and family effects. A number of other studies have confirmed the importance of students' sense of identity and perceptions of their ability as playing a key role in subject choice

(Munro and Elsom, 2000; Vidal Rodeiro, 2007; Tripney *et al.* 2010). Lyons and Quinn (2010) found that around two-thirds of students choosing not to continue with science report difficulties in seeing themselves as scientists, and that school science had not opened their eyes to new and exciting careers. Archer *et al.* (2013) also found that many students (and their parents), and particularly those from households with low science capital, see science subjects as leading only to a narrow range of jobs, such as scientist, doctor or science teacher.

Clear gender differences emerge in reasons for choice. For example, Haste (2004) found female students in England express strong interest in acquiring further knowledge in science and less interest in learning about new developments in technology, but were concerned about the environment and ethical issues. Male students think science is beneficial, and were interested in technology, space and hardware. They believe that science can solve human problems, but are less interested in ethical issues. This led Haste to suggest that the very different characteristics point to a particular mismatch between female students' preferences and the ways in which physical sciences may be portrayed in school science teaching. In mathematics, Matthews and Pepper (2005) found enjoyment was likely to be cited by female students as the main reason for continuing their study of mathematics, and, whilst important for male students, was less influential than career intentions.

Studies of students' career aspirations show that many young people have a firmly held view of what they want to do early in their secondary schooling. For example, the Institution of Mechanical Engineers (2010) report that 85% of students aged 11 already know what career they want to follow, and 65% have held this view for at least two years. Archer *et al.* (2013) report similar findings. Few of the careers cited by these students involve mathematics and science. Taken in conjunction with the findings of the Wellcome Trust Monitor (Clemence *et al.* 2013), which report just under two-thirds of young people saying they know little or nothing about STEM careers, suggesting that students are unconsciously passing decision points at age 14 and 16 which then rule them out of STEM careers.

3.3.10 *Teacher effects*

All the evidence on teacher effects points to their significant influence on students' attitudes to both mathematics and science. Students see their science teachers as being influential in determining their response to science, particularly in the early years of secondary education (Osborne and Collins, 2001; Bennett and Hogarth, 2005; Archer *et al.*, 2013; Clemence *et al.*, 2013; Mujtaba and Reiss, in press). Cerini *et al.* (2004) also reported students' desire to be taught by subject specialists who are enthusiastic and knowledgeable. The responses are similar in mathematics, where teacher support and encouragement emerge as particularly important in building confidence during lessons and in influencing study decisions post-16 (Matthews and Pepper, 2005). Nardi and Steward (2003) also established that teacher effects are more influential than the use of any particular work scheme or textbooks in influencing students' responses to mathematics. Whilst the majority of work identifies teachers as having a positive effect, Van Langen and Dekker (2005) found that some STEM teachers, either deliberately or subconsciously, give the impression that their subjects are hard and further study is only for a clever elite.

3.3.11 *Perceived difficulty of mathematics and science subjects*

The evidence on the difficulty, or perceived difficulty, of mathematics and science, and the subsequent impact on subject choice, is mixed. The majority of work suggests that many students perceive the physical sciences and mathematics to be subjects that only a clever few can study. Most report finding the subjects difficult, resulting in a disinclination to consider studying the subjects beyond the period of compulsory schooling (e.g. for science: Osborne and Collins, 2001; OCR Examination Board, 2005; Lyons and Quinn, 2010; Archer *et al.*, 2013; for mathematics: Blenkinsop *et al.*, 2006). Blenkinsop *et al.*, (2006) also asked students to comment on the comparative difficulty of science, mathematics, English and languages, at age 14 and age 16. Mathematics and science were seen as harder than English, but not as hard as languages, with all subjects other than English being reported as becoming harder from age 14 to age 16. There is evidence that suggests that these student perceptions of difficulty are reflected in examination performance. For example, the Curriculum Evaluation and Management (CEM) Centre at the University of Durham has undertaken extensive analysis of its databank on examination entries, drawing on methods originally developed by Fitzgibbon and Vincent (1994). Data on GCSE examination entries at age 16 show that a higher percentage of students are awarded grades A*-C in English and history than in mathematics and science. At A-level, the subjects in which it is hardest to achieve the highest grades are the sciences, modern foreign languages and mathematics (Coe *et al.*, 2008). A more complex analytical procedure undertaken at the CEM centre, looks at subject grading on the basis of a number of comparative indicators such as the performance of students taking particular pairs of subjects. Chemistry, physics and mathematics have consistently emerged as the most difficult subjects in that students are less likely to achieve higher grades in these subjects than in others.

3.3.12 *Self-efficacy in relation to mathematics and science subjects*

Exploring links between self-efficacy and engagement and participation is a relatively new area of work in relation to science, though more established and extensive in relation to mathematics. Self-efficacy is concerned with the extent to which individuals believe they have the ability to perform specific tasks (Bandura, 1997). Students' learning experiences play an important part in their notions of self-efficacy. Self-efficacy is seen as an important predictor of success with learning which, in turn, may be linked to increased levels of engagement.

PISA has looked at self-efficacy in science (OECD, 2007). Questions were included to address students' belief both in whether they can handle tasks and overcome difficulties in science (self-efficacy) and in their academic abilities (self-concept). The findings indicate that self-efficacy is closely related to performance, with strong gender differences in the pattern of responses: in 22 of the 30 OECD countries in the survey, including the UK, males thought significantly more highly of their abilities in science than females. Lyons and Quinn (2010) found self-efficacy to be an important influence on choice, particularly for girls, who have lower self-efficacy than boys and are particularly sensitive to anticipated difficulties in chemistry and physics. Tsai *et al.* (2011) have also suggested a link between students' self-efficacy and the learning of science concepts. However, Gorard *et al.* (2012) suggest that there is currently insufficient evidence from high quality studies to support the notion that self-efficacy influences attainment or later participation in science.

