Impact assessment of STEM initiatives in improving educational outcomes

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Thesis abstract

Science, technology, engineering and mathematics (STEM) skills are globally valued. In United Kingdom, serious concerns have long been raised over the apparently insufficient number of young people studying science and maths beyond compulsory education. A range of STEM schemes have been introduced and sustained for over a decade now to raise attainment and improve attitudes of students in school towards pursuing STEM subjects and careers. These schemes call for huge investments of time, money, and resources. Over the same period, government reports have pointed out the pressing need for large scale evaluations to understand what works in public policy including education. This is important for accountability and to achieve better results by building on the best schemes for similar or reduced investments.

Increasing and widening participation in STEM are clearly priorities for UK's education policy. However, in the absence of proper evaluations the impact of spending on STEM schemes on raising attainment or improving participation remains unclear. Addressing this gap in literature, using official datasets in the form of National Pupil Database (NPD), this project evaluates the impact of STEM enrichment and enhancement activities on all pupils, disadvantaged pupils and schools with a large share of such pupils. A part of this research project tries to understand the reasons linked to underachievement of disadvantaged pupils in school science and maths through a systematic review.

To ensure comparability across evaluations, the public sector guidance for evaluation issued by the National STEM Centre was followed. Using a prospective longitudinal (2007-2014) research design, a 1000 intervention secondary schools and 80,000 students exposed to STEM interventions were followed-up from the beginning of key stage-3 to A-levels. The study uses various deprivation measures such as eligibility for free school meals (FSM), speaking English as an additional language (EAL) and ethnic minority status. The outcome measures considered are school GCSE performances in science and maths, individual pupil attainment in GCSE science and maths, and continued post-16 participation in STEM subjects.

Correlation-regression approaches are used and a range of effect sizes have been calculated to estimate the impact. Results show overall science and maths results have improved for schools, students and disadvantaged pupils (since 2007). However, this success cannot be

attributed to STEM enrichment and enhancement activities, because the improvements are not peculiar to schools known to have been involved in STEM interventions. Synthesising 771 research reports, the systematic review concludes that a range of individual, social, family and school related factors interact to holdback a child from realising their full academic potential. Recommendations from this evaluation research project should be of particular interest to policy makers, schools, educators, STEM activity providers and anybody working towards improvement of the learning trajectories of disadvantaged students.

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List of Abbreviations

CBI - The Confederation of British Industry

DBIS - Department of Business Innovation and Skills

DCSF - The Department for Children, Schools and Families

DfE - Department for Education

EAL - English as an Additional Language

GCSE - General Certificate of Secondary Education

HEFCE - Higher Education Funding Council for England

IDACI - Income Deprivation Affecting Children

LSYPE - Longitudinal Study of Young People in England

NAU - The National Audit Office, UK

NPD - National Pupil Database

NVQ - National Vocational Qualification

QCA - The Qualifications and Curriculum Authority

UPN - Unique Pupil Number

SCORE - Science Community Representing Education

SEN - Special Educational Needs

SES - Socioeconomic Status

STEM - Science, Technology, Engineering and Mathematics

TIMSS - Trends in International Mathematics and Science Study

TISME - The Targeted Initiative on Science and Mathematics Education

UCAS - The Universities and Colleges Admissions Service

Declaration

Some sections of the results chapter have been published in The Conversation, a copy of which has been included in the Appendix.

Some articles are currently under peer-review at the time of writing-up of this thesis - a discussion article on Emergence of STEM initiatives has been submitted to Kaleidoscope, the systematic review protocol has been registered with PROSPERO.

Statement of copyright

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Chapter 1 Introduction

1.1 Statement of the problem

During the last decade, STEM education was increasingly seen as a key contributor in providing a highly skilled workforce for continued economic development of the United Kingdom (UK). The Science Council launched in 2003, is a membership organisation in the UK that brings together forty-one learned societies and professional bodies across science and its application based disciplines. It is known for undertaking research and analysis into the nature of current and future science workforce and for providing a voice for policy issues affecting the science community. Research commissioned by the Science Council in 2010 suggested that by 2017 over 58% of all new jobs will require Science, Technology, Engineering and Mathematics (STEM) skills (Garnham, 2011). This demand for STEM skills was over and above the national demand at that time (but see UKCES 2015, and Smith and Gorard 2011).

A good indicator of the ease of meeting this future demand could come from an estimation of the number of students studying STEM subjects after compulsory education. The Office for Standards in Education, Children's Services and Skills (Ofsted) inspects and regulates - a) services that care for children and young people, and b) services providing education and skills for learners of all ages in the country. Thus, an evidence-based forecast regarding the possibility of meeting predicted STEM demand was likely to be reflected in Ofsted reports. However, Ofsted reports (2011a, 2011b) showed student progression rates to specialist science and maths courses were very low. The 2011 report indicated that although enrolment to science courses in colleges had improved in recent years, the quality of provision remained variable and in 2009/10 the inspection outcomes for science were rated poor.

A difficulty was thus foreseen in meeting the anticipated STEM skills demand. This is because factors affecting student subject choices are deeply embedded in a specific social and educational framework (Homer et al, 20114). They cannot be easily shifted and there are no ready policy measures that can change the picture. To combat this problem, a wide ranging set of outreach programmes targeting different sectors were designed. These programmes operated at local and national level and were funded by government, private organisations and educational charities. However, neither the perceived problem of STEM skills shortage nor the implementation of schemes is very recent. Sustained efforts have been made since at least the start of 2000 to encourage student engagement in STEM higher education.

Evidence regarding the key influence of families, schools and neighbourhoods on young people's STEM aspirations have all been reported (Bryant, 2007; Hanson, 2011; Vaz, 2014). At the individual level, motivation and aspirations have been shown to be positively linked to academic attainment and engagement (Gorard et al., 2012). An efficient approach towards sustaining pupil interests in STEM would thus be expected to incorporate school effects, consider cognitive elements and work towards raising pupil attitudes and aspirations. Such an initiative would also have to remain unaffected by barriers in education such as those that might be caused by participants' socioeconomic status, gender, ethnicity and other deprivation measures.

One such initiative which fit well into the criteria above was the introduction of STEM informal education to enthuse young minds. It was hoped these activities would expose students to the fascinating aspects of STEM subjects/careers and break the myth held by young people – 'STEM is meant only for the brainy' (TISME, 2013), thereby, encouraging pupil participation in STEM subjects. This thesis maps some policies related to these interventions and evaluates how successful one such approach has been – STEM enrichment and enhancement activities.

1.2 Policy background

The Trends in International Mathematics and Science Study (TIMSS, 2007) uses internationally comparative assessments dedicated to improving teaching and learning in mathematics and science for students around the world. This study is carried out every four years at the fourth and eighth grades. TIMSS also provides data about trends in mathematics and science achievement over time. To inform educational policy in the participating countries, this world-wide assessment research project collects extensive background information that addresses concerns about the quantity, quality, and content of instruction. For example, TIMSS 2007 collected detailed information about mathematics and science curriculum coverage and implementation, as well as teacher preparation, resource availability, and the use of technology. The research reports showed English pupils' actual achievement in maths had improved between 1995 and 2007. The study also concluded that students with positive attitudes towards these subjects attained higher.

The Targeted Initiative on Science and Mathematics Education (TISME, 2010-2014) was a research programme funded by the ESRC in partnership with the Gatsby Charitable Foundation, The Institute of Physics and the Association of Science Education. The programme was launched in the summer of 2010 and ran until 2014. Through a range of research studies and dissemination activities, TISME aimed to find new ways to encourage children and young people to greater participation, engagement, achievement and understanding of Science and Mathematics. The five major research projects were - ASPIRES, EISER, epiSTEMe, ICCAMS and UPMAP. The TISME study pointed out students' aspiration by the age of 14 gives a good indication of their willingness to continue with STEM when they get older. Thus, the earlier the intervention the more effective it is likely to be.

However, the proportion of young people in United Kingdom with a positive attitude towards maths was around ten percentage points below the international average in 2007 (UK Parliament Report, 2007 cited in DfE, 2010). Policymakers thus targeted STEM attrition in schools, with the rationale of retaining more students in science and maths in secondary school – supposedly a low-cost, fast and efficient way of producing the STEM professionals the nation would need. Several funded STEM enhancement and enrichment activities were run to motivate students to pursue science and maths beyond compulsory education. Some of these initiatives aimed to increase knowledge, while others focussed on raising attainment and participation by adopting different strategies to stimulate young minds. This worked on the notion that students achieving higher in science and maths would be more likely to continue studying these subjects.

In addition to increasing STEM participation a pressing concern faced by the government was the underrepresentation of disadvantaged pupils in STEM education and careers. The widening participation (WP) agenda was the government's response to this unrelenting problem. WP seeks to remediate unfair under-representation of certain social classes, ethnic or language groups in higher education (HE). Attempts have been made by governments to increase the participation of under-represented groups in HE. For social justice, efforts are still being made to provide high quality education and training alongside venues for life-long learning and equality of opportunities in employment.

It is sometimes contested that, in trying to foster social justice, greater access for students from under-represented groups in HE with a low population share, might be unfair for groups with a higher share in population (Brink, 2008). Especially as HE participation has been slowly widening for decades. However, the above claims are largely unwarranted. This is because, opportunities for pre- and post-compulsory education and training are available to the entire population but research reports still reflect under-representation of certain groups qualifying for deprivation measures, suggesting a continuing problem.

A centrally coordinated database of STEM activities being implemented locally or nationally was not available until recently. Beginning in 2000 the initiatives, schemes and budget have all increased considerably. However, major studies or surveys of participating schools and students, looking at the medium or long term impact the schemes have in improving take up, performance and achievement in STEM subjects are relatively scarce (Wynarczyk 2008, 2009). There have of course been a range of short term program evaluations which capture pupils' and teacher's experiences during and immediately after the programme but these have little or nothing to do with solid evidence about whether students' lives were changed. This new research is one of the first evaluations of the impact some of these enrichment and enhancement activities have had on long term outcomes, such as raising school attainment, narrowing the achievement gap and continuing participation.

1.3 Research Questions

This thesis began by looking at the major factors which have been identified in academic literature as being linked to underachievement of disadvantaged pupils. Rather than doing a traditional narrative literature review a systematic approach was followed. This systematic review addresses the research questions:

RQ 1. Which factors are linked to underachievement of disadvantaged pupils in school science and maths education?
RQ 2. What recommendations are available from literature for improvement?

The primary focus of this project was to assess whether participation in the range of STEM initiatives can ameliorate these factors associated with the attainment and participation of disadvantaged pupils. STEM interventions are intended to motivate by increasing knowledge and raising curiosity. Informal STEM education has thus been supported by government and external agencies with the belief that it will effectively raise science and maths achievement by adopting a student-focussed approach. Some of these schemes operate on the theory of learning-by-doing and offer practical hands-on activities to students outside the classroom atmosphere. These STEM initiatives were implemented and have been run for nearly a decade now for a very good cause, to improve young people's attitudes towards STEM subjects to support longer term engagement in STEM subjects and careers. However, as the government reports (DfES 2004, 2006) point out it is extremely important to evaluate their impact. Therefore, the main research questions being addressed are:

RQ 3. Does continued participation in enrichment and enhancement activities raise school attainment levels?
RQ 4. Can STEM activities effectively reduce attainment gaps between underprivileged pupils and their peers?
RQ 5. What is the impact of STEM initiatives in widening STEM participation of students from disadvantaged backgrounds?

1.4 The nature of this thesis

This thesis is divided into seven chapters. The next chapter provides a detailed account of the STEM education policy background. It is divided into seven sections and covers the major literature around which the project was built. This chapter opens with the importance of STEM education. It tries to answer why governments over the years have felt the need to allocate funds and resources in trying to boost post-16 participation in STEM. The next section takes up the case of four home nations in United Kingdom in the STEM scenario and explains what is unique about England. Section three introduces the concept of STEM initiatives while section four deals with the current STEM agenda in England. Section five explains the need for the implementation of the widening participation policy. Section six discusses the role of attitudes and aspirations in raising attainment and participation in STEM as shown in literature. Section seven summarises the various types of enrichment and enhancement activities currently being administered as a policy initiative across schools.

Chapter three highlights the contribution of this thesis, the need to address this issue, who will benefit from the research findings and how the study will add to what is already known about the problem.

Chapter four describes the overall approach – research design and methods. It summarises the designs involved in the review and secondary data study, data collection procedures, and ethical issues. Chapter five reports data analysis. The sections here deal separately with datasets as provided by NPD – school level attainment data, pupil level attainment data, post-

16 pupil STEM participation data. Chapter six summarises the results in four subsections – systematic review, maths educational attainment, science educational attainment and STEM participation.

Chapter seven summarises the conclusions that can be drawn from the study. The last chapter also offers the implications of research findings, limitations of this study, and recommendations for practice and further warranted research.

Chapter 2 STEM education policy

"A strong supply of people with science, technology, engineering and mathematics skills is important to promote innovation, exploit new technologies, produce world-class scientists and for the UK to compete internationally."

- *Educating the next generation of scientists, Department for Education, 2011*

2.1 STEM education - should it matter?

STEM, an acronym for science, technology, engineering and mathematics, is used to address education policy, subject choices, programmes, careers and practice in education. As an area of concern it has implications for workforce and technology development. For the purpose of this thesis, STEM refers to STEM qualifications (science, maths and equivalents for level 2 qualifications) which enable progression into further STEM study (level 3) or a STEM occupation. This includes the 'hard' sciences taught as part of the secondary school National Curriculum and mathematics. For a later part of the study involving the longitudinal component which follows up the learning trajectories of pupils, STEM includes specialist science and mathematics courses, physics, chemistry, biology, design & technology, information & communication technology engineering, medicine and allied fields.

2.1.1 Importance of the issue

STEM qualifications are valued. This is because almost every industry requires workers with STEM skills – sectors including tourism, entertainment, health and medical services, business, information technology, ecosystems, energy, mining, materials, and manufacturing, logistics and operations, aerospace and defense. STEM skills are thus in high demand across the workforce, not just for clearly STEM-related jobs.

In the UK, as in virtually every developed country, it is widely accepted that more people are required studying and working in STEM at all levels. The Council for Industry and Higher Education report (CIHE, 2009) looked into the demand for STEM graduates and postgraduates. The report concluded, "… the workforce of the future will increasingly require higher-level skills as structural adjustments in the economy force businesses to move up the value chain. These jobs of the future will increasingly require people with the capabilities that a STEM qualification provides".

2.1.2 Evidence about STEM skills shortage – labour market returns

STEM industries are vital elements of the UK economy and are predicted to expand relative to other fields. For example the Royal Academy of Engineering (2012) reported more than 100,000 STEM graduates would be needed per annum for the period 2012-2020. Only 90,000 graduate each year in STEM. This includes international students and those who do not choose STEM occupations. There is thus a reasonably widespread consensus that there is a STEM skills gap and that this gap is growing. It is feared this lack of both graduates and technically qualified workers in particular STEM sectors will impact negatively on the UK's long term economic competitiveness. One pointer of whether employers really do value STEM skills above more general skills is the remuneration they pay to STEM qualified individuals. Maths for example commands the highest earnings in the job market and roles in technology and science are paid 20 percent more than other jobs (Elizabeth Truss, Welcome speech at the launch of Big Bang Fair, Birmingham, 2014).

Labour market reports suggest the demand for them is likely to increase further. This forecast is further supported by some organisations and recent reports. The Confederation of British Industry (CBI), representing 24,000 employers, urged the UK Government to slash tuition fees for STEM subjects to help overcome the "skills crunch", which could threaten the country's economic recovery (IB Times, March 12, 2014). Four out of five (80%) graduate jobs do not require a specific degree discipline, but studying STEM subjects gives students a competitive advantage in the labour market. When asked whether they prefer any particular degree subject when recruiting graduates, half of the employers said they prefer those with STEM degrees (CBI, 2012).

Research findings suggest some STEM degree subjects have greater labour market value than arts and humanities subjects (Sloane and O'Leary, 2004; Walker and Zhu, 2010 all cited in Greenwood, 2011). The results from this literature are mixed. Sloane and O'Leary (2004) found very high wage premium for STEM degree subjects such as electrical engineering, mechanical engineering and mathematics and computing. However, Walker and Zhu (2010) found higher wage premium for economics, management and law but not for a number of science subjects, such as biology. Whilst it is beyond the scope of this thesis to consider labour market returns for specific STEM subjects in much detail, the overall value of STEM at degree and sub degree levels of qualification cannot be underestimated.

2.1.3 An unconvincing account?

Alarms were raised about the drop in attitudes towards Science and Mathematics education. Educational research, policies and resources were thus channelized towards improving and increasing participation in STEM education. The Royal Society (2011) expressed serious concern over the insufficient conversion numbers of 16-19 year olds studying science and mathematics into Science, Technology, Engineering and Mathematics (STEM) graduates. A seemingly self-perpetuating cycle was thought to have been established, with too few scientists and mathematicians being produced to work, help, inspire and educate the next generation.

However, some academic literature suggests there is an over play of STEM shortage and the lack of significant evidence does not persuade one of the gripping account. Studies following up university applications, admissions and graduate destinations suggest that any deficit may be exaggerated (Smith and Gorard, 2011; UKCES, 2015).