PISA has also looked at self-efficacy in mathematics (OECD, 2003), where findings point to a lack of confidence in mathematical abilities, with 50% of male students and over 60% of female students reporting feeling concerned and anxious about their abilities in the subject. There was also a very strong link between self-efficacy and performance, with students who felt confident about their mathematical abilities performing best in the PISA assessment items. Similar findings have emerged from a number of other studies (e.g. Williams and Williams, 2010; Wang, 2012; Lewis, 2013), which have also pointed to links between self-efficacy and post-compulsory engagement.

3.3.13 *Other areas of activity*

A comparatively recent focus for work has been on identity, values and science culture. A number of authors have suggested that there is a tension between the development of identity and the match with the culture of science (Schreiner and Sjøberg, 2007; Taconis and Kessels, 2009; Shanahan, 2009). Taconis and Kessels found that Dutch students aged 12-13 saw their peers who favour science subjects (the science prototype) as less attractive, less popular, less socially competent, less creative and emotional, but more intelligent and motivated than their peers who favoured language subjects. Subsequent subject choices were associated with students' perceived match of their own characteristics and those they associated with the typical science prototype.

3.4 External factors

3.4.1 *External factors that may influence engagement and participation in STEM subjects*

A range of formal and informal activities may shape responses to STEM subjects. The majority of activities have a science focus, and include science centres, visits to museums, science fairs, workplaces involving science and scientists, experiences of science in the media, and leisure activities with a science focus.

Braund and Reiss (2004, 2006) describe a number of ways that informal sites for learning might contribute to an education in and about science in ways that are difficult to provide in schools. They describe contributions to students' overall understanding of science as including, for example, 'big science' (such as in visits to astronomical telescopes and particle accelerators) and the more integrated understanding of ecological and Earth science processes that comes from field studies, and argue that science outside the classroom and in the informal world contributes to making science more authentic for young people.

The last ten years has seen increasing activity in research and policy formulation to take account of the fact that mathematics and science learning takes place outside formal schooling. In the UK, following two reports on the uses of out-of-school learning (NFER and Dillon, 2005; House of Commons Education and Skills Committee, 2005), the UK government published its *Learning Outside the Classroom Manifesto* (DfES, 2006), aimed at stimulating greater use of outdoor environments by school-age students and accessing the wide diversity of organised opportunities such as in museums and gardens. In the USA, the National Research Council (NRC) of the National Academies of the US published *Learning Science in Informal Environments: People, Places and Pursuits* (NRC, 2009), which identified a number of informal environments that contributed to learning. These include visits to

museums, mathematics and science-related exhibitions, programmes, events, festivals, science camps, engagement in public and community projects such as conservation, and engagement with mathematics and science-related surveys such as the annual Audubon breeding bird survey in the USA, which engages tens of thousands of people. A recent review of informal science learning (Wellcome Trust, 2012) comments that participation in such activities is important from an early age, as there is evidence that preferences for leisure-time use are fairly well-established by the age of eleven.

The review by the Wellcome Trust (2012) included a survey of 196 informal science providers, and found around half felt experiences in informal environments should be significantly different to those at school and not seek to replicate what can be done there, with more than half believing that informal learning should not exist merely to support learning in the formal school sector. Despite this, 80% of providers reported their most common services as 'in-school enrichment', with more than 50% of providers running activities after school, during school holidays or festival activities.

3.4.2 *The impact of informal learning on student engagement in STEM subjects*

It is clear from the literature that there is a high level of enthusiasm on the part of a number of groups, including charitable trusts and museums, for STEM-related informal learning activities, with much being claimed for their value in relation to improved engagement and attainment as a result of participation in such activities. None-the-less, the literature on the evaluation of the impact of informal learning environments and initiatives is fragmented and unsystematic, and does not provide a solid evidence base to inform decision-making. Indeed, given the diversity of the activities, it is hard to see how it could be anything other than this. Where it exists, the focus is on science, and evaluation of initiatives appears more common in the USA.

There is some evidence to suggest that structured non-school science programmes, such as summer science camps, can stimulate science-specific interest in school students and appear to influence positively future academic achievement in science and orientation towards future science career options (National Research Council, 2009). Interviews with summer camp participants two years later reveal that the hands-on and inquiry based nature of activities are those best remembered and enjoyed (Gibson and Chase, 2002).

Evaluation of the newly refurbished *Launchpad* exhibition at the Science Museum in London shows young people commented positively on how the experiences differ from those in school. They report enjoying opportunities to try things out themselves, to formulate questions, to share experiences and to learn from making mistakes (Teixeira and Burch, 2007).

The evaluation of a museum project in the USA, *Raising Interest in Science and Engineering*, aimed at increasing confidence in mathematics and science of middle school girls, reported substantial increases in the numbers of girls planning to pursue careers involving mathematics and science, and taking action to change plans (Jarvis, 2002). An important aspect of this programme was that each girl had a female mentor acting as a positive role model for STEM.

The evidence on the impact of activities such as science fairs is inconclusive. For example, Rodd *et al.* (in press) report that such fairs do not appear to influence undergraduates' choice to read physics at a university.

4 Discussion

This section summarises and discusses the key findings of the review, both in relation to methodological considerations and substantive findings.