2.1.4 Desirable STEM skills

Previous research has shown that most academic qualifications and higher level vocational qualifications are significantly appreciated in the UK labour market (Dearden et al., 2002; Dickerson 2005). It thus appears from this literature base as if the skills embodied in these qualifications are valued by employers. However, some literature has also indicated that many vocational qualifications, particularly at lower levels, have considerably lower labour market value in terms of wages, but offer an increased probability of being in employment (Dearden et al. 2004; McIntosh, 2004; Dickerson 2005; Jenkins, Greenwood and Vignoles, 2007 all cited in Greenwood, 2011). A gender based difference is also noted in the wage return to NVQ2 qualifications, largely nonexistent for men but positive for women (De Coulon and Vignoles, 2008). The wage returns for the same qualifications were also higher when they were acquired through an employer (Dearden et al, 2004; Jenkins et al. 2007).

The value of many credentials, including NVQ2, varies substantially by sector and the occupation of the individual (McIntosh, 2004, Dearden et al. 2004, Dickenson and Vignoles, 2007; Jenkins et al. 2007). A possible explanation of these inconsistencies could be the value of the qualification acquired differs according to the precise skills learnt and how those skills are used in the labour market. These findings suggest the value of vocational qualifications are likely to vary across subject areas – between STEM and non-STEM subjects and equally likely amongst various STEM subjects.

Labour market Reports (SEMTA, 2006) suggest there are plenty of STEM graduates but not with the STEM skills required for the kind of jobs available. Higher education entry requirements suggest having only a single science qualification is not encouraged for entry to many STEM degrees. Across UK, the proportion of students with a single biology qualification for instance is by comparison very large (possibly alongside geography or psychology). This may allow entry to psychology, sports, environmental sciences or nursing but they are ineligible to study biological sciences at many higher education institutions as opposed to those who have studied chemistry and physics as well.

This argument is supported by the 2012 report of the Royal Academy of Engineering. The number of entries in the cohort taking A-levels in England in 2009/10 was 411,000. Of these:

- 280,000 achieved A levels not including any in STEM subjects
- 131,230 achieved one or more STEM A levels
- 68,700 achieved Mathematics A level
- 31,200 achieved three or more STEM A levels
- 27,200 achieved Physics A level
- 20,700 achieved both Mathematics and Physics A level

The number of children studying separate GCSE biology, chemistry and physics (known as 'Triple Science' when studied together) has risen by almost 150% between 2004-05 and 2009-10 (House of Commons, 2010-11). Triple Science is particularly relevant to the Government's aim of increasing the supply of scientists, as pupils studying Triple Science at GCSE are more likely than those studying combined science to choose and succeed in science at A-level and degree level.

Thus while there has been an increase in STEM participation, students are not necessarily making informed choices or perhaps equally likely are not motivated to pursue STEM careers. A student studying a STEM subject at A-levels does not necessarily follow up this subject for a specialist degree or career. The conversion rate from A-levels to career choices declines for Arts and Humanities as well, and none of the subjects have a 100% conversion rate; the dip however appears to be more pronounced for STEM (State of the Nation Report, 2011). While it is not desirable to have mostly STEM graduates in the community, STEM literacy certainly increases student’ understanding of how things work besides improving their use of technologies. Engineering for instance, is directly involved in problem solving and innovation – two high priority themes on every nation's agenda. STEM curriculum incorporates group activities and laboratory investigations thereby, providing students with the opportunity to develop essential 21st century skills like higher level thinking, teamwork, problem solving, innovative solutions and effective communication (DBIS, 2010).

Thereby, citizens are prepared to make decisions about personal health, energy efficiency, environmental quality, resource use and national security. Indeed the competencies needed to understand and address such issues, from personal to global perspectives are as clearly linked to knowledge in STEM disciplines as they are to economics, politics and cultural values. Yet another reliable indicator for the need to boost STEM literacy are the measures taken by the Government, policies and availability of funding resources for priority areas and STEM education clearly is one of them.

STEM education matters. First, UK needs more people with STEM skills. Second, there is a greater need for specialist qualifications than current vocational qualifications as is evident from wage returns. However, this could vary subject-wise and warrants more focussed investigation. Third, STEM subjects offer valuable skills sets. There is a growing concern over STEM education – not only in terms of pupil attitudes, achievement, take-up and drop-outs but also in terms of efforts made by the government and the effectiveness of these efforts.

2.2 Current concerns for STEM education in the UK

The current landscape of mainstream science education in the United Kingdom operates at two different levels - a) 'Science for All' - Pre-16 compulsory science education, delivered with the belief that science has something to suit students of all abilities and aspirations. It is important for every citizen to have a good understanding of the basic sciences and maths. b) 'Science for progression' – STEM take-up is optional for the post-16 age group. The government considers it important to have more people studying and working in STEM at all levels for the country's advancement (SCORE, 2010).

2.2.1 Number of students studying STEM subjects

A comparison was made amongst the four home nations regarding progression into STEM courses. The enquiry (Royal Society, 2011) revealed the proportion of students completing full A-levels in science and maths in England is far lower than the equivalent proportion taking highers/advanced highers in Scotland. In Scotland, almost 50% of highers students take at least one science or Mathematics qualification compared to only 28% of A-level students in England (Table 2.1).

Table 2.1 Mainstream science qualifications as function of cohort-size [(a)]

	A-levels			Highers
	England	Wales	N Ireland	Scotland
Cohort size	283,798	15,087	11,805	36,654 [(d)]
Numbers taking core sciences	78,540	4,008	4,412	18,233
% cohort taking core sciences	27.7% (28.6%)[(b)] (28.9%)[(c)]	26.6% (27.5%)[(b)] (32.2%)[(c)]	37.4% (38.2%)[(b)] (37.6%)[(c)]	49.7% (50.1%)[(b)] (49.4%)[(c)]
(a)A proportion of these students also took Mathematics (b)Equivalent percentage for 2007 (c)Equivalent percentage for 2005 (d)Includes candidates taking Highers and Advanced Highers				

Source: State of the nation report, 2011

In the UK as a whole, only 17% of 16-18 year olds study sciences or mathematics (Royal Society, 2012). To deal with the problem a recommendation given by the Royal Society was to reform A-levels in England so that they looked more like the Scottish system or had a Baccalaureate flavour. It was hoped allowing students to continue longer with science and mathematics post-16 might be helpful. The Advisory Committee on Mathematics education (ACME) suggested similar reforms for Mathematics.

2.2.2 The quality of the 'pool' of students opting for sciences

There have been conflicting reports about the prevalence of STEM qualifications. Some reports suggest the number of students taking a science qualification during A-levels in England has been slowly increasing. Others however suggest there is still a shortage of STEM skills. This is because beyond compulsory education many students may opt for a single A-level STEM subject. However, this single STEM qualification does not make them eligible for entry into undergraduate STEM programmes. Across the UK, the proportion of students with a single science qualification for instance is by comparison very large. However, students who have a single A-level/Higher in biology, for example, have a reduced number of STEM degree options.

Biological Sciences, one of the most popular subject choices across all home nations in UK is thus more often used as a 'bridge subject' between the arts and sciences. This is gradually leading to a decline in availability of biology subject specialists, teachers and scientists across UK. STEM 'deserts' have been created and these are expected to become more pronounced with the passage of time. This is more noticeable in England and relatively better in Scotland – where students make informed subject choices and then take up STEM careers (Royal Society, 2011).

2.2.3 Progression to STEM higher education

To understand how cohort size limits the overall supply of STEM skills to higher education and beyond, destinations of school and college leavers need to be analysed. Students holding science and mathematics qualifications have a range of options before them, only one of which might be to study a STEM subject at degree level. An analysis of data relating to further studies in Higher Education in detail, for example by considering UCAS acceptance data, could be an interesting avenue for further research.

Plausible explanations as to why students might not choose to continue studying science and mathematics at university mirror those at the post-16 boundary: perceived difficulty, low prior attainment or a lack of knowledge about the types of STEM subject choices that can lead to a STEM degree. If higher education funding is cut and tuition fees rise, these STEM deserts are expected to expand. The State of the nation report, (The Royal Society, 2011) summarised the number of students studying A-level core sciences and other sciences in England during 2005, 2007 and 2009. Clearly, the lowest share was of those students who study core sciences (biological sciences and/or chemistry and/or physics) as well as other science subjects as seen in table 2.2 below.

Table 2.2 Number of 16-18 year olds in England taking GCE A-level sciences

Core Sciences	Other Sciences	2005		2007		2009	
		Numbers	% of cohort	Numbers	% of cohort	Numbers	% of cohort
No	No	145,676	58	154,630	60	179,234	63
	Yes	33,554	13	30,048	12	26,024	9
Total not taking core sciences		179,230	71	184,678	71	205,258	72
Yes	No	61,747	25	64,289	25	70,677	25
	Yes	10,933	4	9,518	4	7,863	3
Total taking core sciences		72,680	29	73,807	29	78,540	28
Total size of GCE A-level (only) cohort		251,910		258,485		283, 798	

Source: State of the nation report, 2011

2.2.4 Are Scottish Highers students better prepared for STEM careers?

The importance of human biology in Scotland (Scottish highers) is well known. This subject has attracted increasing levels of participation since the mid-1990s. In complete contrast GCE A-level human biology is taken by so few students in the other home nations that the national educational authorities in England, Wales and Northern Ireland produce combined data for biological sciences which includes both biology and human biology. Biological sciences despite being quite popular across all home nations, a more even balance of core science combinations is observed in Scotland.

Findings from the government reports thus suggest Scotland outperforms rest of the UK in atleast two measures:

i. The proportion of the highers cohort in Scotland taking core sciences with/without mathematics (50%) is greater than the equivalent proprtion of A-level cohorts in England (28%), Wales (27%) and Northern Ireland (37%).
ii. Scottish students appear to be better prepared for STEM higher education as shown in Table 2.1 and 2.3

2.2.5 Are students making uninformed subject choices?

Entry requirements to STEM degrees vary between Universities and even between different departments at the same university. Whilst efforts to improve curriculum design and teaching-learning strategies have been made, the inconsistencies in STEM degree entry requirements are yet to be explored. The SCORE Admission Tutors: Round Table Discussion, 2010 concluded admissions tutors highly value mathematics as a subject. This is because, competence in mathematics is deemed a very important element in preparing young people for STEM degrees. However, it was acknowledged by admissions tutors that this is not always specified clearly in the entry requirements information. Physics admissions tutors hinted a preference for applicants with Further Maths A-level 2 but were unlikely to specify this requirement as it could drive down numbers. Representatives from biology departments also stated that applicants with Maths A-level might receive lower point offers.

Prospective STEM degree applicants are required to hold at least two STEM A-levels. But in terms of making offers, universities are changing their admissions policies in response to grade inflation. With more and more students obtaining the required grades, the screening requirements have been raised to three STEM related A-levels and require an applicant's grades to be achieved in the first sitting, without retakes. These changes however are not made clear to prospective students (SCORE, 2010).

It is important to make all of this information available to young people at the right stage to help inform their A-level choices. Failing which there is always a danger of students taking up the wrong combination of subjects for a HE course/career they want to pursue due to lack of clarity of entry requirements. Similar to comparisons made earlier, the percentage of 16-18 year olds taking core sciences in combination with mathematics and further mathematics across all institution types in England has by far always been much lower than Scotland (Table 2.3).

Table 2.3 Percentage of 16-18 year olds taking core sciences and mathematics

Home nation	2005	2007	2009
England	8.6	10	10.7
Scotland	87.6	89.9	88.7

Source: State of the Nation Report, Royal Society 2012

2.2.6 Lack of attitudes and aspirations

Despite the high demand for STEM skills there is concern over the insufficient interest in STEM subjects among students in school. A major reason why children and young people give up science and maths may be a deficit in enjoyment and interest. In the United Kingdom, the proportion of young people with a positive attitude towards maths was around ten percentage points below the international average in 2007 (UK Parliament Report cited in DfE, 2010). While acknowledging pupil enjoyment is important, this declining interest was not considered to be a major problem. This is because English pupils' actual achievement in science and maths had been among the most improved in the Trends in International Mathematics and Science Study (TIMSS, 2007) between 1995 and 2007. The other justification given was that, countries where pupils achieved most in science and maths were not necessarily the ones whose children had the most positive attitudes to the subjects.

This opinion was further supported by The Targeted Initiative on Science and Mathematics Education (TISME, 2013) research which showed a lack of interest in science is not 'the problem' underlying low post-16 participation rates. Despite liking science (and expressing an interest in further study) many young people do not plan to study science post-16 either because they have very constricted ideas about the 'usefulness' of science qualifications or perhaps they do not feel 'clever' enough to pursue post-16 science and science careers. Students' aspiration by the age of 14 gives a good indication as to whether they will continue with STEM when they get older (TISME, 2013). Drawing on two projects: ASPIRES (Science Aspirations and Career Choice: Age 10-14), five year longitudinal study of how children in years 6-9 develop science and career aspirations; and UPMAP (Understanding Participation rates in post-16 Mathematics and Physics, a three year longitudinal study of the factors that influence school students to continue with mathematics or physics after the age of 16, TISME suggested science careers (excluding medicine) are not popular aspirations amongst 10-14 year olds. This national survey of over 9,000 pupils (10-11year olds) showed that while most young people report enjoying science in and out of school, few aspire science careers.

A very important aspect considered in this context was, how often do visitors go to schools to talk about science and engineering that is happening in the real world to sustain interests in STEM? These could be people like doctors, engineers, scientists, forensic experts successful in STEM careers who merely by sharing their experiences could help students understand what these careers can offer. The Department of Business Innovation and Skills

DBIS (2010) administered an online survey questionnaire to test students' attitudes towards science. The sample included 500 learners aged 14-16 undertaking GCSEs at that time. One of the questions asked in the survey was, "How often, if at all, do visitors come to your school to talk to you about science and engineering happening in the real world?" Most students never had a visitor in school talking to them about STEM in real world (figure 1).

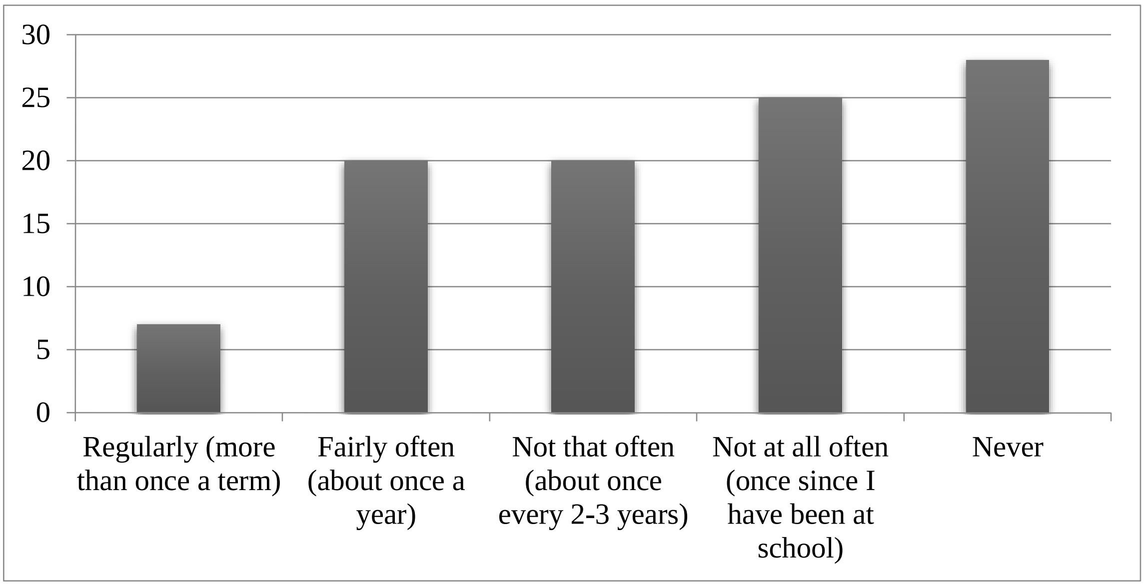


Figure 1 How often do visitors come to your school to talk about STEM?

Graph constructed from DBIS survey data, 2010

2.2.7 Perceived difficulty of STEM subjects

In terms of understanding of the subject matter preconception of students plays an important role in subject-choice beyond compulsory education. Gender based studies on subject choices made by students for example, suggest male dominated subjects like Physics have continued to remain so in some cases and at worse have seen a decline in the number of girls opting for them. There could be a whole range of factors behind subject choices made by students one of which is cognitive. Science subjects have been shown to be difficult as compared to non-science subjects. As such when an option is available not many students prefer taking up a combination of core sciences and other STEM subjects.

2.2.8 Difficulty in scoring (UCAS)

The reliability of UCAS point scoring system has been questioned quite often. Is it fair to treat all subjects as equally difficult? Reviewing existing work on subject examinations, the 'Inter subject Comparability study' (QCA, 2008) affirmed 'there are no substantial or consistent differences in standards between any subjects at any level'. Subject choices at A-level are however made by students fully aware of the fact that it is difficult to obtain a higher grade in the science subjects. This perception is worsened by the UCAS tariff, which awards the same points to all A-level subjects.