4.1 Overview of the nature and scope of the literature

There are three particularly striking features of the literature on attitudes, engagement and participation in STEM subjects. The first is the sheer volume of publications. The second is the diversity in type of publication. Studies are reported in peer-reviewed journals, practitioner-oriented publications, books and a very substantial quantity of 'grey' literature, (i.e. literature produced by government, charities, academics, business and industry, but which is not controlled by commercial publishers). Gaining an overview of what exists in 'grey' literature is problematic, as there are no central repositories of such publications, and they may well not appear in electronic databases. The diversity in the type of publication reflects interest on the part of a large number of groups, but poses a substantial challenge in synthesising the research findings. The third feature is the broad similarity of the findings, both from study to study and over a period of time in which there has been considerable change in the mathematics and science curricula experienced by students. This points to the deep-rooted and persistent nature of the attitudes and their resistance to change.

The gathering of data on attitudes to STEM subjects is characterised by an emphasis on survey methods, many of which employ items with Likert-type scales (i.e. inviting a response on some form of an agree/neutral/disagree scale). Attitudes are assessed by gathering information in a range of areas, including dispositions towards school mathematics and science, teachers and teaching, relevance to everyday life, careers involving mathematics and science, the influence of peers and parents, and mathematics and science outside school. A further discernible developing strand of work focuses on students' beliefs both in their capabilities to achieve a goal or an outcome (self-efficacy) and in their academic abilities (self-concept).

The emphasis on survey methods leads to a substantial weakness in much of the literature, in that it is descriptive, rather than explanatory, making it difficult to infer causality. Thus, for example, the most recent studies of students' interest in science suggest that interest is fairly high across the period of secondary schooling, in contrast to earlier work that points to interest declining sharply between the ages of 11 and 14. However, it is not possible to determine why this change has taken place.

The last five years have seen an increase in longitudinal studies (a previously identified weakness), though there are still relatively few studies comparing attitudes across subjects. There is also a noticeable trend towards analysis of large datasets such as the National Pupil Database (NPD), either as the focus of the study and/or to assist in the identification of a sample for more in-depth work. There has been some shift in the focus of the work in that

earlier studies tends to focus on either science or mathematics, with some of the more recent work focusing on STEM subjects collectively.

Analysis of reports of studies suggests that attention has been paid to some of the methodological weaknesses identified in the early work, with greater care being taken over matters of sampling, sample size, reliability and validity (in both instrument design, and analysis). Despite these gains, the most recent comprehensive review of instruments developed to assess attitudes to science (Blalock *et al.*, 2008) notes that a number of the weaknesses identified earlier were still apparent, and that there are very few instruments available with the necessary psychometric data to merit recommendation. The body of work as a whole is also characterised by a further, and very substantial, weakness: whilst individual studies may be designed with considerable care, the notion of 'a new study, a new instrument' persists. The lack of co-ordination of previous work with new work, and the lack of replication studies, means there is little sense of building up a detailed and cumulative knowledge-base of work on attitudes to STEM subjects. This, in turn, means that it is very difficult to make direct comparisons between studies and undertake any detailed meta-analysis of work.

A further challenge relates to making cross-country comparisons. In part this is a practical challenge related to the language of publication of documents. However, as noted by Van Langen and Dekker (2005), a number of contextual factors, including government policies and education and examination systems, make it difficult to compare data from different countries. This may, in practice, be less of a problem than it might seem at first, as any changes in policy in a country have to take account of local contexts. However, it does mean that what might appear to work in one country may not work in another if aspects of the context are different.

The language of publication also imposes constraints on the studies that can be included in a review. Inevitably, a review of the literature undertaken in the UK is going to draw heavily, if not exclusively, on publications in English, many of which come from English-speaking countries. A review of work on attitudes to STEM subjects is therefore likely to be drawing on publications from the UK, North America and Australia.

4.2 Key findings from the review

The key findings presented below are those which have emerged from high quality studies and/or emerged consistently from a number of studies with a similar focus, thus enabling a reasonable level of confidence to be placed in the findings.

The most extensive literature focuses on individual and school factors influencing engagement and participation. Rather less exists on the influence of systemic factors and external factors such as informal learning.

4.2.1 Systemic factors

Countries that appear to be strong in STEM subjects, and with good rates of post-compulsory participation, share a number of common features. The teaching of STEM subjects is set within a national policy on STEM, supported by substantial investment. Teaching is seen as

a well-paid and high status career and, in STEM subjects, the expectation is that teachers will be fully qualified in the subject they teach, and will only teach their main subject. Structurally, there is some form of bifurcation into clear STEM and non-STEM tracks in the later years of secondary education, often accompanied by development of 'STEM-heavy' technical and vocational schools and tertiary institutes running alongside the academic track. There is also more compulsion to study mathematics and science at upper secondary level, often accompanied by the setting of STEM-specific requirements for entry into higher education.

One development which has received some attention is the STEAM (STEM plus Arts) curriculum in South Korea, a government initiative aimed at fostering students' creativity through the inclusion of arts subjects in a STEM-focused curriculum. Currently, there is insufficient evidence to reach a view on the impact of such an approach, and more empirical research is needed on the effects of arts education and the transferability of skills that might be developed.

A key contributor to the problem of post-compulsory participation in STEM subjects in the UK, particularly in England, Wales and Northern Ireland, would appear to arise from the combination of early specialisation and lack of opportunities to re-enter the STEM 'pipeline' at a later stage. The work reported suggests that it may be possible to address this issue through government investment in post-compulsory STEM provision which then allows participants not on a STEM track to move to a STEM track.

A review of mathematics provision in twenty-four countries shows that England, Wales and Northern Ireland have the lowest levels of participation in upper secondary mathematics, and are the only countries in which fewer than 20% of upper secondary students study mathematics, compared with a minimum of 50% of students taking the subject in most other countries. The four countries in the UK are comparatively unique in not requiring compulsory participation in mathematics (together with the study of the country's first language, a second language and a science) at upper secondary level. The reviews conclude that the key drivers for take-up of mathematics at upper secondary level are compulsion and the entry requirements set for higher education. The reviews also recommend development of different models of post-16 mathematics, drawing on the successful mathematics programme in New Zealand that focuses on statistics as part of mathematical application and fluency, and the provision of a simple system of vocational qualifications.

Levels of post-compulsory participation in the physical sciences and mathematics are substantially higher in Scotland than in other UK countries (though note the comments in the preceding paragraph about the position of all the countries in the UK relative to non-UK countries). Explanations tend to attribute the difference in participation to flexibility in the upper secondary curriculum such that it that allows for both breadth and depth of study, and a higher proportion of teachers teaching their specialist science subject. However, it has not been possible to identify any detailed studies of explanations for the higher levels of post-compulsory participation in Scotland.

4.2.2 School factors

Private schools and schools that select on the basis of ability demonstrate higher uptake of STEM subjects than state schools. Higher levels of post-compulsory participation are also associated with single-sex schools, with the effects being much more marked for girls than boys. In around half of maintained co-educational schools, no girls go on to study physics, whilst boys in most of such schools do go on to take physics. Higher levels of post compulsory participation in science are also associated with subject specialist teaching, and with schools that take students from age 11-18, rather than 11-16. There is comparatively little research evidence on the effects of teaching students in single-sex groups within co-educational schools. This would merit further investigation.

The structure of the curriculum in science appears to exert a considerable influence on participation. The popular notion that triple science leads to improved post-compulsory participation may be over-simplistic. There is some evidence to suggest that it is curriculum diversity that may exert the stronger effect, i.e. provision of dual-award, triple science and vocational options. This is an aspect that would benefit from further exploration.

The nature of the curriculum appears to influence levels of engagement, particularly in science. Context-based approaches lead to higher levels of engagement in science, though this does not result in increased post-compulsory participation. The evidence is less clear-cut for mathematics. Some work suggests contextualisation reduces levels of engagement, whilst early indications from the mathematics 'linked-pair' GCSE provision, one element of which emphasises applications, results in modest gains in engagement. There is mixed evidence on the effects of a GCSE course which places emphasis on scientific literacy (*Twenty-first Century Science*) on levels of post-compulsory participation, and this outcome would merit further investigation.

Post-compulsory participation in science is linked to the entry requirements schools set for advanced level study, with schools that set the entry requirement at GCSE grade C and above having lower levels of participation than schools requiring a grade B or above, though the reasons for this need further investigation.

The impact of careers advice and guidance emerged as an influential feature, with a very strong suggestion from a number of studies that such advice is 'too little, too late'. The evidence points to the majority of students having made some decisions about careers by age 12-13, and that this decision is very often not linked to working in STEM-related areas. Students' knowledge of STEM career opportunities is limited, and very limited in relation to vocational opportunities.

There is mixed evidence on the most influential source of advice, suggesting that both home and school exert an influence. Students are more likely to go on to study STEM subjects if they come from homes with high levels of 'science capital' (i.e. from socially advantaged backgrounds where they have a close family member or friend with STEM qualifications and working in working in STEM-related areas, and science-related leisure interests). Schools that involve STEM subject specialists in offering advice on subject choices and careers have higher levels of post-compulsory participation. The likely outcome of general advice to 'keep your options open' is lower levels of post-compulsory participation in the physical sciences. The provision of carefully-formulated opportunities to engage with the world of

work, such as work-placements, can motivate students to study STEM subjects. The source, nature and impact of careers advice would merit further exploration.

4.2.3 *Individual factors*

Individual factors concern student attributes, such as socio-economic effects, the effects of ethnic background, gender, age and ability, and student responses to their experiences of STEM.

Students are more likely to be interested in science if they come from a more advantaged socio-economic background and if they have a parent with a STEM-related career. There is considerable variation in the patterns for ethnicity. With the exception of Chinese and Indian students, most groups are under-represented in post-compulsory study of STEM subjects compared with their white counterparts. Gender patterns are as one might expect, with more boys than girls pursuing the study of physical sciences and mathematics, with girls being less confident in their abilities in these subjects. STEM subjects tend to attract more able students, with this being particularly noticeable in mathematics, where a 'clever core' of mathematically able students tends to act as a deterrent to others pursuing post-compulsory study.

Many students have a reasonably firm idea about their intended career by the age of 11-12, and, for the majority, this does not include work in STEM-related areas. Those students who do not have clearly-formulated ideas about what they want to do will, none-the-less, already know that STEM-related careers are not something they wish to pursue.

There is mixed evidence on students' interest in STEM subjects. Much of the evidence points to interest declining over the years of secondary schooling. More recent studies have suggested that levels of interest remain relatively high, though the reasons for this remain unclear, and would benefit from further exploration. It is clear that enthusiastic, knowledgeable subject specialist teachers can stimulate or increase students' levels of interest. However, interest appears to be a necessary, but not sufficient, condition to motivate students to engage in post-compulsory study. It seems probable that students who are interested in science, but come from homes with low science capital, are unlikely to go on to study mathematics and science. Again, more data on this effect would be informative.

Attitudes to science outside school are more positive than attitudes to school science, as most students see science as making an important contribution to society, though not something they personally want to study. It may be the case that studies reporting high levels of interest in science are not discriminating adequately between school science and science outside school. Whilst students do not necessarily find mathematics interesting, they recognise the value of a qualification in the subject. The declining interest in STEM subjects is reflected in the low numbers of students wishing to pursue STEM-related careers.

Students perceive STEM subjects to be difficult, and there is evidence to suggest that it is harder to obtain the higher examination grades in mathematics and science at GCSE and A-level. A potentially fruitful and comparatively new area of work has looked at students'

confidence in their abilities to succeed (self-efficacy), and area which has received more attention in mathematics than in science. The evidence suggests that there is a strong link between self-efficacy and success in learning, which may also be linked to increased levels of engagement and participation.