In July 2010, UCAS launched the Qualifications Information Review to understand the information needs of higher education institutions, and consider whether a useful means of supporting fair access was being provided. SCORE commissioned the Centre for Evaluation and Monitoring (CEM), Durham University to investigate the grading severity of A-level examinations in different subjects. The research analysed 250,000 A-level results over five robust statistical methods and found that it is easier to achieve top grades in subjects like Media Studies and Psychology than it is when taking subjects like Maths, Physics and Chemistry. One of the suggested remedial approaches for issues of grading severity was changing the way grades are used by introducing a scaling system. This meant some grades could be acknowledged to be worth more than others for certain purposes such as university admissions.

2.2.9 Ignorance of STEM career choices

The Telegraph (2012) listed the top ten degree subjects for getting a job in the UK (Table 2.4). The table shows jobs arising from STEM subjects are in high demand. Making this kind of information available to students could make STEM career choices more lucrative.

Table 2.4 Graduate jobs: Top 10 degree subjects for getting a job

Rank	Subjects	% graduates who had a job within six months
1	Medicine, Dentistry and Veterinary Sciences	99.4
2	Education	94.8
3	Subjects allied to medicine (Biomedical Science and Neurology)	91.9
4	Law	91.9
5	Agriculture and related subjects	91.3
6	Biological Sciences	90.9
7	Languages	90.3
8	Historical and Philosophical Studies	90.1
9	Mathematics	89.9
10	Physics	89.9

Data source: Telegraph, 2012

It would be in the interest of researchers and policy makers to design a longitudinal study following up learning trajectories of students from A-level science courses over a period of time to track their career progression. It will be interesting to find out where A-level science students are - if not in the higher education system.

2.2.10 Unavailability of teaching/learning resources

Until 2012 Physics was the least popular option amongst all STEM subjects. In 2012 Physics gained a place in top ten subject choices at A-levels. It is however not clear what was the real motivation amongst students for this increase. ‘Has Physics become cool again?’ asked Ghosh in BBC news (2012). It could be that recent discoveries in the scientific world impressed students or perhaps vacancies in the related job sectors was the guiding force. A strong emphasis presently lies on specialist subject choices and combinations, hoping more students will opt for these subjects. One of the barriers widely cited is the lack of teaching and learning resources and even hands-on practical activities to fascinate and enthuse young minds. The more disadvantaged area of location of a school, the lesser resources are available to them in terms of access to HEIs, teaching work force and out-of-school enrichment centres.

2.2.11 Rising tuition fees – Is higher education becoming a luxury?

2012 saw the tuition fees rise up to £9,000 at many universities for home students in the UK. An investigation report by the Independent Commission on Fees chaired by Will Hutton, principal of Hertford College, Oxford showed a drop in the number of university applicants in England by 8.8%. This meant some 15,000 "lost" students, who might otherwise have been expected to apply for a place on a degree course (The Guardian, 2012). Students in the UK now typically graduate with huge debts hunting for a job. This could be a major factor shunning students away from higher education. Laboratory based courses such as STEM subjects have an even higher fee in the UK.

This is contrary to the recent higher educational reforms in the United States. PhD students at The Graduate School of Arts and Sciences, Harvard University are charged full tuition for the first two years of study and have a reduced tuition fee during third and fourth years. Similarly, with the motive of offering high quality degree at low-costs, the government of Texas has announced a $10,000 degree scheme as a response to the soaring college tuition fee and student debt. Both of these examples serve the purpose of extrinsic financial motivation towards course completion rather than dropping-out of education. Recommendations have been made to the government towards actual cost reduction or the possibility of increased scholarships (TOI, 2012). It could be argued that the UK higher education system (STEM careers) would benefit if tuition fee costs are reduced for science subjects as compared to subjects that are saturated with subject specialists for example languages, arts and humanities.

2.3 STEM initiatives

Primary and secondary research, government reports and media articles have all voiced concerns about the sustainability of the next generation of scientists and engineers due to fewer number of young people wanting to pursue these subjects for over a decade now. This section discusses some of the measures initiated by the government in order to encourage students to take-up STEM subjects and stay-on in related fields.

After the 2012 Ofsted inspection SCORE issued generic grade descriptors and drafted supplementary subject specific guidance for inspectors of science. Over the next four years remedial measures were prioritised to improve the curriculum, qualifications, assessment, the school and college teaching workforce and the wider learning experience. Some of the prominent issues identified were:

2.3.1 The National Curriculum

The National Curriculum was originally envisaged as a guide to study in key subjects. It was expected to give parents and teachers confidence that students were acquiring the knowledge necessary at every level of study to make appropriate progress. However, over the years, the National Curriculum began covering more subjects, prescribing more outcomes and taking up more school time than originally intended. International comparisons showed England had fallen in the rankings of educational performance in reading, mathematics and science. High-performing jurisdictions (Singapore, Finland) had coherent and ambitious curricula that allowed for steady accumulation of knowledge, whereas, the National Curriculum had lost much of its initial focus (SCORE, 2012).

Science and Mathematics curricula needed to be inspiring and engaging for the high and not-so-high achieving, whilst developing of subject-specific knowledge and skills. Governments worked closely with experts from learned societies, the higher education sector and other key stake holders to develop appropriate subject curricula. The Education Select Committee recommended forming national subject committees to oversee the development of criteria for and accreditation of new A-levels. Proposals for a systematic and comprehensive review of the National Curriculum in England for 5-16 year olds were thus announced.

The revised National Curriculum was slimmed down to reflect a body of essential knowledge which all children should learn. This did not absorb majority of teaching time in schools. Individual schools and teachers thus had the freedom to construct their own programmes of study in subjects outside the National Curriculum and develop need specific approaches to learning. The National Curriculum was expected to compare favourably with the most successful international curricula, reflecting best collective wisdom about how children learn and what they should know.

2.3.2 Recruitment, retention and CPD of subject specialists

The 2007 McKinsey report, "How the world's best-performing school systems come out on top", compared successful education systems across the world to identify the factors crucial for providing best quality of education. The report concluded the quality of an education system ultimately depends on the quality of its teachers. Education for a strong STEM economy relies heavily on strong subject teaching – in terms of both number and quality of teachers recruited to teach STEM subjects. This is because as pupils progress they require specialist knowledge to challenge them. This is important for students to develop good understanding of the subject, achieve better and aim higher.

The estimated population of science and mathematics teachers in the UK is not correct (Royal Society, 2007a). This inaccuracy exists because there isn't a consensus on the definition of a "specialist" science or maths teacher (Royal Society, 2007; BBC, 2008a). Specialist teachers are not always the ones teaching at A-levels (Science Council, 2011). Also often they teach different subjects, a biology specialist teacher for example, could be teaching chemistry or physics. The shortage of science and maths teachers is thus worsened by lack of reliable data and statistics (Royal Society, 2008). The targets set by the Government are hence based on unreliable information and teacher shortages are likely to be much higher than what is perceived.

To address the unacceptable shortages, one of the recommendations (SCORE, 2012) was to recruit and perhaps more crucially to retain subject specialist teachers in secondary schools and colleges. These demands were to be met by working closely with employers, the STEM community and educational institutions to address weaknesses in the UK's educational systems. Schools were advised to run workshops and training sessions from time to time so that teachers stayed updated. Science and mathematics teachers were advised to undertake subject-specific continuing professional development (CPD) as part of their overall CPD entitlement. Funding was to be maintained for the National Science Learning Centre, the National Centre for Excellence in the Teaching of Mathematics and the Scottish Schools Equipment Research Centre, to allow these bodies to continue to support effective subject-specific CPD for science and mathematics teachers (Royal Society, 2012).

2.3.3 Career guidance for progression routes into higher education

Some science subjects despite being popular subject choices for A-levels, do not lead post-16 students to HEIs for a variety of reasons. This is often because they do not chose at least two science subjects in addition to Mathematics hence are ineligible for STEM specialist careers. Major programmes were to be introduced in collaboration with HEIs, government and private sector to run career guidance and counselling events for students in and out of schools.

In England, the Department for Business, Innovation and Skills launched new careers services. These were adequately equipped to provide high quality and easily accessible information, advice and guidance on STEM careers to school and college students. They were linked to STEM careers-related websites, such as, Future Morph and Maths Careers.

2.3.4 The role of awarding organisations

The increasing diversity of level 3 qualifications in England was asked to be reviewed and its impact on the number of students taking science and mathematics post-16 evaluated. Awarding organizations were advised to make available detailed data on the participation, attainment and progression of students taking their specifications in science and mathematics. In undertaking reforms to A-level qualifications in England, the Department for Education was advised to consider modifying their structure to enable students to study a wider range and increased number of subjects.

2.3.5 STEM motivation

Educational Neuroscience, is an understanding of neurological processes involved in learning. It maps factors that influence motivation to learn. Collaborations were encouraged between neuroscientists, cognitive psychologists and educational researchers. It was aimed at a more complete understanding of the factors underlying subject preferences and to provide any relevant information. Further investigation was advised to understand motivations for post-16 students' continuing with science and mathematics at university, with a view to take appropriate action for others.

Some suggested areas were, role models, for example, identifying whether the lack of female physics teachers affect girls' perceptions of physics. The Department for Education was advised to investigate the diversity of schooling structures in England to establish which of these is generally best suited to educating students and optimizing performance and progression in science and mathematics.

2.3.6 Better use of data

The UK Government and the Devolved Administrations were advised to make better use of the data collected on 5-19 science and mathematics education. Regular monitoring of the combinations of subjects and qualifications being taken up by young people could be helpful to understand progression from prior attainment and participation (as in Homer, 2014). This was deemed necessary to determine actions for improved performance of the education system. The unique Pupil Number (UPN), or equivalent, was to be set-up to follow school and college students into and through higher education (linked datasets) to make it easier to track student progression. Linking these records to details of STEM initiatives that young people may have experienced was expected to provide an efficient mechanism for measuring long-term impact.

2.3.7 Lessons from high performing jurisdictions

Over the past ten years the UK education system as measured by performance in the Organisation for economic co-operation and development's (OECD) Programme for international student assessment (PISA international league tables) was shown to have deteriorated. To ensure schools and young people, become internationally competitive again fundamental questions were raised about educational practice. The existing assessment model assumed that a certain proportion of young people will never be able to master crucial curriculum content. This led to an unjustified lowering of expectations early on. Expert panels recommended learning from the approach to assessment and pupil progression used in many high-performing jurisdictions, including the most successful South-East Asian education systems. This meant ensuring every pupil mastered subject content before the class moved on to tackle next part of the curriculum (Michael Gove, https://www.gov.uk/government/speeches/national-curriculum-review-initial-findings).

2.4 Current STEM agenda

The STEM education policy in United Kingdom as in most other developed countries focusses on increasing and widening STEM participation. UK is the world's sixth largest manufacturer, with an engineering turnover around £800 billion per year. Despite having one percent of the world's population share, it produces 10% of the world's top scientific research. Ironically, even though STEM graduates in UK have the potential to earn amongst the highest salaries of all new recruits, employers are finding it difficult to recruit STEM skilled staff.

Alongside need for a skilled STEM workforce, it is crucial that all young people, regardless of their future career pathway, have STEM knowledge and skills in an increasingly scientific and technological society. Hence, rather than leaving STEM subjects as a matter of choice, efforts are being made to increase STEM participation for UK's economic success. Government has thus long identified STEM education as a priority at both school and HE. Well equipped, effective and inspiring teachers/adults, are vital to raising students' enjoyment of, enthusiasm for, and achievement in STEM subjects.

2.4.1 Major STEM reports and their recommendations

The work of STEM organisations builds on government's ongoing strategies for developing a strong supply of scientists, engineers, technologists and mathematicians. Individuals and organisations working towards improvement of the quality of STEM education share the same objectives. The next section discusses some reports which have guided these goals.

2.4.1.1 SET for Success (Sir Roberts' Review, 2002)

During 2001, the government was concerned that the limited supply of STEM workforce could constrain UK's research, development and innovation performance. Clear strategies were framed during Budget 2001 to address the concerns – one of which was the commissioning of this review. The Review considered the supply of SET skills in the UK and the difficulties faced by employers in recruiting them. A number of problems were identified in the development of STEM skills in school, further and higher education, and the review made specific recommendations to government and the education sector to address these problems, including the establishment of the National Science Learning Centre.

2.4.1.2 Science and Innovation Investment Framework (2004)

The government published a ten-year investment framework for science and innovation. Ambitions for the STEM sector during the next decade were set out. The contribution to economic growth and public services, attributes and funding arrangements of a research system capable of delivering this were all highlighted. The importance of improving the flow of STEM qualified people into the economy was reiterated. Immediate action was to be taken a) to achieve a step change in the quality of science teachers in every school, college and university; b) improve pupil attainment for science at GCSE level; c) raise the numbers taking-up STEM subjects in post-16 education and in higher education; d) increase the proportion of better qualified students pursuing careers in research and development.

2.4.1.3 The STEM mapping review (2004)

This review investigated whether STEM initiatives addressed the concerns raised about the drop in demand of university places in STEM. Second, it tried to understand whether the perceived lack of supply of graduates and qualified technicians in the engineering and related professions including craft persons is being addressed. Finally, the review assessed whether the recommendations from Sir Roberts' report 'SET for Success' were being taken forward.

The first phase of the review extensively mapped STEM teaching and learning activities in STEM from primary to post graduate level collecting numeric and textual data as much as possible. STEM activity related information was collected across the DfES, other Government Departments and professional bodies/associations. The second phase of the project analysed data from the mapping exercise and drew findings. It externally assessed ongoing activities and identified gaps. Recommendations were formulated on how various activities might best be brought together. The third phase disseminated findings of the review.

The review showed that a plethora of STEM programmes were operating in the public and private sector. These schemes needed to be more coherent. This could be achieved through proper coordination between the activity providers in both sectors which was lacking at that time. Second, a lack of promoting and mainstreaming women/girls and ethnic minorities in STEM was noted. Third, the need for better evaluation of initiatives in relation to supply/demand was stressed upon. Finally, better links were to be made across schools, further education colleges, higher education institutions and employers to ensure a seamless transition across the key stages to degree level.

2.4.1.4 STEM Programme Report (2006)

A long-term plan was set out by the Science and Innovation Investment Framework (2004-2014) for a supply of STEM work force to support the science base. The STEM Programme, jointly managed by DfES and DTI (now DfE and BIS), was a part of this strategy. It examined the range of initiatives and looked for ways to enhance the effectiveness of government funding in increasing STEM literacy and the flow of qualified people into the STEM workforce.

The need to improve delivery of STEM initiatives for professional development of staff and enrichment of learners was identified. This was important to make the STEM system more coherent in terms of advice and access available for learning providers. The report explored how best to support STEM through compulsory, post-16 education and university; and how to implement STEM initiatives more effectively.

STEM Cohesion was seen as important. The report acknowledged the support available to STEM education in the UK from the government, businesses, industries, academia and charitable organisations. A strong need for closer collaboration between these supporting organisations was important to improve the effectiveness of STEM education support for schools and colleges. At the same time the report laid emphasis on maintaining diversity of choice of these initiatives.

Led by Sir John Holman a team at the National STEM Centre the STEM programme shortlisted eleven areas of high priority. These were teacher recruitment, continuing professional development, enhancement and enrichment activity, curriculum development, and infrastructure. Each of these action programmes were driven forward by a specialist Lead Organisation, working collaboratively with the National STEM Centre. Some of these identified action programmes relevant to the thesis are summarised below -

i. To improve the recruitment of teachers and lecturers in shortage subjects.
ii. To provide the right continuing professional development (CPD) by improving teaching and learning through CPD for mathematics and science teachers.
iii. To bring real world context and applications of STEM into schools and colleges by enhancing and enriching the science and maths curriculum.

iv. To introduce young people to the range of career opportunities that STEM study opens up by improving the quality of advice and guidance about STEM careers.

v. To get STEM curriculum and infrastructure right by widening access to formal science and mathematics curriculum for all.

vi. To improve upon the quality of practical work in science and capacity building of the national, regional and local infrastructure.

2.4.1.5 Race to the Top (Lord Sainsbury's Review, 2007)

In 2007 the UK science and innovation system was reviewed. UK's record of scientific discovery and rapidly growing share of high-technology manufacturing and knowledge-intensive services in the national GDP were acknowledged in the report. Opportunities to build on the successful policies that have been introduced in recent years were highlighted. Key recommendations included:

i. Improvement of science and technology teaching by raising the number of qualified STEM teachers.

ii. Increasing the number of young people studying triple science,

iii. Improving careers advice,

iv. Establishing a National Science Competition, and

v. Rationalising the many schemes to inspire young people to take up careers in science and engineering.

2.5 Why is widening participation in STEM education important?

"Educational disadvantage, starts in the womb – free maternal and child health care are an education imperative."

- Education for All, Global Monitoring Report, 2010

The UNESCO 2010, Global Monitoring Report, focused on reaching the most marginalised. All education systems, internationally, have to address problems of marginalisation. Chronic poverty, social exclusion and deprivations linked to race, conflict, neighbourhoods and disability can interact to put underprivileged groups into extreme educational disadvantage (Gorard, 2007; Strand, 2014). Sustained efforts are needed to ensure that children and young people regardless of their background can benefit equally from education's transformative power. This is one of the main reasons for having universal, compulsory and free early education in developed countries (Gorard & Smith, 2007).