4.2.4 External factors

The impact of external factors such as informal learning opportunities related to STEM subjects (such as visits to museums, science fairs and science camps) is an under-researched area, though one which poses considerable problems in undertaking much in the way of cohesive, systematic evaluation of effects. There is some evidence from the USA suggests that summer camps stimulate interest and engagement in science.

PART 2 Commentary on the future

5 Going forward

5.1 Introduction

The preceding literature review has pulled together the evidence to inform answers to four questions:

1. What does the evidence say about student attitudes, engagement and participation in STEM subjects?
2. How can mathematics and science education be made most enjoyable, rewarding and effective?
3. What types of evidence need to be collected in future in order to assess more reliably students' choices and the reasons for these?
4. How should research and intervention strategies evolve to collect this evidence?

This section of the report draws on the evidence to provide a commentary on possible future directions for work on student attitudes, engagement and participation in STEM subjects, and implications for mathematics and science education.

In addition to the review, a series of informal interviews was held with six experts in STEM. The purpose of these interviews was to clarify some of the findings from the review, to gather supplementary evidence and views, to check the validity of the emerging findings, and to gather perspectives on areas that might benefit from further research, and/or point to possible interventions and methods of evaluating their effects. The interviewees consisted of a STEM government advisor, the director of education at a major funder of research and development work in STEM, a senior member of staff in the National Network of Science Learning Centres, and three university academics with expertise in research, curriculum development and initial teacher training in mathematics and science. (Due to this part of the review being conducted over the school summer vacation, it was not possible to talk to Heads of Mathematics or Science in schools.)

The discussion is structured around areas where there appears to be sufficient evidence to support action, together with an indication of areas where further work is desirable.

5.2 General observations

It is clear from the review that countries seen as successful in STEM (i.e. where there do not appear to be persistent concerns about participation in STEM subjects) appear to have initiated a strategic mix of policies and actions, and one outcome of this is that it can be difficult to identify the effects of individual actions. It is also important to see policies and actions in context, and not to assume that a particular aspect (or aspects) which look potentially attractive will transfer successfully to other countries. There may well be other factors operating that militate against this happening. Policies and practice from other countries provide a potentially informative perspective, rather than something for direct

transfer. The art is in distilling out from what appears to be successful in other countries that which can be adapted and adopted in a different country.

There are considerable gaps in the research evidence base, and that the most comprehensive evidence from the review focuses on *describing* what happens. There is considerably less evidence on explanations and causal factors.

It is important to note that initiatives that might increase participation, and therefore be deemed to be successful at one level, may not necessarily increase interest and engagement, thus failing at another level.

In making the recommendations that follow, it has been assumed that there will continue to be some form of common examination at age 16, and that 18 will be the normal age for university entrance. However, what is in the following sections could still apply if these age points were to change.

Finally, in making any recommendations, it needs to be recognised that most are likely to involve some financial cost - very substantial cost in some cases - and initiatives undertaken in countries seen as successful in STEM have normally been well-supported by government funding. Thus some sort of priority is likely to need to be assigned to possible actions.

5.3 Systemic factors

The structure of the education system and the curriculum

The evidence suggests that it would be timely to undertake a major review of the structure of the education system and the curriculum in relation to mathematics and science provision in England. The principal aims of such a review would be two-fold. Firstly, it would seek to develop alternative pathways for students from the age of 14 onwards. These should take the form of academic pathways and vocational pathways, with both STEM and non-STEM routes in each pathway. In the case of non-STEM pathways, there would be a basic requirement to gain qualifications at a specified minimum level in mathematics and science (as there would be for other, non-STEM subjects, such as English). Secondly, the review would seek to develop an upper secondary level (post-16) curriculum that built on the preceding pathways to offer both breadth and depth of study.

In proposing the above aims for a review, it is recognised that England has a culture of academic specialisation. It has proved very difficult in the past to establish vocational pathways that have parity of esteem with academic pathways. It has also proved difficult to change post-16 provision in any substantive way, with A-levels being seen by many as the 'gold standard' for several decades. Any major change would require the active support of a wide range of stakeholders, including government, policy-makers, professional societies, teaching bodies, employers, universities and parents.

There is no strong evidence to suggest that STEM-related subjects should have a higher priority than other subjects, as proposed, for example by supporters of a STEAM (STEM plus Arts) curriculum. Rather the subjects should form part of a balanced baccalaureate-type curriculum, irrespective of whether the emphasis is on STEM subjects or not. It is beyond

the scope of this report to make specific recommendations on the structure of the educational system as a whole, but the academic track in such a curriculum might comprise, for example, of a core of English, mathematics, science, an arts/humanities subject, and an additional language, with other options available depending on interests. In the light of the evidence in the review that careers advice to 'keep your options open' reduces uptake of the physical science subjects, it would seem desirable to have some choice in the science option. This could take the form of, for example, an option that covers all the sciences within the time allocated to one subject, as well as separate sciences options. A vocational pathway would also comprise a core of subjects with options, but with an approach that is more applied in nature and more closely related to the world of work.

In creating new pathways, it will be also important to have more diversity, particularly at the post-16 level, such that there are attractive options for those who do not want to take academic A-levels or study STEM subjects at university level. Such vocational options would need the support and engagement of employers to enhance their status and relevance. The GCSE Additional Applied Science component of *Twenty-First Century Science* would appear to have much to offer in the development of science provision in a vocational pathway, and the successful alternative mathematics courses introduced in New Zealand, with a focus on mathematical fluency, applications and statistics, would appear to be useful when considering mathematics provision.