Widening participation (WP), a major component of government's education policy in the United Kingdom is an attempt to increase the proportion of such people from under-represented groups. Lower income families, people with disabilities, women, ethnic minorities are all included in this category. Having emerged as one of the strategic objectives of the Higher Education Funding Council for England (HEFCE), it hopes to level the inequalities in participation between various groups in the society. This policy was originally linked to the Labour government's target of increasing participation in higher education to 50% by 2010. A number of measures, including the payment of financial incentives to universities and funding programmes like Aim higher have been run. Aim higher ran from 2004-2011 which saw the coming together of two programmes, 'Partnerships for progression' and 'Excellence challenge.' The partners included universities colleges, schools, training providers and connexions services.

WP works on the notion that disadvantaged social groups are unfairly under-represented in HE. It is expected that if these exclusion patterns in HE are checked they will provide a fulfilled life for individuals, a successful and developing economy, a genuinely participative democracy and equality of opportunity in employment and citizenship. It hopes to create a successful learning society, where everyone would have access to high quality education and training. There will be suitable opportunities for life-long learning and a higher education institution within geographical reach of everyone (Gorard et al, 2007)

One of the criticisms faced by the widening participation policy has been the anticipation that widening participation of underrepresented groups could mean bringing down the number of students from overrepresented groups. In the event of number of seats for college admissions staying constant and efforts being focussed to reduce the poverty gap, there has been concern of the likelihood of participation based on merit being compromised. If seats allotted to underrepresented groups are at the expense of overrepresented groups this would not be a fair allocation and social justice and equity would be compromised in a differently.

The government has spent enormous funds on WP activities since 1997. Several schemes are simultaneously working to increase access and widen participation in HE. Some of these measures include enriching teachers, providing learning resources, raising aspirations, offering scholarships, suggesting future pathways. The job market suggests plenty of jobs are available in the STEM sector at present as well as during the next few years. Opportunities for post-compulsory education and training are available to the entire adult population yet investigations reflect under-representation of certain groups – thereby suggesting a pervading problem. What could be the possible reasons?

One argument could be that students from lower socio-economic backgrounds and ethnic minorities have a smaller percentage share in the population right from the preliminary stages of education. Beyond post-16 education the ratio of participation decreases for overrepresented groups as well. Disadvantaged groups with a smaller population share would thus be expected to have lesser number of participants in HE. Further, progression rates to HE have been shown to decrease irrespective of social class.

2.5.1 Stratification in STEM education

Maths and science form a compulsory part of the national curriculum in England till the age of 16. However, beyond compulsory education a conscious choice needs to be made by every student whether to continue studying maths and science. This is really important as for admission to higher education in Science, Technology, Engineering and Maths (STEM) degree courses, a level3 maths qualification is a pre-requisite. From amongst the various level 2 qualification routes available, most students in English state maintained secondary schools choose to take the nation-wide examination - General Certificate of Secondary Education (GCSE).

Pre-existing records, official documents, large-scale national surveys suggest the stratification of educational outcomes in terms of pupil level impact indicators still persist (Strand, 2014; Gorard, 2010). A synthesis of these findings shows that national school intakes tend to be patterned and segregated by prior attainment and socio-economic factors. There is no evidence that compulsory schooling can undo the effect of uneven resources.

2.5.2 Attainment Gap

Attainment is important. Research shows students who achieve higher in GCSE mathematics and science are more likely to continue studying these subjects post-16. Improving attainment should thus be a logical effort to increase the pool of students taking up post-16 STEM education. However, equally qualified students from different socio-economic backgrounds do not follow similar learning trajectories? Literature suggests a clear stratification in the pattern of achievement and participation in STEM subjects. Students from deprived backgrounds have been shown to perform not so well academically. Subject-choices are made during A-levels. Modern foreign languages, History and Geography were the most common subject choices made by pupils from disadvantaged backgrounds (Research Report DFE-RR160, 2010)

Gender, ethnicity, poverty, disability, prior attainment and speaking English as an additional language have all been deemed to be measures of disadvantage by previous research and linked to underachievement. Educational research uses several measures of a lower socio-economic status such as eligibility for free school meals, neighbourhood statistics, and family income below a certain threshold. The attainment gap between poor pupils and their elite peers has been termed as the “poverty gradient” (Gorard et al, 2012). Analysis of attainment data for 2012/13 suggests this poverty gradient is much wider than gender gap or the gap between ethnic groups (Table 2.5). This suggests addressing research towards narrowing the poverty gradient is more crucial.

It is hoped that raising attainment of disadvantaged pupils might encourage them to study maths (Gorard, 2012). The 2010 commitments of “Education for All” and “Education for sustainable development” by the UK government has further strengthened and supported the widening participation policy.

Table 2.5 Percentage attainment by disadvantaged groups, 2012/13

Percentage pupils attaining 5+ A*-C including English & Maths (KS4_LEVEL2_EM)			
Groups	High achieving	Low achieving	% points difference
Language	First language English = 59.1	EAL = 56.2	2.9
Gender	Girls = 63.3	Boys = 53.8	9.5
Ethnicity	Chinese = 76.4	Black = 54.6	21.8
FSM	Non-FSM = 62.5	FSM pupils = 36.2	26.3
Disadvantaged pupils	Schools with high proportion of deprived pupils = 82.5	Schools with low proportion of deprived pupils = 45.6	36.9
SEN	No identified SEN = 69.2	SEN = 22.4	46.8

Source: National pupil database

2.5.3 Transforming lives

The unique power of education will certainly secure it a central place in the post-2020 development framework and in the plans of policy-makers in developed and developing countries alike. This is because it is remarkably an investment that pays off in every sphere of people's lives and aspirations. In most developed countries achievement disparities now outweigh enrolment inequalities. A considerable gap still exists between the average recorded school attainment of children from richer and poorer families in the UK – a "poverty gradient".

The augmenting demand for highly skilled Science, Technology, Engineering and Mathematics (STEM) graduates has led to the evolution of numerous initiatives to enthuse young learners to participate in STEM subjects. Significant investments in human capital have steered an increased participation in higher education during the last thirty years in United Kingdom. However, it could be argued that, this knowledge economy might create greater social and economic divides, polarising between those in relatively well paid, secure knowledge related jobs and those in poorly paid, lower skill jobs. One way of dampening this anticipated polarity could be by motivating students from deprived backgrounds to participate in STEM education.

Pupils staying in an area of disadvantage were shown to have benefitted the most in terms of future educational outcomes if they studied triple science. However, this option was not as widely available in areas of higher deprivation according to the UK National audit office (NAU 2010, State of the Nation report, 2014). This Lack of equality of access adds on as students make uninformed choices whilst already struggling to stay on in education. Thus, STEM education and in particular participation of those from disadvantaged backgrounds is of prime importance on grounds of equity, social justice, economic growth and wellbeing.

Education transforms lives by illuminating every stage of the journey and preventing transmission of poverty between generations by fuelling economic growth and improving people's chances of a healthier life. Mother's education for example has been shown to save millions of children (Gadikou et al., 2010) and reduce maternal deaths. Extending girl's education could save many more lives, as literate mothers are more likely to seek support and ensure their children are vaccinated averting severe diseases and containing those infectious (UNESCO, 2010). This ensures healthier societies and builds the foundations of democracy and good governance by fostering political participation, tolerance and social cohesion.

2.6 Raising attitudes and aspirations for improving STEM attainment and participation

Research in STEM education has been prompted by concerns over a reduction in the uptake of STEM subjects such as physical sciences post-16 and especially in higher education. Constructive ways of encouraging the study of science among children from lower socio-economic backgrounds have been explored. Using large-scale official datasets it has been shown that participation and attainment in science are stratified by socio-economic status. Students from poorer families are less likely to take sciences post-16 than many other subjects and those who do are then less likely to obtain grades high enough to encourage further study of the subject. No conclusive evidence has been found to explain this satisfactorily. Possible reasons suggested in literature include a) insufficient local opportunities such as lack of learning resources in schools in disadvantaged areas and no universities, putting off those who do not wish to study away from home, b) perceived demands of studying science in terms of time and efforts, and so the difficulties of combining part-time study and part-time work for those needing to continue earning while studying, c) lack of support and role models in family and neighbourhood (Gorard and See, 2009).

Students from higher SES especially from families whose parents are professionals are known to participate more in post-16 sciences. These students receive more parental support and attain higher than their peers. Higher prior attainment has been shown to be linked to increased participation. There are clear differences in science attainment at age 16 between students of different backgrounds. This is therefore likely to be one of the biggest deciding parameters for differences in post-16 STEM participation. The largest gap exists between students eligible and ineligible for free school meals. These patterns appear early in primary schools. Attainment in English, maths and science at the end of key stage 1 and key stage 2 for example is negatively correlated to living in an area of deprivation.

2.6.1 Individual aspirations and expectations

Cuthbert and Hatch (cited in Gorard, 2011) showed using data from the Longitudinal Study of Young People in England (LSYPE), aspirations of young people and their parents are associated with their educational attainment. However, whether attitudes and aspirations are also the link between disadvantaged groups and their underachievement is yet to be explored. If the link exists it would be of particular interest to policy and practice to use this avenue for improving educational outcomes of deprived pupils (Gorard, 2012).

Even the sequence of the causal relationship between attitudes and aspirations and educational outcomes is not yet clear. This is because aspirations have sometimes been considered a predictor of educational achievement in some studies and an outcome of it in others. Factors like self-esteem, personal traits, experiences, influence of family are all known to be in the pathway. None of these are constant and can change rapidly as children grow making it all the more difficult to understand the order in which these influence educational outcomes.

During systematic searches for the thesis no rigorous evaluations of interventions explicitly concerned with raising or lowering aspirations or expectations and/or influencing educational outcomes were found. There was some evidence for associations of aspirations and school outcomes, but most of these studies did not consider SES and prior attainment. It is thus hard to gather if aspiration is an indication of success or its cause.

2.6.2 Individual motivation

Motivation could be extrinsic or intrinsic. Rewards like cash payment, gifts, certificates are quite varied and might motivate children differently depending on what actually appeals to them. The effect of extrinsic financial incentives on student achievement has been studied by Fryer (2010) through randomised trials. The study analysed data on 38,000 students from public schools in Chicago, Dallas, New York City, and Washington, DC. Students were given monetary payments for performance in school, three times a year immediately after verification of their achievement. No effects were found on standardised maths or reading outcomes. Focus group interviews were conducted where students said they were excited about the incentives but not sure how to improve their grades. Thus clearly, the extrinsic motivation was quite lucrative for these pupils but they knew no means to achieve the desired outcomes to earn the cash reward.

Similarly, paying students for behavioural changes like attendance, good behaviour, doing homework, and wearing their uniforms showed moderate improvements in reading and maths achievements. Likewise, when students were paid to read books a noticeable increase in their reading comprehension was noted. Thus for extrinsic gains as evaluated here, students corrected themselves if they knew what kind of behaviour was expected from them in return for the monetary gains and knew how to do it (Gorard, 2011). There is however no evidence to support intrinsic motivation can be influenced in a similar way.

Motivation, attitude and self-esteem are known to be linked. Efforts have been made to improve pupil attitudes towards education in general and STEM subjects in particular. It is harder to improve educational attitudes for less advantaged families though if successful these are likely to have the strongest effect on school outcomes. Improvements in some attitudes are likely to be beneficial in the wider context, even if not linked directly to school outcomes. This is because attainment despite being very important is only one possible educational outcome. There are also other behavioural changes and outcomes which are equally important, such as continued informed participation in education, well-being, citizenship, civil order, resilience, and happiness.

Often changes in pupil attitudes can bring about outcomes for which these were not actually targeted, but can be equally useful in the long term. For example, interventions to make school more pleasant and enjoyable increase the likelihood of school engagement. The effects of these cannot be immediately seen in terms of improved grades but these might positively influence young people in the long-term. Such psychological interventions could be very effective for poor children in narrowing down school readiness gaps. This in fact holds true for all deprived pupils. Approaches like improved teaching, peer mentoring, parental involvement, and outreach programmes like summer schools could thus have an effect somewhere other than attainment.

Attitudes, aspirations and expectations are malleable and it is certainly desirable that educational programmes like the STEM initiatives being considered in the study change them. The actual level of volatility makes them unreliable as indicators. It has proved hard to provide definitive answers on the effectiveness of the varied psychological constructs such as - aspirations and attitudes. The strongest claims made for the impact of aspirations and attitudes and educational outcomes emerges from studies in which measures of prior attainment or SES or cognitive ability were missing or when they were small scale studies. When these datasets have sometimes been reanalysed with fuller contextual data, or replicated with larger datasets a reduced or missing association has been found. It makes these ideas almost impossible to be tested (Gorard, 2011).

The evidence in most areas is generally too immature to estimate effect sizes or carry out more sophisticated analyses of any type of intervention. So it is important that future work can be broken down into estimates of cost-effectiveness for specific subgroups of learners such as low achievers, low SES families and considers other deprivation measures.

2.6.3 Conclusion

This research was motivated by a recognition amongst the STEM community that there is a need to raise young people's awareness of the progression routes and career opportunities that can be accessible through studying STEM subjects. Accurate and accessible advice is being delivered to young people, relating to subject choice, entry requirements (for higher education) and progression in STEM at various levels. How successful have these initiatives been?

Academic literature suggests a possible link between school, neighbourhood and family related factors to a pupils STEM aspirations. Several factors such as maternal education, role model in the family affect student subject choices deeply. These factors embedded in the social framework cannot be shifted and there are no ready measures to influence the outcome. However, parental involvement, individual motivation and aspirations have been shown to positively impact attainment and participation of students (Gorard, 2012). It would be interesting to explore the causal link between educational activities beyond in-school teaching and individual motivations and how these impact learning trajectories in the long term.

Several policies have ensued. Various progression routes have been created. This research focusses on only one of the possible progression routes for young people - progression from GCSE to post-16 education in schools to STEM courses at AS- and A-levels. Certainly success in terms of other progression routes need to be considered in other research.

2.7 STEM informal education

"Clearly remediable injustices around us which we want to eliminate."

-The idea of justice, Amartya Sen

The patterns of participation in Science higher education (Smith, 2009) have helped social scientists to develop an understanding of the determinants of participation (Osborne et al., 2003), barriers leading to non-participation (Gorard et al., 2007) and factors leading to a failure in sustaining interests in science beyond A-level. Far too many students who study Mathematics and core sciences at A-levels do not pursue these subject for an undergraduate degree. Of the ones who do a proportion opts for a non-STEM career (Jones and Elias, 2005; Wynarczyk, 2008). A policy need was therefore felt to address the drop-outs. These form three parallel agenda, firstly guiding the motivated secondly, motivating the unmotivated and thirdly, availability of information to avoid uninformed choices.

Diverse outreach programmes have been designed to raise the aspirations of students to expand science higher education participation in the United Kingdom. A substantial quota of these efforts have been targeted towards inspiring and enthusing young minds to enhance the uptake of STEM subject choices and career pathways beyond post compulsory science education. STEM initiatives have mushroomed at the local, regional and national levels covering public and private sector. Major Government, Non-government, charitable organizations Higher Education Institutions conducted on-campus activities, peripatetic workshops, schemes and web based resources.

Literature surrounding young people's views and attitudes towards science suggest the final years of primary school form the critical points of decline (Murphy and Beggs, 2006; Osborne, 2007). Gender differences have been shown to impact take up of STEM subjects like physics (Osborne et al., 2003). Home and school environment influence girls' visions of their role in society as well as their levels of assertiveness, experimentation, self-motivated exploration and risk taking; all of which can affect their choice of subjects at school. Consequently, studies looking into participation of women in science have picked up (Blickenstaff, 2005). Compared to time and place, a deficiency in interest has been held as a bigger hindrance to participation in education (La Valle and Blake, 2011). Investigations positively linking improved take up or higher achievement in STEM and participation in extracurricular activities however are not much existent.

2.7.2 STEM enrichment and enhancement activities

Within HEIs STEM subjects are usually taught individually, providing young people the benefit of specialist teaching. STEM experiences for younger people outside school are however far more complex. Technology and engineering for example draw on a broad science base and mathematical expertise. One of the challenges for STEM teaching therefore is to help young people recognise how science, design & technology, computer science, engineering and mathematics that they study at school or college can lead to rich and varied career pathways.

This complexity despite being a challenge offers enormous opportunities for STEM teachers to engage young people. By reaching outside their own classrooms, teachers can collaborate across subjects, enhance and enrich the school curriculum, make links with career trajectories and use varied contexts to help young people relate school STEM subjects with their real-world experiences. This in no way undermines the fundamental fascination that young people have with major scientific explanations, or the excitement that results from grasping the power of a mathematical model. But for some students the route to this satisfaction starts from an experience of STEM in the wider world, and thinking of STEM as a group of inter-related subjects helps to open up those doors.

A range of activities are currently being administered in England to inspire and motivate young minds to study science and maths. Some of them aim to improve understanding of the subject while others to raise attainment and sustain STEM participation beyond compulsory education. These are broadly classified as –

i. *Teacher focussed* - These are based on the theory that if teachers are enriched with resources and have ready support available at all times, they will be better equipped to teach students, thereby leading to greater chances of arousing interest in STEM subjects.

ii. *Student Focussed* - These work on the theory of stimulating experiences and motivating student interests, attitudes and aspirations. These initiatives thus target students directly by giving them hands-on experience in STEM subjects, enlightening them through role models and mentors, suggesting future pathways to help them make informed choices and often by providing extrinsic financial motivation in the form of scholarships and bursaries.