Careers education and enhancing science capital

The evidence points to a number of desirable systemic changes in relation to the provision of more and better careers education. Many young people and their families have very narrow ideas of the value of STEM qualifications and the broad range of careers, scientific and non-scientific, that are open to those with such qualifications. National policy needs to ensure that a number of steps are taken to broaden awareness and convey the message that science is for everyone, whether or not they pursue science careers. Careers awareness should be fully embedded into the mathematics and science national curricula, and this should include helping students to appreciate that qualifications in these subjects have value in the labour market even if they do not go on to use them directly in jobs. It is particularly important that career awareness should be integrated into mathematics and science teaching, and not seen as a separate area. This is most likely to happen if appropriate resources are developed for use in the classroom. It is also clear that teachers of STEM subjects need to be involved in careers education, and this requires provision being made for appropriate CPD. Any resources developed for use in schools could also be used to support CPD.

The need to develop a co-ordinated programme of STEM careers awareness extends beyond provision for students in schools. Evidence from the review has pointed to the importance of 'science capital' in influencing student choice, with students being far more likely to elect to study mathematics and science if they come from socially advantaged backgrounds where they have a close family member or friend working in STEM-related areas, and science-related leisure interests. Thus STEM awareness programmes should involve both students and their families, and local employers and STEM role models. This would help increase science capital amongst a more diverse range of students, and fostering more positive attitudes to STEM-related careers. In schools, such a programme could include school-level strategies to involve families in mathematics and science, strategies such as mentoring and

work placements to foster interaction between students and STEM role models, and enrichment programmes linking students to local projects related to STEM. Beyond school, awareness campaigns could be launched to improve public understanding of STEM-related career options.

A STEM database

The evidence points to the need for a dedicated, publicly accessible, national STEM database to serve two functions. Firstly, it would pull together a range of STEM-related data, such as numbers taking mathematics and science subjects at various levels in the education system. Data could be reported in a number of key categories, for example, gender, social class, ethnic background, school type, and numbers going on to post-compulsory study of STEM subjects. The dataset could include all the countries within the UK, and selected comparator countries, whilst noting that the nature of cross-national data does not always lend itself readily to straightforward comparisons. Much of the data are already available, but have to be accessed from a wide variety of sources. Such a database would not only enable systematic monitoring and dissemination of data, but would also form a basis for the setting of targets for participation in mathematics and science for a variety of different groups of young people. It would also provide an evidence base for incentives, such as, for example, scholarships and bursaries to support under-represented groups. Secondly, the STEM database would form a central repository for reports on STEM-related matters and STEM research. This would provide a very valuable resource for future work, and help address the challenge of identifying the large quantity of 'grey' literature on attitudes, engagement and participation in STEM subjects. The existence of such a database would also assist with the identification of instruments to assess attitudes and engagement (see comments in Section 5.7 on methodological considerations).

Other systemic changes to consider

Other countries have seen some improvement in levels of participation in STEM subjects in the following ways: raising the minimum requirements for university entrance in mathematics and science; funding programmes that make it possible for people who have left the 'STEM pipeline' to re-enter it; and by implementing a range of policies to improve the quality of STEM teaching and the career progression of STEM teachers. Policies focusing on STEM teachers include a requirement for teachers to have higher degrees, the introduction of meritocratic careers structures, and ensuring that specialist mathematics and science teaching is undertaken by appropriately qualified teachers who only teach their specialist subject.

5.4 School factors

Improving engagement and participation in STEM will ultimately depend to a significant extent on what happens in schools and what goes on in mathematics and science classrooms, as this is where strategies developed to make mathematics and science education more enjoyable, rewarding and effective will be played out. In the long term, much of what could or should happen in schools will depend on the nature of any systemic changes made. In the meantime, there are also clear messages from the research about strategies that schools can adopt could help make a difference in the shorter term.

Age range taught at school

The evidence indicates fewer students in 11-16 schools than 11-18 schools go on to study physical science subjects. However, geographic and financial constraints make it unlikely that all schools could become 11-18 schools, unless the school leaving age was raised to 18. Thus efforts at improving the post-compulsory uptake of physical sciences of students from 11-16 schools should be directed at developing a targeted STEM subject strategy for managing the transition to the post-16 institutions where students go on to study.

Teaching groups

Given the evidence on gender effects and post-compulsory participation, co-educational schools should give consideration to teaching mathematics and science in single-sex groupings.

The nature of the curriculum

The suggestion that curriculum diversity in science provision for students aged 14-16 improves levels of post-compulsory participation would benefit from further exploration. Set in the wider context of the evidence from the review, there could be benefits to all students in looking at offering a more vocationally-oriented curriculum for less academic students.

Schools should ensure that their science curriculum reflects ways in which science is used in everyday life and the world of work, as this improves student engagement. They should also offer enrichment activities, integrated into the curriculum. These might take the form of days or half days off timetable to focus on particular aspects of STEM, particularly those which involve engagement with the world of work.

Careers provision and guidance

Schools should take a number of actions in relation to their careers provision and guidance. Where feasible, parents as well as students should be involved in careers-related activities in order to help build 'science capital' for students from backgrounds traditionally under-represented in STEM careers.

Current provision should be reviewed with a view to ensuring that STEM subject specialist teachers are involved in giving advice. Those involved in careers provision should be aware of the negative effects on STEM participation of the general advice to students to choose subject such that they keep their options open.

Opportunities should be taken to link subject teaching to careers involving STEM. Subject resources and careers resources should be examined to ensure that they reflect the range of careers open to people with STEM qualifications, and provide images that are likely to map onto the identities of a range of groups, particularly those who are currently under-represented and/or come from disadvantaged groups.

Opportunities should be identified for students to engage with the world of work and find out more about the possibilities opened up by STEM qualifications. These could include developing mentoring programmes for students that involve local employers who would act as STEM ambassadors and provide illustrations of good role models.