The new research presented here considered only student focussed programmes as educational interventions (For a detailed exploration of the various types of STEM interventions currently being administered see Banerjee, 2015). A scoping study of the various types of student focussed interventions currently being administered:

a) *Financial incentives*

Scholarships and bursaries provide extrinsic motivation to students and are delivered for retention and attendance of at-risk students. These generally work well with population groups having low expectations and low emphasis on the value of post-16 and higher education. Conditional cash transfers programmes have found positive effects on attendance in large-scale randomized experiments, and this has encouraged similar initiatives throughout the world (Slavin, 2010; Torgerson et al., 2007). Research however suggests effects of providing families with significant financial incentives on graduation rates and actual learning are less well documented. Most disadvantaged students are thought to drop-out of education when the monetary incentive ceases.

b) *Mentoring programs*

These programs are executed through school teachers and are aimed at students perceived to be at-risk of discontinuing education. Such students are identified and put in contact with a mentor, who is generally a teacher from the same school. The program works on the assumption that spending extra time under the guidance of a responsible adult will enable the student to make right decision about education. However, these programmes need to be more intensive and long term for the effects to be observed.

c) *Faculty Mentoring programme*

Faculty participants from Universities and institutions are matched with students based on shared academic interests. Subject specific workshops and social events are organised to ensure students interested in STEM subjects spend time with faculty and staff of higher educational institutions. It is hoped this will give students the opportunity to ask any questions regarding subjects, career choices and learning trajectories to a specialist expert.

d) *Career Guidance Programmes*

These programmes are delivered in school often by external organisations through STEM clubs to help pupils make informed choices. Secondary schools also hold special career guidance fairs and events where they invite employers in STEM areas, STEM ambassadors and representatives from HEIs who can offer the necessary insight into STEM trajectories.

e) Peer group connection programmes

This program quite popular in the USA, harnesses the power of school juniors and seniors to create an encouraging environment. Peer leaders meet with groups of 10-14 students in outreach sessions to strengthen relationships among students across grades. These peer leaders themselves are first trained by school faculty during regular school hours. They are enrolled in a daily, for-credit, year-long leadership course taught before they can start take-up their roles. A four-year longitudinal, randomized-control study conducted by Rutgers University, funded by the United States Department of Health and Human Services found that these programmes improve the graduation rates of student participants in an inner city public school by ten percentage points and cuts by half the number of male students who would have otherwise dropped out of education. More information on this is available from the Centre for supportive schools at http://supportiveschools.org/solutions/peer-group-connection/

f) Academic internship Programme

These placement programmes are organised by schools for most able students in collaboration with other organisations, HEIs or prospective employers. These provide a bespoke programme of opportunities and experiences linked to specialist areas, enabling students to learn more about their subject specialisms and future choices. This work placement opportunity gives them an insight to the chosen area. It might positively provide a reason for subsequent training or negatively to give up STEM if the participant feels overwhelmed by the experience.

g) Hands-on STEM initiatives

STEM enrichment and enhancement activities are run by several organisations across UK. Based on the principle of learning-by-doing, students are provided laboratory support and required set-up to perform experiments. Activities designed are quite varied ranging from rocket propulsion to DNA fingerprinting. Several government, private and educational charities have set up organisations across the UK in this capacity.

h) Ambassadors and Role Models

STEM enthusiasts who have achieved significant milestones, scientists and professionals pursuing successful careers or those who have a passion for science volunteer to inspire others by becoming STEM Ambassadors. STEMNET for instance is one such organisation whose registered ambassadors come from a wide range of scientific backgrounds. They volunteer their time and expertise to motivate young minds in the UK. However, unfortunately the extent to which schools are aware and willing to make use of this expertise - which comes for free - could be another debatable topic!

Several studies and reports (Royal Society, 2006; London Skills Council, 2006) have cited and promoted the use of role models, mentors and ambassadors as a key source of influencing young minds, particularly amongst underrepresented groups. Royal Society's Role Model Good Practice Guide, (2005) concludes that although it is not possible to measure the ultimate impact of the role model programme on final career choices, evidence provided in these studies suggests that exposure to role models during the critical junctures - earlier years of education has a positive influence on inspiring career choices among young adults (Royal Society, 2005)

Major government, non-government and charitable organisations, higher education institutions and foundations in the public and private sectors strive to promote science and innovation beyond compulsory education. They aim to foster the interest and participation of young people in STEM through role models, mentors, ambassadors and networking opportunities. Prominent amongst them being The Royal Society, Computer Clubs for Girls (CC4G), The Vega Science Trust, The British Society of Science, SEMTA, SETNET, SETPOINTS, RCUK's Researchers in Residence Programme, National Endowment for Science, Technology and Art (NESTA), Engineering and Technology Board (ETB), Wellcome Trust, Gatsby Foundation, Science and Discovery Centres (SDCs), Science and Learning Centres and Science Initiatives to name a few. Current initiatives and schemes operate through events offering hands on experience, networks of STEM Ambassadors or activity providers who visit schools, public campaigns and after school clubs visited by ambassadors.

Role Models can make STEM subjects seem more exciting, interesting and relevant (Royal Society, NESTA, DfES, 2005). They can challenge persistent stereotypes such as Physics being mainly for boys or super intelligent beings. They can also help teachers and add value to their science lessons and help youth group leaders to enrich their activities (Royal Society, 2005). Hackett (2004) carried out a survey of over 1000 scientists and revealed nearly 52 percent had been influenced by a scientist or engineer visiting their school. 41 percent respondents cited they were not planning to study science or engineering prior to participating in an activity with a SET role models. 28 percent of the participants indicated they had planned to study science or engineering even before participation. Research into participation of women and ethnic minorities in science has revealed that a lack of role models and mentors is perceived to be one of the underlying causes of minority status in this field (Quimby and DeSantis, 2006; Wynarczyk, 2007)

Ambassadors have a moral obligation to disseminate knowledge to future generations so that future generations learn from their experiences. In addition to a sense of satisfaction and peer recognition engagement in such creative pursuits enables mentors to reflect on best practices and continuous learning to become a role model (Marshall, 2001). Some organisations offer incentives and status recognition to overall enhance career of their employees for demonstrating organisational citizenship (Jandeska and Kraimer, 2005). However, not much systematic research has been done on Role models, Ambassadors and mentors particularly those from underrepresented groups acting as STEM Ambassadors. Neither is much academic literature available on enthusiastic and inspiring teachers who acted as role models for several cohorts during their teaching careers. Such investigations and recognitions could probably see the younger generation thinking of teaching careers and adding on to the skilled teaching force.

Chapter 3 Contribution of this thesis

3.1 The need to address this issue

The development of a knowledge intensive workforce has been established as one of the primary sources of advantage (Smith, 2005) in trying to make UK's economy more competitive globally. The government considers increasing and widening STEM participation (Conway, 2009) important to enhance the quality of labour (NCC, 2006) and promoted the concept of lifelong learning (Report of the Task Force on Lifelong Learning, 2002). The 2020 Vision aims to improve a) graduate and employability skills of STEM students, b) student confidence in their employability, c) student awareness of their career options and d) employer engagement with HEI. This objective has seen the growth of several motivating initiatives. The effectiveness of these schemes are however yet to be examined.

The STEM Mapping Review (2004) established by DfES, DTI and external agencies identified more than 470 STEM initiatives (Wynarczyk and Hale, 2009). Among these 70 on-going government funded initiatives were analysed by the STEM Cross-Cutting Programme (2006) advised '...the need to rationalise Government supported initiatives and build on the best ones so as to achieve better results for the same amount of money' (DfES, 2006a, p.3). STEM Education, budget, initiatives and schemes have all incessantly increased since then, however, there has not been a major study or survey of the school and students who have participated in them, looking at the short term or long term impact the schemes have had. It is not clear how STEM initiatives are linked to the increasing or widening participation agenda. This is because the impact of these initiatives on improving take up, performance and achievement in STEM subjects has not been fully investigated. This study addresses some of the gaps identified in this review.

3.2 Rationale for conducting the systematic review

"Educational disadvantage, starts in the womb – free maternal and child health care are an education imperative"

- *Education for All, Global Monitoring Report, 2010*

A range of factors can interact in various combinations to limit a child's academic achievement. Socio-economic issues continue to be the determining parameters for educational attainment, learning trajectories and careers. Research considers speakers of English as an additional language (EAL), ethnic minorities and poorer pupils to be in a position of disadvantage (Strand, S, 2013). Eligibility for free school meals (FSM) /reduced price lunches, family income below a certain threshold, residence in a potentially deprived area are all indicators of a lower socio-economic status (SES). Disadvantaged pupils do not perform as well academically as their elite peers (Steele, 2010; Reardon, 2011). Evidence comes from a study exploring the effect of poverty on achievement of urban African American students successfully completing high school. Welch (2014) shows cumulative tenth grade GPA had a significant negative correlation with student poverty level. As the poverty of the student increased, the cumulative GPA decreased. An extrapolation of this research finding would mean beyond compulsory education poorer scores render deprived pupils ineligible for several courses held in high esteem such as science, technology, engineering and mathematics (STEM).

This situation certainly needs remediation as a) it is always desirable to have a range of people from different sections of the society studying and working in different fields for instance, having a diverse intake for STEM courses will lead to a more innovative and responsive STEM workforce (Royal Academy of Engineering report, 2012), b) for narrowing the socio-economic divide as people in STEM occupations earn almost 26% more than those working in other fields (U.S. Department of Commerce, Economics and Statistics Administration, STEM report, 2011), c) for issues of social justice - higher education has a responsibility to maintain fair access to all irrespective of SES, gender or race (HEFCE, 2014), d) to enable students to harness on STEM skills even if opting out of a STEM career e) educational attainment appears to have a protective effect against accelerated cellular ageing (Adler, 2013), major depressive disorders (MDD) (Shi, Jianguo, 2014) and degenerative diseases particularly in disadvantaged groups.

The first step towards bringing about this change is to have a thorough understanding of the reasons linked to underachievement of disadvantaged pupils in science and maths education in schools as evidenced in research literature. The second step is to understand how some pupils or schools despite operating in most adverse conditions refused to become statistical failures and whether the lessons learnt from them can be translated to society at large. The third step is to explore whether recommendations have been made based on experimental success, which could be picked up for policy and practice.

A child born in a family qualifying for one or more deprivation measures is held back from reaching full academic potential in school. This later on translates into compromised leaning trajectories, reduced employment opportunities and lower income, setting thereby a trend of poverty/disadvantage. It is essential to break this chain for uplifting deprived sections of the society. This systematic review was conducted to understand the various factors which provide an explanation for the underachievement of disadvantaged pupils in school science and maths.

3.3 What was evaluated?

The thesis considers any teaching or learning activity beyond in-school effective teaching which supports the development of the supply of science and engineering graduates - a STEM intervention. All chosen programmes for this study were delivered by staff other than school teachers. Most of these programmes included in the study were hands-on experiences.

The study focussed on outcome evaluation in terms of educational attainment and continued participation in STEM education of all students as well as those from deprived backgrounds. It was not intended within the scope of this thesis however to extend any findings and recommendations as part of programme evaluations. All interventions were treated as a group of educational programmes and evaluated whether they are able to increase or widen participation.

3.4 Who will benefit from this research?

Time and place are deciding factors. This is because several important parameters like curricular framework, socio economic backgrounds, and educational participation are all directly linked to it. The data for this project was collected for England and the findings apply to England. This however does not imply that the local approach of this study could limit the generalisability of the research findings. Recommendations obtained from the study could be relevant internationally. This is because STEM informal education occupies a major position in education policies of several countries. Given the global concern over STEM education, and similar approaches put in for boosting STEM uptake, visibility of local effects from this and other similar studies can help devise national strategies for encouraging specialist subject choices and careers for future generations.

Some STEM initiatives provide case study reports on their websites which merely appear to echo positive views and success stories. There is also a complete contrast in the limited number of such case studies as opposed to the huge number of schemes currently being run. Empirical evidence on relative importance, cumulative effects of and interrelationships between separate but equally important initiatives are scarce. As Sir Roberts Review (Roberts, 2002, p.50) states one way of monitoring progress is through looking at policy solutions which are combating it, both at home and abroad through relevant studies.

Several organisations in the UK now provide support for STEM formal and informal education through hundreds of individual schemes and initiatives. Good evaluation provides insight into an activity's impact on young people to inform future improvement. Meaningful evaluation helps to ensure that funding is well-used, and when findings are shared with teachers and lecturers, evaluation can help them to select appropriate initiatives for their students. Clearly, time and again the importance of these evaluations for improving STEM education and initiatives have been stressed upon. The National STEM Centre encourages the effective evaluation of STEM initiatives, summarising it as ‘Better evaluation: better STEM’.

3.5 Conclusion

Having identified participation in STEM career pathways as the major source of economic progress enormous amount of time, energy and resources have been spent on studies focussing on this domain. It is however difficult to ascertain how effective all or any of these interventions are in raising attitudes and aspirations of pupils towards STEM subjects in the absence of proper evaluation. Thus to inform policy and practice robust large scale evaluations are required to assess activities that are designed to increase chances of staying on in education and likelihood of participating in higher education and improved performances in STEM subjects for pupils.

The link between determinants like gender, socioeconomic backgrounds and patterns of participation in STEM are well established. The only possible way to weaken this link seems to enhance interest of the younger generation in these subjects. However, the knowledge of what works best can be used in planning and targeting initiatives for increasing and widening STEM participation. In the best interest of economic competitiveness impact of STEM initiatives needs to be assessed and schools need to be more informed. This could check the galaxy of STEM initiatives active at the moment, to put forth the best and most effective as a compulsory activity for sustained interests and growth.

It is equally important to understand the reasons associated with or causing underachievement in school science and maths. This is very crucial for implementing measures for widening participation in STEM education. The systematic review addresses exactly this gap. The next section discusses the research design and methods for the research project.

Chapter 4 Research design and methods

4.1 Systematic review – design and methods

The systematic review was conducted to understand why certain sectors of the society are in a position of educational disadvantage. The term disadvantage here refers to the absence of certain conditions as in other more privileged sub-groups who face lesser hardships in life and encounter fewer barriers during their learning trajectories. While the review focusses on research findings relevant to the population of England, it is hoped that recommendations arising will be equally applicable to other countries looking forward to improving educational outcomes of disadvantaged groups.

4.1.1 Objectives and research questions

The review aimed to systematically locate, quality appraise and synthesise academic literature suggesting potential factors for poor academic performance of underprivileged pupils in science and maths in school. Thus, problem specification considered the population, age group, disadvantage measures, educational/behavioural outcome variable. The main research question being addressed is:

> Which factors are associated with disadvantaged pupils' lower attainment levels in science and maths in schools?

While focussing on the above research question the review also tried to look for evidence on schools/pupils qualifying for several measures of disadvantage who performed extremely well for instance high-poverty, high-achieving schools. Some programmes from robust studies shortlisted for the above research question were very effective in raising academic achievement of disadvantaged pupils. These were identified and categorised as effective recommendations discussed later in chapter 7. Studies retrieved from the systematic searching and screening offering insights to the main research question were mostly correlational in research design. Some causal studies known to the author were added. Although these were included through expert knowledge of the literature and not through the systematic searching (and therefore could be a biased sample of such studies), nevertheless it was important to include these because these were robust studies addressing the research question.

4.1.2 Systematic review design and methods

Systematic reviews and meta-analyses have become increasingly important in health care. Clinicians use them to keep up to date and as a starting point for developing clinical practice guidelines. Funders use systematic reviews as a step towards justification for further research. As is the case with every form of research, to be rigorous (valid and reliable) and useful a systematic review depends on the methods of the review, that is, what was done, found, and the clarity with which the research findings were communicated. Failing in any of these steps, limits the readers' ability to assess strengths and weaknesses of those reviews. Thus while it is very important to conduct the review well it is equally important for the study to be replicated to rule out any bias and report any limitations of the review process.

Several studies have evaluated the quality of review reports in the past. Mulrow (1987) examining 50 review articles published in four leading medical journals in 1985 and 1986, found that none met all eight explicit scientific criteria, such as a quality assessment of included studies. Sacks and colleagues (1987) evaluated the adequacy of reporting of 83 meta-analyses on 23 characteristics in six domains. Reporting was generally poor; between one and 14 characteristics were adequately reported (mean = 7.7; standard deviation = 2.7). However, a 1996 update of this study found little improvement.

In 1996, to address the suboptimal reporting of meta-analyses, an international group developed a guidance called the QUOROM Statement (QUality Of Reporting Of Meta-analyses http://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(99)04149-5.pdf), which focused on the reporting of meta-analyses of randomized controlled trials. In 2009, the guideline was updated to address several conceptual and practical advances in the science of systematic reviews, and was renamed PRISMA (Preferred Reporting Items of Systematic reviews and Meta-Analyses).

The PRISMA protocol

This review followed the PRISMA protocol. It is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses, aimed at helping authors. Focussing primarily on randomized trials, PRISMA can also be used as a basis for reporting systematic reviews of other types of research, particularly evaluations of interventions. PRISMA may also be useful for critical appraisal of published systematic reviews, although it is not a quality assessment instrument to gauge the quality of a systematic review.

The PRISMA Statement consists of a 27-item checklist (Moher, 2009) and a four-phase flow diagram. It is an evolving document that is subject to change periodically as new evidence emerges. The PRISMA explanation and elaboration document (Moher et al, 2009) explains and illustrates the principles underlying the PRISMA Statement. PRISMA is primarily an effort, towards improving the reporting of different types of health research, thereby improving in turn the quality of research used in decision-making in healthcare. However, it can be extended with equal ease for systematic reviews in education as shown here. This is because, the PRISMA statement and the PRISMA explanation and elaboration document are distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

This systematic review protocol has been registered with PROSPERO (http://www.crd.york.ac.uk/PROSPERO/), which contains over 5,000 records of prospectively registered systematic reviews. The register provides an increasingly valuable resource for identifying on-going reviews to help avoid any unplanned duplication.

Cochrane evidence

One of the several organisations endorsing the PRISMA protocol is the Cochrane Collaboration. Healthcare providers, consumers, researchers, and policy makers are inundated with unmanageable amounts of information, including evidence from healthcare research. It is unlikely that all will have the time, skills and resources to find, appraise and interpret this evidence and to incorporate it into healthcare decisions. Cochrane reviews respond to this challenge by identifying, appraising and synthesizing research-based evidence and presenting it in an accessible format (Mulrow 1994). Each systematic review addresses a clearly formulated question. To answer this question, all existing primary research on a topic that meets certain criteria is searched and collated; this is then assessed using stringent guidelines, to establish whether or not there is conclusive evidence about a specific treatment or answer to a specific research question.

Cochrane reviews are seen as exemplifying best practice in the quality of both their conduct and reporting. This is because they constantly improve and maintain the quality of output as standards and expectations for systematic reviews increase generally; and ensure consistency across all Cochrane Review Groups (CRGs) and all reviews. Thus within the Cochrane Collaboration the Methodological Expectations for Cochrane Intervention Reviews

(MECIR) were defined. The documents associated with the MECIR project form a major step forward aimed at ensuring that both researchers and editorial teams have a shared understanding of the expectations of conduct and reporting for reviews in the Cochrane Database of Systematic Reviews (CDSR).

The standards summarize attributes of the conduct of reviews of interventions described in the Cochrane Handbook that have been established should be either mandatory or highly desirable for new Cochrane Reviews. The judgments are accompanied by a rationale and reference to the appropriate section of the Cochrane Handbook. The process for determining the expectations for conducting Cochrane Reviews of interventions, including the methods used to develop the initial list and the management of all feedback received during the consultation process (see: www.editorial-unit.cochrane.org/mecir) have been summarised in the MECIR document (Chandler et al., 2011).

As suggested by the Cochrane collaboration after formulating the research question, systematic and explicit methods were used to identify, select and critically evaluate relevant research reports. The framework for all stages was pre-planned. Prominent educational databases were searched. A balance between sensitivity and specificity in searching literature was aimed at by using thesaurus terms of keywords, truncation and using the "NOT stem cell" term for excluding all studies that were being returned for stem cell research in the preliminary searches. Explicit inclusion and exclusion criteria were developed specifying which studies were to be included in the review, for instance, criteria in terms of research design, population, language and timeline. All relevant published and unpublished literature was identified. Each study or report was quality assessed individually by three researchers, on parameters such as relevance to research question, robustness of evaluation, research design, sample size, comparator and trust worthiness of the study. Findings from individual reports were synthesized, interpreted and presented in a balanced and impartial summary with due consideration of any flaws in the evidence.

This systematic review is thus more reliable than a narrative review as it provides minimisation of bias for information on the research question. However, statistical methods (meta-analysis) were not used to analyse and summarise the results of shortlisted studies. This is because the studies addressed a range of disadvantage measures hence it would not have been fair to cluster them together.

4.2 Overview of secondary data study

Is the level of STEM attainment and participation at school rising or declining as a result of STEM initiatives introduced as policy reforms in England? Are the results rising faster for schools identified as taking part in STEM initiatives? Is the gap in attainment and participation, between schools and pupils from various disadvantaged contexts and others, declining as a result of STEM initiatives? These questions are addressed via a quasi-experimental study - ‘quasi’ in the sense both that the researcher was not the one manipulating the environment via an intervention, and the cases were not allocated randomly. Such evaluations can provide information about naturally occurring events, behaviour, attitudes or other characteristics of a particular group. Also, these studies are helpful in demonstrating associations, for example here between STEM initiatives and attainment and/or participation in STEM without disturbing the informal and formal education system or introducing a bias.

The educational performances of identified intervention secondary schools were compared with all other schools. From a total of 2,400 eligible schools (only state maintained secondary schools were considered in the study) a thousand intervention schools were identified. This is a little less than half of the population of schools spread out across England, as the activity providers deliver activities all over England. Thereafter, from the intervention group around three hundred schools were considered over time. All participating pupils from these three hundred intervention schools were followed from the beginning of key stage 3 to the end of key stage 5. GCSE science and maths results and continued participation in STEM subjects in A-levels were the outcome measures for assessing the impact of STEM initiatives on various disadvantaged groups. Nearly, 80,000 intervention pupils were followed up in the study.

Data for the project was collected from existing records of management and information systems of STEM activity providers, national pupil database (NPD) and desk research. Programme delivery to 11-16 year olds at STEM activity-providing organisations was observed to get an idea of what the actual activity entailed. And a systematic review was conducted to identify factors influencing the attainment of disadvantaged students. Table 4.1 summarises the framework for this research project. Each section is dealt with separately in the sections below.

Table 4.1 Overview of research project

Design type	Quasi-experimental and longitudinal
Method of data collection	Observation of programme delivery by staff of activity providing organisations
	Analysis of documents from management information systems
	Participant observation
	Secondary data – National Pupil Database
	Systematic review
Data analyses	Correlation /regression methods – multiple linear regression and binary logistic regression
	'Effect' sizes, cross-tabulation, comparison of means
	Grounded coding and synthesis

4.3 Research design

In the absence of secondary data relating to the entire population, a high quality sample and a good sample size are necessary preconditions for the pursuit of high quality and safe research findings (Gorard, 2007). This is because sampling is a useful shortcut leading to results that can be almost as accurate as those for a full census but for a fraction of the cost, time and efforts. This research project makes use of population data and identifies intervention schools and treats the remaining as comparator. A similar approach is followed for pupil level datasets. Population data is independent of the methods of data collection and by definition generalisation is already achieved. Thus estimates of sample size and statistical power were not required for this study.

The study makes use of two distinct census datasets, a school-level and a pupil-level database along with respective performance/attainment tables. The school level data is analysed in two different phases in terms of research design. The first phase considers nearly thousand intervention schools and the rest as comparator. By the end of 2012, a total of 317 schools had participated in STEM enrichment activities every year from 2007 onwards and were termed longitudinal intervention schools for the second phase. A further 483 schools had participated on and off, but for at least one complete academic year during this period (see table 4.2) and were termed discontinuous intervention schools. All remaining schools were termed as comparator. The third phase considered only pupil level data. Children completing education in intervention schools were termed intervention pupils and all others were treated as comparator. These phases are explained in more detail below.

Table 4.2 Schools participating in STEM activities from 2007-2012

Participation status in intervention	Frequency	Percentage
Longitudinal	317	10
Discontinuous	483	16
Unknown	2287	74
Total	3087	100

Phase 1 - Repeated cross-sectional design – school-level

A repeated cross-sectional research design was used to assess the impact of STEM initiatives on school science and maths performances. All ten STEM activity providers participating in the study delivered educational programmes through school-visits, hands on experience programmes, pupil visits to STEM centres, School science clubs, ambassadors and mentors. Each provider had a set of schools registered for each academic year which meant a range of STEM enrichment activities were delivered throughout the academic year. Some schools were registered with one, two, three and at times four activity providers. Registration with many activity providers meant almost all year-groups of some schools were being enrolled for STEM enhancement activities. All schools registered with at least one STEM activity provider for each academic year were shortlisted. This meant the schools engaged their pupils in various year-groups into several age-appropriate STEM activities provided by at least one organisation each academic year from 2007-08 to 2011-12.

Making use of England’s school level database in the form of Annual School Census (ASC) and school attainment data a longitudinal record of all secondary schools participating in some chosen similar STEM initiatives was constructed. This group was termed as the intervention group. The comparator group was the population of all other secondary schools excluding special schools and those schools for which attainment data was not available (such as independent schools).

Through correlation techniques and comparison of population means attainment figures in maths and sciences of schools were compared between these groups from 2007-2012. The set of schools was largely similar each academic year as schools decided to renew their contract every academic year with the STEM Activity providers being chosen for the study. However, there were almost always new schools joining each academic year and these were included in the intervention group for the years they were registered.

Phase 2 - Longitudinal design – school level

For the second phase, a sub-sample of 300 state maintained secondary schools was identified from the intervention group in phase one - which had continued to participate in STEM activities every year from 2007-12. The number of organisations the schools registered with varied from a minimum of one to a maximum of four of the ten being considered in the study. All of these interventions were delivered from the beginning of key stage 3 to the end of key stage 4. This meant students from these intervention schools were exposed to an advanced version of STEM activities every following year. A longitudinal record of these schools was constructed by merging several individually provided bulky files. The final dataset carried details of school census, attainment data and participation in STEM schemes. Mean school GCSE Performances for the intervention group were then mapped before and after intervention in 2007 and 2012 respectively. Correlation coefficients and population means of intervention group were compared with the comparator group.

Phase 3 - Study design using pupil level data

Students from the 300 longitudinal intervention schools were followed from the beginning of year 7 till the end of KS5. The GCSE maths and science results of the various disadvantaged and privileged groups were compared. This cohort was further tracked to the end of key stage 5 to assess post compulsory STEM participation of this cohort. The number of pupils from this 2007, year 7 cohort in each sub-group at the end of key stage 4 and key stage 5 are shown in table 4.3.

Table 4.3 Number of students in sub-groups - STEM activity participation

Sub-groups	End of KS4		End of KS5	
	Numbers	Percentages	Numbers	Percentages
Comparator	5,55,295	88	5,54,861	88
Intervention group	76,462	12	76,406	12
Total	6,31,757	100	6,31,267	100

Students who dropped out of education or left the country were not followed up as their records were not available from NPD. The next section explains the data collection procedures.

4.4 Primary data collection procedures

This section explains the data collection procedures planned, the difficulties faced during the process and then the revised plan for successful completion of the research project.

Original plans for identifying intervention schools

The Income Deprivation Affecting Children Index (IDACI) is an index of deprivation used in the United Kingdom. This index is calculated by the Office of the Deputy Prime Minister and measures the proportion of children under the age of 16 living in low income households in a local area. The IDACI score and rank of IDACI are sourced from Communities and Local Government, Indices of Deprivation 2010. These local areas for which the index is calculated are called super output areas (SOAs). IDACI is used for calculation of the contextual value added score and for measuring children's educational progress. The Department for Education (DfE) makes available an IDACI tool for the ease of calculation. This allows users to determine the IDACI score and rank of any postcode in England.

The initial data collection plan for the study was to identify a set of schools located in an area of disadvantage as reflected by this IDACI tool. This could have been possible as school level data from NPD comes with the post code. Schools with a high percentage of pupils eligible for free school meals and actively engaging in STEM enrichment activities beyond in-school teaching would have formed the intervention group. The planned comparator was schools in an area of disadvantage with high percentage of FSM pupils not participating in any STEM programmes. A comparison of school GCSE performances-school characteristics and pupil attainment- pupil background identifiers was to be taken up to evaluate the bearing of these programmes on educational attainment of disadvantaged pupils from a lower socio-economic status.

From the NPD school level data, all those secondary schools following the national curriculum which had a very high percentage of pupils eligible for free school meals were selected (one standard deviation from the mean). Their geographical location was mapped. Edubase and Performance Tables on the Department for Education (DfE) website were then checked to ascertain which of these schools were performing exceptionally well. Letters were sent to Head teachers of all these schools, to request their co-operation in the research project by responding to some simple questions.

Information asked was whether the school has been taking part in any external or informal STEM schemes or programmes in the last five years? If so, they were requested to identify the scheme (name or web link), the years it was implemented and the year groups involved? If not, the schools were requested to respond clearly stating that their success is solely due to in-school effective teaching or similar.

Some of these schools had been doing exceptionally well despite being located in an area of disadvantage and having a very high share of FSM eligible pupils. It was hoped exemplary evidence from these schools and research findings could help address widening participation issues which is very highly placed on the national STEM agenda. School cooperation could benefit future students, schools, researchers and policy makers by enabling them to make evidence-informed decisions. The same was highlighted in the email request and assurances regarding maintenance of anonymity were made such that no school or individual will be named or identifiable in any report resulting from this research. Of the schools contacted, only three Head teachers wrote back. Two said the information could not be disclosed while one said the achievements were solely due to in-school effective teaching (table 4.4).

Table 4.4 Initial response rate

Total schools excluding PRUs, special and independent schools	3110
Eligible schools (Mean + 1SD)	2509
Requests sent to Head teachers	179
Responses received	3

There is no reason at all why the information requested concerning participation in a STEM scheme should not be made available. Nevertheless, a second strategy was adopted. Correspondence details of head teachers were collated from Edubase and search engines. The study now planned to consider several measures of disadvantage such as language group major, ethnicity, geographical location, poverty instead of just free school meals and the IDACI tool. This was because of the unanticipated difficulties faced in data collection. The primary focus was now to have a set of schools responding to email requests merely stating their participation or non-participation in STEM informal education. Hundreds of schools were contacted from amongst thousands of secondary schools in England. The response rate was extremely low, as before. The emails sent to Heads of Science Departments and Head teachers went unanswered despite reminder requests. This continued non-response from contacted secondary schools led to the formulation of an alternative pathway for data collection.

Eventual plan to identify participating schools

A third strategy was now adopted for data collection. 2009 saw the launch of online STEM Directories supported by the Department for Education (DfE), maintained and managed by The Royal Institution of Great Britain, The British Science Association and University College London (UCL). The Directory lists available STEM activities across United Kingdom along with relevant details of STEM providers. Accessed on 25th August 2013, a total of 238 initiatives showed up in the search results for the age groups 11-14, 14-16 and 16-19 years. A further manual screening was done to select only those schemes which were operating in England. Some Providers offered more than one activity and hence were listed separately in the directory. Thus, while making a list of providers, sub-headings were created under the same Provider name. This brought down the number of active STEM Providers in England for secondary schools to 162. This included free schemes as well as those for which schools or parents were required to pay. Some contact details were wrongly entered or not being updated on STEM directories as e-mails kept bouncing back. Desk research and internet searches enabled the researcher to collate contact details of all of these STEM activity Providers. Additionally, any information about these schemes, such as the nature of the intervention or materials available from the individual websites of these providers was collected.

The lists of schemes did not identify which schools they worked with. Therefore, email requests were sent to government, public and private STEM providers operating in England requesting the names of participating English secondary schools. The programme leaders were asked to respond to a few simple questions, as the ones chosen had been running relevant schemes for schools in the past five years. A list (ids, names or web links) of all STEM initiatives and programmes run or launched relevant to schools, in the past five years was requested, ideally with the year groups involved. The emails highlighted the significance of their support in terms of possible benefit to future students, schools, researchers and policy makers by enabling them to make evidence-informed decisions. And as before, anonymity for individuals and schools was assured.

However, despite repeated e-mail reminders, and other attempts at contact such as phone calls, STEM activity providers were generally not responding. Of the 161 correspondences (one spam entry) only one STEM provider had initially shared some school names. A few organisations were worried revealing school names to third parties would be against the data protection act (this is clearly not so as no individual details were requested) while others denied having a well- maintained database of all schools they have worked with during the past five years (and even though the request was for any information even if incomplete). Some promised to get back but were probably too busy to. The majority simply did not respond. When the request was pressed the providers began contacting each other to plan how *not* to respond. Some sent strongly-worded, even abusive, emails to the researcher, and threatened to complain to the university and some did complain to the supervisor. A small group of programme leaders responsible for STEM Education of the current and future generations of the country were extremely distraught at the e-mail request made by the researcher. It was surprising to realise that a request for institution-level information for non-commercial purposes would apparently be so upsetting to STEM professionals. All could have responded to the request in less time than they took to refuse. This was more than non-response. It raised the possibility that they did not want any evaluation of their activities (other than the post-event happy sheets that they used).

Eventually, seven near-government organisations agreed to share the names of participating schools and the programme materials used in the various activities run by them. The researcher had previously volunteered to work for three of these organisations, and contacts with the organisation north east head of one of these providers facilitated the process of obtaining more data. Another private organisation allowed access into its massive infrastructure, state-of-the-art laboratories, archived and current school data files, programme materials and introduced the researcher to its entire STEM staff. The researcher was given the opportunity to witness sessions run for school children at this institution every day for a couple of months. Data was available in the form of filed paper feedback forms. This organisation ran several types of educational programmes:

1. Outreach programmes - A team of trained and well equipped staff from the organisation visited schools and demonstrated science experiments leaving students in awe. The demonstrators carried with them all required equipment and chemicals. Attending school science teacher was requested to fill up the feedback form at the end of the session. These demonstrations were sometimes put up as part of "Inspire science learning weeks/days" and at other times for STEM clubs.

2. School-visits - Schools approached this organisation and scheduled a date when pupils of same year visit the organisation, where a day full of STEM activities is planned for them beforehand. The activities were quite diverse and ranged from

rocket propulsion to DNA finger printing. Pupils were accompanied by teachers from school who were requested to complete the feedback form at the end of each session.