Where it would be useful to know more

There are two particular areas which would benefit from further research, as they would provide a useful evidence base to inform decisions about systemic level change. The first of these concerns inter-school variations in levels of post-compulsory uptake of STEM subjects and factors that influence these variations. These factors would include school leadership and management, the use of single-sex groupings in mathematics and science teaching, the nature and effects of careers advice, links between curriculum provision (double science, triple science, vocational courses) and uptake, the effects on students aged 14-16 of following a course emphasising scientific literacy, the effects of using contexts and applications in the teaching of mathematics, and entry requirements for post-compulsory study. The second area would be to explore the effects of a range of pedagogic approaches and learning activities with a view to establishing what engages students, particularly those in traditionally under-represented groups.

5.5 Individual factors

Students' background

Students who aspire to study STEM subjects typically come from homes where there is a high level of science capital. Typically, this does not include students from minority ethnic groups, with the exception of Chinese and Indian students, and students from socially disadvantaged families. Although science capital appears to be a particularly influential factor, many of its components relate to home environment, and are therefore not easy to influence. It seems likely that the most profitable course of action is to identify a range of strategies that schools can undertake to compensate for lack of science capital. A number of these have been identified in the previous section, and relate to engaging students and their families in STEM-focused careers activities.

Students' responses to science

A multiplicity of studies has been undertaken documenting students' responses to science. Despite some concerns over the instruments used, the findings are consistent, and suggest enough is known to make further self-report studies of students' responses to science of limited use, unless they are exploring the effects of targeted interventions. Rather, the effort needs to be put into identifying a limited range of reliable and valid instruments to gather information on students' responses.

Where it would be useful to know more

There are four particular areas where it would be useful to know more, as the evidence gathered could inform the nature and timing of targeted interventions. The first of these is a more detailed exploration of the links between student self-efficacy, performance,

engagement and participation in science, drawing on the more extensive work that has already been undertaken in mathematics. The second area is the gathering of data on critical decision points in relation to subject choice, how these are shaped by attitudes, and at what point attitudes become well-established and resistant to change. Such research would, for example, help identify the age(s) when it is most useful to provide students with information on STEM-related careers. The third area is to look in particular at the levels of 'interest' students declare they have in science, with a view to establishing why some studies report interest declining over the years of secondary schooling, whilst others suggest interest remains high. The final area is exploring the effects of interventions aimed at improving the participation of traditionally under-represented groups in STEM subjects.

5.6 External factors

A wide variety of external factors can influence students' attitudes, participation and engagement in STEM subjects. Activities that are intentionally structured to engage students and their families with STEM-related matters, such as science fairs and festivals, science centres and museum visits, are likely to have some beneficial effects. There is no doubt that groups committed to providing such experiences consider them to have current and future benefits. However, very little exists in the way of systematic evidence of the effects, and it is not easy to see how this might happen. The diversity of providers and events makes co-ordination of research and evaluation very difficult. The most feasible way ahead would seem to be to work with some of the larger groups offering such events to assess the feasibility of a more co-ordinated approach to assessing their effects, and to see what scope there might be for the formal school sector to learn from ways in which STEM is communicated successfully in informal settings.

5.7 Methodological considerations

There are two particular ways in which the research on attitudes and engagement needs to evolve, and each has a direct bearing on the quality of evaluation of targeted interventions.

Firstly, the approach, or approaches, to evaluation need to be considered. The use of experimental methods and, in particular Randomised Controlled Trials (RCTs), has received considerable attention in recent years, with some groups viewing them as the only way to gather evidence of 'what works'. However, it needs to be recognised that large-scale systemic change is unlikely to lend itself to such experimental approaches. Rather, the approach is more akin to engineering, where decisions will be informed by a variety of evidence in order to implement what is hoped will be the optimal solution. However, within this, there will certainly be a number of areas where it would be useful and important to develop and test targeted interventions, initially on a small scale to test 'proof-of-principle', with a view to testing on a larger scale if the initial evidence suggests the intervention may be having the desired effects. Such larger-scale testing should involve a mixed methods approach, which could involve the use of RCTs, supplemented by case studies of practice to illuminate the experimental data. For example, a targeted intervention aimed at improving levels of self-efficacy, or at exploring the effects of providing particular forms of careers guidance, would lend themselves to this approach. In this context, note should be taken of the potential offered by large scale data sets such as the National Pupil Database, in providing a sampling frame for more rigorous research design.

Secondly, a crucial element in the evaluation of any interventions is the use of sound measures to assess effects, and repeat studies to build up a solid evidence base. Thus there is much to be gained from pulling together and evaluating the quality of a range of instruments to assess attitudes and related constructs (such as self-efficacy). The quality of such instruments could be judge on the basis of criteria such as those employed in EPPI systematic reviews. Putting together a bank of high quality, reliable and valid instruments with sound psychometric underpinning would be challenging but, ultimately, enhance the quality of the research evidence on attitudes and engagement in STEM subjects. Such a bank should be made publicly available, and ideally contain a core of items to be used in the evaluation of interventions in order to facilitate comparisons between studies.

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Appendix: Empirical studies included in the literature review

1. Studies have been undertaken in the UK, unless indicated otherwise.
2. Details of large-scale international and national studies, such as the PISA and ROSE studies and the Wellcome Trust Monitors, are not included.