Data from these paper feedback forms filled-in by attending school teachers was available in the management information system. This data was entered into excel sheets by the researcher into several columns under the following heads: name of school, address, contact number, contact person (Head, Science Department or Head, Maths Department), date of visit, year group visited, academic level of pupils visiting, name of programme, brief description, name of programme leader/demonstrator, feedback and suggestions for improvement.

As is evident the data was very rich and the organisation was visited by a large number of schools, this being one of the largest STEM activity providers of north east England. However, routine challenges were encountered. Some of the forms had illegible handwriting and it was difficult to decipher what was written. Some teachers preferred to fill in short forms like RGS instead of complete school names like Royal Grammar School. Some other forms had merely the school name, and the address was not filled in. This was particularly challenging when the school name was something like St Mary's as there are so many schools with the same name in England. However, every possible effort was made to extract data correctly from the paper forms. This sometimes meant using the google search tool. For instance, when a school name like St Mary's and its contact number was entered and the address field left blank, school websites were checked to match the telephone number and find out which of the eight listed St Mary's had actually registered. Other details from feedback forms were similarly matched with Edubase and the National Pupil Database.

Some other organisations provided names of registered schools and participating year groups for the last five years along with the name of programme/activity in the requested format. As before there were often merely school names without postcodes and there were times when more than one such school existed in England. Activity providers were contacted to check which of these schools had participated. On one such occasion due to change in staff at the organisation it was not possible to ascertain which of these schools with same name had participated. A decision then had to be made by the researcher. Based on the geographical location of the organisation it was clear that the school in the same zone had registered. This school was then marked for participation and later reconfirmed by the activity provider with the school.

The eight organisations, through their co-operation, permitted the project to go ahead. As a next step forward to ensure as large a sample of co-operating schools as possible, the websites of all activity providers in England were explored for clues. The public domain data revealed reviews and testimonials from schools which had engaged in these activities. Desk research along with the previous data collection procedure yielded names of about 1,000 schools all over England from 2007-2012, which had encouraged students to take part in STEM enrichment and enhancement activities. The post codes of these schools were fed into the IDACI tool (http://www.education.gov.uk/cgi-bin/inyourarea/idaci.pl) developed by the DfE, to ascertain whether the schools were located in an area of disadvantage. Further, schools were also matched with the National Pupil Database to verify if they had a large number of students eligible for free school meals. This led to the evolution of a list of intervention schools who had been actively engaging in STEM activities to help promote STEM subject choice, raise educational attainment and encourage continued post-16 STEM participation of pupils.

STEM enrichment and enhancement providers included in the study

Via the various routes described above, the names of schools registered with STEM activity providers for the research project came from ten organisations operating in England. Eight of these were government organisations, one an educational charity and one received public funding. The number of schools registered with each of these organisations is summarised in table 4.5. The names of activity providers have been anonymised however the area they catered for is shown under the activity zone.

Table 4.5 Number of participating schools registered with STEM activity providers

STEM activity provider	Activity zone	2007-08	2008-09	2009-10	2010-11	2011-12
1	North East	68	69	69	72	73
2	North East	56	80	45	65	71
3	Dudley	20	20	20	20	22
4	London	NA*	NA	NA	NA	23
5	London	NA	NA	NA	20	57
6	London	NA	48	58	276	56
7	England	NA	NA	NA	NA	3
8	England	NA	105	135	106	101
9	Tyne & Wear	NA	34	48	28	24
10	England	293	338	335	348	348
Total participating schools+		421	633	653	852	696

**NA= not available, +Duplicates excluded*

These organisations delivered a range of activities. The criteria used for scanning interventions for this research project were:

1. The activities were designed to intrigue and engage students in STEM subjects.
2. The schemes were delivered from beginning of KS3 to end of KS4 in England.
3. All chosen initiatives claimed to improve educational outcomes.
4. All of these programmes reported data which could be used to estimate an effect size.
5. Outcome effectiveness of these interventions could be measured in terms of GCSE performances.
6. All chosen programmes had presented evidence in terms of sustained participation of schools.
7. Programme leaders were willing to co-operate and share data for the research project

Hands-on STEM enrichment and enhancement activities

Guiding students to explore science and watching them learn is truly a passion most science teachers can relate to. It is intriguing to watch a student work through a scientific experiment and get to the "aha" moment of understanding. Their eyes light up and there is a explosion of energy as they rush to explain to someone what they have just discovered. Capitalizing on these "aha" moments to help students not only to understand and get addicted to science, but also to foster a lifelong learning in science is just the rationale behind hands-on STEM initiatives. This is important because it builds up a student's curiosity, scientific temperament, reasoning and logical thinking and ability to make connections as to why the world exists as it does.

This research project evaluated hands-on activities designed to arouse curiosity and improve understanding of STEM subjects. It is expected by providers that these activities help students attain higher in school science and maths and also increase their likelihood of participating in STEM higher education. This was clearly mentioned by head of organisations when the researcher spoke to them. Some other interventions apart from practical activities considered in the study were Faculty mentoring programmes by Universities and HEIs, inspirational programmes, engaging activities and talks delivered by STEM Ambassadors and people successful in STEM careers. Some of these were Mathematics challenges and fun sessions delivered as after-school clubs, competitions or out-reach programmes. The common element between all programmes chosen for the study was they all had a practical element attached to it. Every programme involved active participation of students in some kind of laboratory set-up.

4.5 Secondary data used in the study

Original plan for the study

The initial plan for the research project was to evaluate the effect of STEM informal educational activities by analysing A-level performances and future learning trajectories of students. This was important to support or reject a possible causal claim between participation in STEM extracurricular activities and improvement in opting and achieving high in STEM subjects. A quasi-experimental study design was planned to compare educational outcomes and career trajectories of participants and non-participants of STEM intervention. Using time-series regression analysis the idea was to understand the points of decline or motivation in STEM participation and the factors involved - one of which could possibly be STEM initiatives.

Thus, the two outcome measures for evaluation were performance in standardised national tests and continued participation in STEM education/careers. To understand the impact of STEM Initiatives on widening participation in tertiary education the earlier plan was to use Individualised Learner Records (ILR). The linked NPD-ILR-HESA data is the primary data collected about further education and work-based learning in England of all pupils from the beginning of KS1.

HESA collects data of all students enrolled with UK Higher Education Providers at the end of each academic year. The data is collected on behalf of the government departments and funding bodies who have a statutory requirement to receive data from HE Providers. The Department for Education (DfE) receives HESA data and links it to data from the Individual Learner Record (ILR, which covers Further Education Colleges) and to the National Pupil Database (NPD, which covers schools). Linked data is available for research purposes from DfE for a small administration fee.

This linked dataset was very new in terms of availability for researchers at the time. An application was submitted to request this data as it was the ideal choice for tracking continued STEM participation of pupils into tertiary education. However, after months of exchange of emails the data was not provided for this research project. A significant amount of time was lost, in the administrative process which finally ended up denying approval for use of secondary data. Instead of tracking participation in AS, A-levels and tertiary education the project could now only target STEM participation until A-levels. Also, instead of time series regression analysis a correlation, effect size estimation and multivariate regression analysis was now planned. A new application was submitted to the National Pupil database to request school and pupil level data.

School level data

The school level data used in this research project comes from the National Pupil Database (NPD). The NPD has a number of key features unavailable in other datasets, which influenced the decision to use it for secondary data analysis. First, it is a census containing the population of all schools in England. This is very helpful for a number of different analyses compared to a dataset based on a sample of schools. Second, it is longitudinal, and even if a school changes its status for instance to an academy it has a new unique reference number (URN) allocated alongside the old URN; hence data can be matched. This helps reduce attrition. Third, it provides a lot of information on school characteristics - school population share by ethnicity, a low-income marker (FSM), English as an additional language, special education needs (SEN), gender, enrolment status, pupil head-count (part-time/full-time), attendance, exclusions, religious denomination of schools and school types, to name a few. Separate attainment data is also available in year-wise school performance tables.

This School Census covers nursery, primary (and middle deemed primary), and secondary (and middle deemed secondary) schools. Secondary schools include middle deemed secondary schools, foundation, voluntary controlled, voluntary aided, independent, state maintained and special schools, city technology colleges (CTCs) and academies. Nursery schools include both maintained and direct grant nursery schools and special schools include maintained, non-maintained and hospital special schools.

Pupil level data

The national pupil database (NPD) contains detailed information about individual pupils in schools and colleges in England. This data includes test and exam results, prior attainment and progression at different key stages for pupils in the state sector. The performance tables include attainment data for students in non-maintained special schools, sixth-form and further education colleges. Information about pupils' characteristics, such as gender, ethnicity, first language, eligibility for free school meals (current year, last six years), special educational needs (SEN) and pupil absence/exclusions, names of schools attended is provided. Limited information on pupils in independent schools is available.

Most importantly in a longitudinal study as this it is possible to track the learning trajectory of a child through NPD even if the student changes schools as long as all of the schools attended are in England. This reduces attrition. Subject to approval, extracts of this data are available for conducting research or analysis for promoting education or well-being of children in England. Administration costs are not levied on these datasets and can be used for producing statistics, providing information, advice or guidance.

Application for data

Data available from NPD is divided into different categories based on sensitivity and can be requested in a number of different combinations. These extracts have been organised into four different tiers of access, each with their own governance arrangements. More information on standard extracts and a full list of data items available in each tier, including new information at school level, can be found on the NPD web page.

To summarise:

- Tier 1 contains the most sensitive personal information,
- Tier 2 contains personal information, including less sensitive versions of tier 1 data,
- Tier 3 contains school-level data,
- Tier 4 contains other pupil-level data for example, attainment, absence and exclusions.

In addition to the above four tiers, pre-designed standard data extracts are made available upon approval, which fulfill most requests and involve shorter processing times. These are termed as tier 2 or tier 4 standard extracts. This research project made use of standard data extracts. Tier 3 school level data and tier 2 pupil level data were approved for the study.

To request extracts of the NPD data the completed 'NPD data request application form' and 'Information security questionnaire' was submitted. The former was filled in by the applicant and the latter by the IT security officer, Durham University. This asks that the applicant will comply with all relevant requirements of the Data Protection Act 1998. Some of these compliance parameters were:

- The applicant's organisation should be registered with the Information Commissioner's Office to process personal data or fall within an exemption category.
- Appropriate security arrangements should be in place for data processing.

- The researcher is allowed to use data only for the specified purpose in the request.
- Approved data should only be kept for the specified length of time and thereafter destroyed using proper shredding software.
- The researcher is not allowed to share data without prior written approval from NPD.

There are different approval processes depending on the sensitivity and types of data extract requested. Requests for extracts from tier 1 can only be approved by Data Management Advisory panel. In this case applicant must also give explanations for why each sensitive item is required, and why the same outcome cannot be achieved using less sensitive data. Requests for extracts from tiers 2, 3 and 4, are dealt with by the NPD Data Request team. Following the prior rejection of linked NPD-ILR-HESA data, the applicant was advised by the NPD data request team to apply under fast track process for applications. This was possible because a part of data for the project had been previously approved and this could speed-up the process. A license agreement and completed individual declaration was submitted. Thereafter, the requested compressed, zipped data was transferred securely to a temporary internet folder as text files. The data was encrypted and the password was released to the researcher. This confidential data was downloaded, unzipped and saved in SPSS format (.sav extension) by the researcher in external drives as agreed upon with NPD.

The Census included all pupils who were registered at the school and who should have had a current record on the school's Management Information System (MIS) at the school on the census day. NPD-pupil level data provided information on all pupils in state schools in England, linked to their schools, as they progressed through primary and secondary school. Attainment data, but not pupil characteristics were available for non-maintained schools. However, there were also some cases where records were available for students' no longer on roll, for example, where they had been excluded or left school prior to census day.

Timing of data sweeps

Before 2006, pupil and school characteristics were collected annually and termed as Pupil Level Annual School Census (PLASC). In 2006, secondary schools (maintained secondary schools, city technology colleges and academies) moved from the annual collection of PLASC to a termly collection cycle. Thus data was collected three times a year during spring, summer and autumn as part of the School Census (SC). Each term's data collection is now slightly different. The main census is the Spring Census, taken in January and can be linked with the annual data provided by PLASC. For the 2005/06 school year, secondary schools also provided information on fixed period exclusions and the reasons for exclusion alongside the standard information on permanent exclusions. In 2007, primary, nursery and special schools also moved across from PLASC to termly School Census collection. So for 2006/07 school year onwards, information on permanent and fixed period exclusions as well as the reasons for exclusion are available for primary, secondary and special schools. The cohorts are structured to stand alone on the information they contain, however it is also linked using a unique identifier for each pupil, which can be back tracked to previous records.

Data made available for this research project by NPD was the most up-to-date at that point of time and covered from 2007-08 to 2011-12 for GCSEs and 2013-14 for A-levels.

Data release schedule

NPD produces three data extracts for users every year; ‘unamended’, ‘amended’ and ‘final’, at various stages of the checking process. Attainment data of students are collected at the end of each Key Stage. The standard KS4 extract requested for this project combined KS4 attainment with prior attainment at KS1, KS2 and KS3, and spring census data from the current academic year (and previous 6 years), undertaken by schools.

KS4 entry data is collected by the performance tables contractor from awarding bodies and matched into their existing database. Approximately 150 awarding bodies provide their contractor with separate data feeds of results. This is matched from examination level to the individual student. When this has taken place, some additional indicators and flags are calculated by the contractor and added to the data before ‘unamended’ data is provided for matching into NPD. After matching, the first, ‘unamended’ KS4 extract is released, this is usually around November every year. At the same time as the data is being matched into NPD, performance tables are sent to schools for checking. After schools check and make necessary changes, the ‘amended’ data is matched into NPD. This ‘amended’ extract is usually available for release around January each year. After the Performance Tables have been published, schools are given the opportunity to make errata changes. Again, this new data is matched into the NPD and the ‘final’ KS4 extract is available around April.

All school and pupil level data used for analysis here is amended data. A part of this project uses unamended data for evaluating continued STEM participation. This is because it was the only available dataset when the request was approved.

Access and use of NPD by the Education Community

Schools typically have their own Management Information System (MIS) to collect and analyse pupil level information. Extracts from these systems are used to complete school census returns provided to local authorities (LA) or directly to the DfE. A school may also share other data and information from their management information system with other partners.

Over the last ten years data extracts have been shared by DfE, under strict terms and conditions with named bodies and third parties for educational research. These rich datasets have provided invaluable evidence on educational performance to inform independent research, as well as analysis carried out or commissioned by DfE, maximising its value. The same database was thus used for this study. The next section describes the selection procedures devised for allocation of schools and pupils into intervention and comparator groups.

4.6 Case Selection Procedures

Information obtained from all ten participating STEM activity providers was converted into similar formats and stored in excel workbooks. Each book carried details from one organisation. Each sheet in the book represented one academic year starting from 2007-08 and ending at 2011-12. Details included, were the type of activity, school names, age groups and year groups of participating pupils, ability groups, school contact details, and feedback given by the attending teacher from the school.

Data from this file was collated into a new excel book, with each sheet representing a single academic year, summarising school name, names of STEM activity providers the school has registered with and total number of organisations delivering interventions to the school during the academic year.

A standard data extract with complete list of all schools in England and their background characteristics was provided by the national pupil database. Information from excel files was carefully matched and exported or entered into school and pupil level data files obtained from NPD. The data files were cleaned up to exclude all nursery, primary, middle deemed primary and middle deemed secondary schools. All special schools, pupil referral units and independent schools were excluded from the study. State maintained schools included were academies, city technology colleges, voluntary aided, voluntary controlled and foundation schools.

Performance tables were provided separately these files were now merged year-wise with the above files. Thus the new files created were now ready for analysis. These had details of school identifiers and background characteristics, STEM interventions and performances.

Intervention group

Some schools were known to have been registered with more than one STEM activity provider (amongst the ten participating organisations) in an academic year while there were others whose names did not figure out in the lists provided. Perhaps these schools did not do any STEM activities or equally likely because they enrolled for activities elsewhere - other than the organisations sharing data. Thus, English Secondary schools following the National Curriculum and registered with at least one STEM Activity provider during the academic year were shortlisted as the intervention group.

Further, several independent schools were registered with at least one of the ten providers. However, since the KS4 results as well as the percentage of FSM eligible pupils of these schools were unavailable in the NPD data these schools were excluded from the study. It is expected that exclusion of these schools though affecting the sample size does not affect the results since the percentage of FSM eligible pupils in independent schools is negligible, generally applying only to those given an assisted place/scholarship.

A few Pupil referral units (PRUs) were known to be regularly participating in enhancement and enrichment activities but were excluded from the intervention group as the NPD school level database does not provide details on ethnicity, gender, FSM eligibility details of these PRUs.

The activities delivered advanced in their complexity according to age/grade of participating pupils and science/maths lessons in school. Schools participating in enrichment and enhancement activities every year from the beginning of 2007 till the end of 2012 were tracked. It was observed that a set of 300 schools exposed at least some of their key stage 3 and 4 pupils every year during this period. The intervention schools were thus divided into ever-intervention and longitudinal intervention groups. The former meant students from this school have been enrolled for enrichment and enhancement activities at some point in secondary school. The latter meant these schools have exposed their students to STEM activities every year.