<i>Authors</i>	<i>Study</i>	<i>Year</i>	<i>Subject focus</i>	<i>Sample</i>
Archer <i>et al.</i>	The ASPIRES (Science aspirations and career choice, age 10-14) project: research report summary	2013	Includes mathematics and science	5-year longitudinal study; survey of around 3,250 students aged 10-11 (with 2,100 followed up at aged 12-13); interviews with around 90 students and their parents
Bennett and Hogarth	"Would <i>you</i> want to talk to a scientist at a party?"	2005	Science	Survey of 280 students aged 11-16
Bennett and Hogarth	Evaluation of <i>Twenty-first Century Science</i> , Strand 2: attitudes to science	2006	Science	Survey of around 300 students aged 15-16 participating in the pilot GCSE course, <i>Twenty-first Century Science</i>
Bennett <i>et al.</i>	Schools that make a difference to post-compulsory uptake of physical science subjects	2013	Science	Analysis of National Pupil Database (NPD); eight case studies involving interviews with students aged 17-18, science teachers, careers teachers and senior managers in schools
Blenkinsop <i>et al.</i>	How do young people make choices at 14 and 16?	2006	Includes science and mathematics	In depth, narrative eliciting interviews with around 80 students in four cohorts at fourteen schools
Brown <i>et al.</i>	"I would rather die": attitudes of 16-year-olds towards their future participation in mathematics	2008	Mathematics	Survey of around 2,000 students in 17 schools
Cerini <i>et al.</i>	Student review of the science curriculum	2004	Science	<i>Planet Science</i> survey of around 1,500 secondary students
Department for Children, Schools and Families	Progression to science post-16: An enquiry into the factors which are influential in achieving high levels of take-up of science subjects post-16	2009	Science	Interview with students, teachers and other stakeholders at 86 schools seen as particularly successful in levels of post-compulsory study of science
Gill and Bell	factors determine the uptake of A-level physics?	2013	Science	Multi-level modelling of data from National Pupil Database (NPD)
Gorard and See	The impact of socio-economic status on participation and attainment in science	2009	Science	Literature review and analysis of National Pupil Database (NPD) and Pupil-Level Annual School Census (PLASC) data
Hampden-Thompson and Bennett	Science teaching and learning activities and students' engagement in science	2011	Science	Analysis of selected PISA 2006 responses from 12,000 students
Haste	Science in my future: a study of values and beliefs in relation to science and technology amongst 11-21-year-olds	2004	Science	Survey of around 700 young people aged 11-21
Hutchinson and Bentley	STEM subjects and jobs: A longitudinal perspective of attitudes among Key Stage 3 students, 2008-2010	2011	Mathematics and science	Survey of just over 4,000 students aged 11-12 in 27 schools (with just over 2200 students in 19 of the schools followed up after two years)
Institution of Mechanical Engineers	When STEM?: A question of age	2010	All STEM subjects	Literature review and invited expert comment
Jenkins and Nelson	Important but not for me: students' attitudes towards secondary school science in England	2005	Science	Survey data from around 1,270 students in England aged 14-15 participating in the Relevance of Science Education (ROSE) international comparative study
Lyons and Quinn	Choosing Science: understanding the decline in senior high school science enrolments	2010	Science	Survey of 3,760 students aged 15-16 in Australia

Mansell	Exploring young people's views on science education	2011	Science	Interviews and focus groups with 240 students
Matthews and Pepper	Evaluation of participation in A-level mathematics	2005	Mathematics	Survey of 200 schools and 19 case studies
Mendick	Masculinities in mathematics	2006	Mathematics	Ethnography and semi-structured interviews with 42 students aged 16-19 in three schools/colleges
Millar	Increasing participation in science beyond GCSE: The impact of Twenty First Century Science.	2010	Science	Survey of post-16 uptake in 155 schools before and after a major curriculum intervention
Mujtaba and Reiss	What sort of girl wants to study physics after the age of 16? Findings from a large-scale UK survey	In press	Mathematics and science (physics)	Survey of 23,000 students aged 12-13 (with 7,000 followed up after two years) and 140 teachers; in-depth studies of students aged 15,16 and 17 in 12 schools, with students studying English used as a comparison group
Nardi and Steward	Is Mathematics T.I.R.E.D?: a profile of quiet disaffection in the secondary mathematics classroom	2003	Mathematics	Three case studies of three classes of students aged 14, comprising a total of 70 students
National Audit Office	Young people's attitudes to mathematics	2008	Mathematics	Survey of 1,104 students aged 11-13, and interview with students in 48 schools
National Audit Office	Educating the next generation of scientists	2010	Science and mathematics	Literature review and survey of 1274 students
OCR Examination Board	Science student survey	2005	Science	Survey of 950 students aged 13-16
Osborne and Collins	Pupils' views of the role and value of the science curriculum	2001	Science	Focus group study of 144 students aged 16
Springate <i>et al.</i>	Why choose physics and chemistry?: The influences on physics and chemistry subject choice on BME students. The factors affecting A-level and undergraduate subject choice in physics and chemistry by ethnic group.	2008a 2008b	Science	24 focus groups of 100 A-level students in total and 22 interview with undergraduates, all from under-represented ethnic groups
Reiss	Understanding science lessons: five years of science teaching	2000	Science	Longitudinal ethnography of 21 students aged 11-16 over five years
Rodd <i>et al.</i>	Undergraduates talk about their choice to study physics at university: what was key to their participation?	In press	Physics	Interviews with 50 undergraduates in 21 universities
Taconis and Kessels	How choosing science depends on students' individual fit to 'science culture'	2009	Science	Survey of 54 students aged 13 (in the Netherlands)
Van Langen and Dekker	Cross-national differences in participation in tertiary science, technology, engineering and mathematics education	2005	All STEM subjects	In-depth study of the views of 5-6 experts in four countries (The Netherlands, Sweden, United States, and United Kingdom)
Vidal Rodeiro	A-level subject choice in England: patterns of uptake and factors affecting subject preferences	2007	Mathematics and science	Survey of some 6,500 students aged 17-18 in 60 institutions