A record of all secondary schools known to have participated in STEM activities was created from 2007-08 to 2011-12. This set of schools was not exactly the same every year, if a school participated in a STEM activity during a particular academic year it was included in the record for that year. Table 4.6 shows the number of all schools in England, and the number of such intervention schools each year.

Table 4.6 Number of schools – population and intervention group

Academic year	2007-08	2008-09	2009-10	2010-11	2011-12
Total number of all schools	5586	5732	6088	5006	5121
Intervention group	407	607	624	752	646

A set of 300 schools, registered for STEM activities every year from the beginning of 2007 till the end of 2012, were identified as the longitudinal intervention group. During these five years some schools were closed and some new ones were opened. A school was included in this sub-set only if it participated consistently each year. Thus if a school participated for some years but closed even during the last year of data collection it was excluded. Similarly, if a school just opened during the second year of data collection and participated every year it was still excluded. Some schools converted into academies, the new URN was checked in NPD records and Edubase to ascertain it was the same school. All such schools were included only if they participated each year.

A similar approach was followed with the pupil level data. The cohort of year 7 students in England during 2007-08 were tracked for the study. Their attainment and participation in science and maths GCSEs was mapped. If a child moved school and new school details were available from NPD, the student was included in the intervention group only if both old and new schools were known intervention schools. However, on several occasions students left the country or dropped out of education or simply their details were not available from NPD after the first few years. Such students were excluded from the intervention group. Similarly, new students who joined the cohort any time after the first year of intervention were also excluded even if they were at an intervention school.

Case selection procedures were based on actual treatment received as far as possible and there was no ‘intention to treat’ as sometimes done in RCTs. This elimination of bias was deemed important despite causing attrition to ensure a direct effect of longitudinal interventions could be seen in pupil attainment. It is expected that there might have been a few instances when students were absent on the actual day of intervention delivery, it was not possible to check these cases and is one of the known limitations of this study. However, the huge sample size of nearly 80,000 intervention pupils reduces these considerations.

Comparator group

The school results of the intervention group were compared with the national performance as it was not possible to obtain a comparator group of schools known to have no identified STEM activities. One approach considered towards identifying a distinct comparator was through correspondence with head teachers. The head teachers' refusal to disclose information ruled out this possibility. The second approach was through STEM activity providers. During face-to-face meetings some activity providers claimed to know certain schools which had never enrolled with STEM activity providers but refused to disclose names due to data protection reasons. Thus, in the absence of a clearly matched comparator due to non-cooperation and/or data protection reasons the national performance was considered. All secondary schools in England following the National curriculum whose school results were available from performance tables published by the NPD, excluding the intervention schools, formed the comparator for this study. This clearly included schools not involved in any STEM enrichment activities. It also includes some schools that were participating in interventions. This could dampen any effect size, but was the only feasible comparison. Trying to match schools could be worse, since the matched comparator schools might also be unknown treatment schools. The general comparison must include all non-treatment schools. Note that even this design would not be possible any longer. The growth of STEM enrichment activities since 2006-07 means that there will be few schools remaining that have not tried at least one of them once.

As is true for all studies in social science research possible explicit or implicit ethical issues were considered for this research project. The study despite considering 11-18 year olds did not deal directly with participants and data shared by NPD was anonymised.

4.7 Ethical issues

This research project was initiated at the University of Birmingham in 2012. Ethical approval was obtained for the project. Thereafter, as the researcher moved to Durham University a further ethics form was submitted and approval sought and obtained for this research project (Appendix).

The study involved use of primary as well as secondary data. The aims of the evaluation research project, planned use of data, strategy for dissemination of research findings and its likely implications were explained to all activity providers at the outset when data request was made. Thereafter, the providers were asked if they were willing to be named in the research reports. Anonymity of names of schools and activity providers was promised and has been maintained. None of the schools or activity providers are identifiable in this thesis or any publications arising from this piece of work.

Data provided by NPD was stored in encrypted hard disks in compliance with all relevant requirements of the Data Protection Act 1998. Data was transferred by the NPD data request team through the "key to success" folder – a temporary folder created on the internet. The data was downloaded into a hard disk, unzipped and save as encrypted files. The password was known only to the researcher. A copy of this data was available with the researcher's PhD supervisor as agreed upon in the application process. The data was used only for the specified purpose in the request of this research project and will be destroyed using shredding software after the specified length of time. Alternatively, prior written approval will be sought from NPD if the same data is used for other research projects as advised.

Chapter 5 Data analysis

There are four sections in this chapter. The first section reports searches, screening and quality assessment procedures for the systematic review. The next two sections discuss the analysis of school and pupil level attainment data, and the fourth section post-16 STEM participation pupil level data.

5.1 Systematic review – searches, screening, quality assessment

Search strategy

Electronic searches began with major educational databases ERIC, ProQuest, PsycINFO and Social Science Citation Index. English language peer reviewed journal articles, reports, government & official publications, dissertations & theses, conference papers & proceedings were all included. First, a standardised Boolean search strategy (table 5.21) with defined terms was used. Second a pre-selection criteria was framed. This was followed up with hand searching of relevant journals. Research papers from experts in the field were also included in the review. The term for design element "correlation OR association OR link" was then included in the search strategy – research articles using a research design whether longitudinal or cross-sectional, correlation, regression studies with a control group/comparator were included.

Inclusion criteria

Studies relevant to the research question using clear measures of deprivation such as FSM eligibility/reduced price lunches, geographical location of residence in a disadvantaged area, speakers of English as additional language, ethnic minority status, and low parental income were included. All studies used an outcome academic measure of achievement in science and/or maths such as student performance in standardised national level tests, state level exams or school performances.

English language papers published between 1.1.2005 to 31.12.2014 were shortlisted for the review. During the first few stages the focus was on covering the breadth of all information available including grey literature and beyond research evidence. Conference proceedings, government & official reports, Master's, EdD & PhD dissertations and theses, journal articles were thus included in the earlier searches. Studies carried out internationally but relevant to the research question, overviews of current policies were all included.

Exclusion criteria

An article was excluded if it -

1. Did not clearly specify the outcome variable such as learning gains, educational attainment, test results or participation in science and/or maths education.
2. Did not consider a deprivation measure
3. Did not use a robust research design for example single case studies without comparator were excluded in favour of studies making use of population datasets with matched comparators in a longitudinal or experimental design.
4. Did not include a control group/comparator were excluded.
5. Did not answer the research question
6. Did not have a convincing sample size, for example single case studies.
7. Master's theses were huge in number (in thousands), most often short superficial reports. Some of these for example were essays on underachievement and not real investigations. It was difficult to manage reading all of them thus these were excluded in favour of PhD theses which were also in thousands but gave a relatively detailed robust research report.

First stage screening

The number of hits returned was unfathomable. All government and official reports, working papers, conference papers and books were excluded, only real research reports like dissertation, theses and journal articles were included. However, not all of these addressed the research question. A filter was now added to identify only those papers which focussed on the subjects of secondary education, maths education and/or science education. Preliminary screening was conducted by scanning titles and abstracts of all these journal articles and theses.

However, scanning through the broad coverage of the review it was evident that information able to answer the research question came mostly from PhD/EdD theses or peer-reviewed journal articles. Further, the titles or abstracts of the shortlisted papers did not always reveal enough information for instance regarding the comparator group or sample size. All such papers were retained during first stage screening done by the author. Duplicates were removed and all Master's theses were excluded.

Second stage screening

All retained reports were completely read to understand the research methods and scanned once again. For instance, single school case studies with no matched comparator groups were excluded from the review despite their claims of investigating best practices, as it was thought in the absence of a convincing sample size and comparator group it was not possible to justify the claims being made in the study and test its reliability and validity. Research findings from such studies which did not report or use a convincing design and research methods were excluded from the review. A list of all papers screened during the various searches are available with the author but only those studies whose findings have been summed up in this review are listed in the references.

During the next stage relevant robust research reports capable of answering the research question offering recommendations for raising academic competence of disadvantaged pupils were collated. All information available in terms of measure of disadvantage used, research design, cases, sample size, methods used, outcome measure, results, conclusions drawn by the author and recommendations made (table 1) were considered. Some studies included in the review were PhD theses which were not available online. For such grey literature research data available from the abstract was summarised for the review. On certain occasions adequate information had not been provided by the author in the abstract, nor an e-theses was available such reports had to be excluded.

The researcher did not have access to all the research papers. DDS requests were made and electronic copies of all such papers were made available for a small fee by the British library. In some other instances a direct correspondence with authors of these shortlisted publications was made and some of them shared an electronic copy of the publication. This brought down the number of robust evaluations capable of answering the research question. These full length papers/theses were available to read for data extraction. For a complete breakdown of papers accepted/rejected at each stage of the review see PRISMA flow diagram (figure 6.1).

Double blind screening

Systematic reviews are ideally conducted by teams to enhance credibility of research and rule out any chances of bias. If reviewers agree articles can either be included or excluded. If reviewers disagree the research reports are re-examined by the team and discussed to reach a common decision. This review was initiated as a part of this PhD project by a single reviewer. Hence an alternative strategy was adopted. The database was screened by one researcher only. A double blind screening and a second time data extraction was carried out by another independent researcher on a ten percent random sample of the database (Torgerson, 2003). Due to time and financial constraints it was not possible to replicate screening of the complete database.

The review questions and protocol were discussed and the process replicated. Cohen's kappa coefficient was used to measure inter-rater agreement for this review. It is considered to be a more robust measure than simple percent agreement calculation, since κ takes into account the agreement occurring by chance. Cohen's kappa measures the agreement between two people who each classify N items into C mutually exclusive categories. See Cohen (1960) in the journal Educational and Psychological Measurement. The equation for κ which was used here is:

$$\kappa = \frac{p_o - p_e}{1 - p_e} = 1 - \frac{1 - p_o}{1 - p_e},$$

Here, p_o is the relative observed agreement among raters, and p_e is the hypothetical probability of chance agreement, using the observed data to calculate the probabilities of each observer randomly saying each category. If the raters are in complete agreement then $\kappa = 1$. If there is no agreement among the raters other than what would be expected by chance (as given by p_e), $\kappa \le 0$.

Quality assessment

After screening of research reports a bigger challenge was to assess the trustworthiness of screened papers. Gorard (2014) offers a procedure for, and a description of the elements involved in judging how reliable a research finding is. The idea is very valuable for designing research as well as creating a synthesis of existing evidence. As the author suggests though the paper primarily focuses on active designs to address causal research questions, the ideas can easily be extended to other types of research.

Other than research design, the elements suggested were sample size and quality, data quality, fidelity of intervention, and threats to validity. These are combined in a kind of ‘sieve’ to produce a judgement-based star-rating for the believability of a piece of research. Data extraction table was thus designed to accurately collect all information needed to address the review questions and quality criteria based on the quality assessment tool of judgement based star-rating.

Quality assessment was done by three researchers. The author screened, assessed the trustworthiness of all identified papers and rated them. This was then independently screened by a second researcher. The ratings of both researchers were compared. There was not complete agreement regarding inclusion and reliability of all shortlisted papers. The second researcher excluded all papers whose abstracts did not clearly appear to be able to provide an answer to the research question of this review. Primary research reports are sometimes poorly reported. It is thus not always possible to determine how to assess a quality criterion. It is possible to assume that because something wasn't reported it wasn't done. This assumption is incorrect and can lead to loss of valuable information and even misleading results. This review was planned to be as inclusive as possible. Hence, to resolve conflict regarding inclusion/exclusion of papers, full papers were read and some authors were contacted to obtain more information about the study.

The third researcher was now requested to do double data extraction (10%) according to the pre-decided criteria. The focus of the review and data extraction procedure was discussed however; the ratings given by the researchers earlier were not disclosed. The reliability index was discussed and the third researches was now asked to judge the trustworthiness of these chosen studies allocating a star rating. The same reliability index (Gorard, 2014) was used by the new researcher who assessed all these research papers. There was a high agreement between the author's ratings and the third assessment. The ratings shown in the data extraction table are an average of the values allotted by all three researchers.

Synthesis

For synthesis of results from potentially relevant papers the grounded theory approach (Glaser and Strauss, 1967) was followed. A substantive area of interest for the review had already been identified (see research question). Data had been collected from major educational databases and a double blind data extraction had been completed and the credibility of these studies established. In order to conceptualise the latent social patterns and structures which are linked to underachievement of disadvantaged pupils in school science and maths, the data obtained was coded into relevant themes. All papers following a certain theme were grouped into the same category. Papers suggesting a new theme were classified separately. The process continued till all returned hits were categorised and it was found that no new themes emerged thereafter from existing literature (table 107). Research findings from all papers categorised under one theme were discussed under the same strand (chapter 6). Recommendations available from these studies as what works were included together (chapter 7)

5.2 School level data

5.2.1 Indicators used in the study for school level data

School level data obtained from NPD was merged with Key stage 4 performance indicators, notably the percentage of pupils achieving the Level 2 threshold including A*-C in both English and Maths GCSE (or equivalent). This variable was chosen for the study as it was available for all academic years being considered 2006/07 to 2011/12, and the equivalencies had already been created by the DfE (it is unlikely that this could be improved). Using the same indicators for all years reduces the chances of error which could possibly arise in matching of variables for comparison in a longitudinal evaluation.

A grade of C or above in GCSE maths was considered a 'success'. Figure 5.1 shows how schools the clear relationship between percentage of FSM pupils and the percentage gaining C or above in each school. Schools with a higher percentage of FSM eligible pupils had a lower percentage of pupils achieving A*-C in maths, and vice versa. A similar trend was observed each year and for both science and maths.

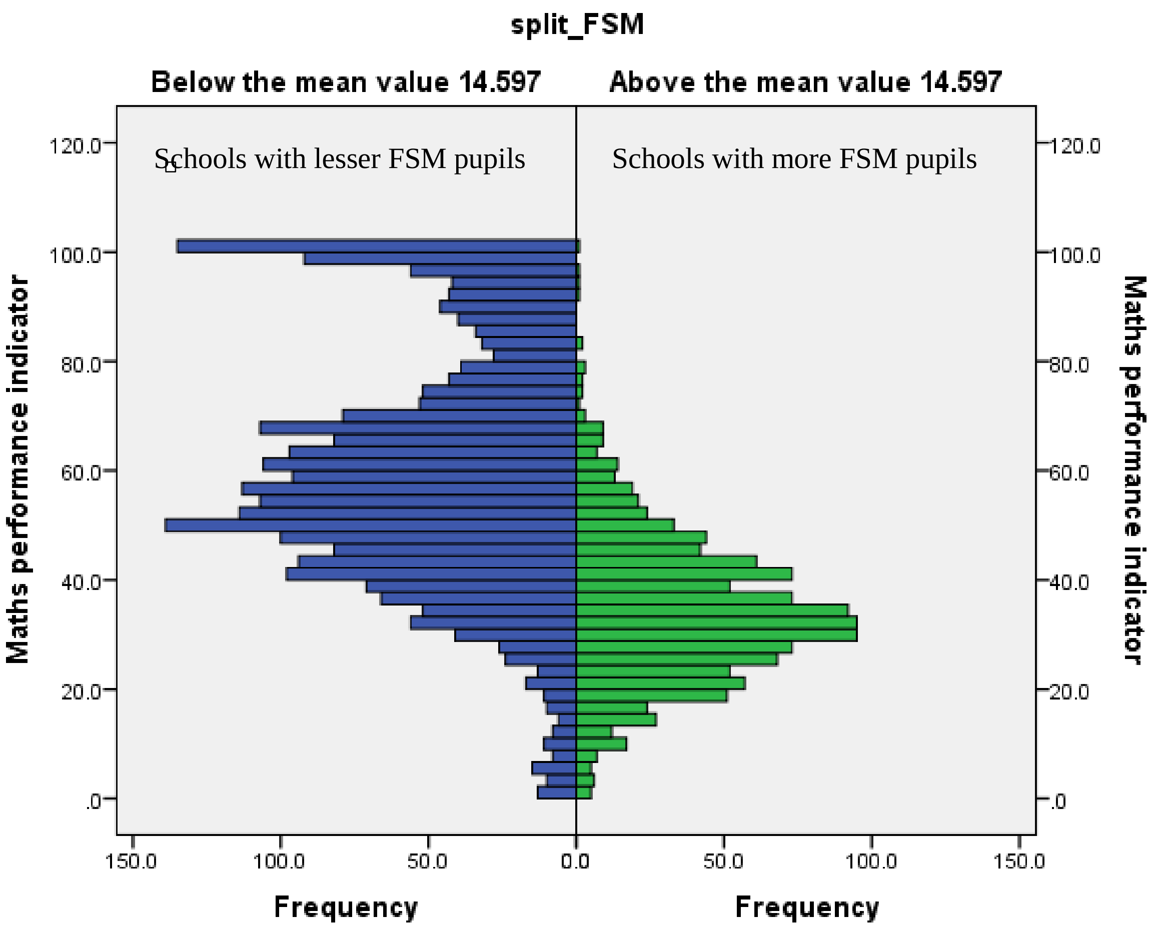
Similarly, the percentage of pupils at the end of key stage 4 achieving two GCSEs at grades A*-C or equivalents covering the KS4 science programme of study was considered as the school science performance indicator. This was the only science performance variable available for 2007-2010. Due to a change in methodology from 2010-11 by the National Pupil Database this variable was removed and an equivalent variable was not generated (see letter from NPD confirming the same in Appendix). This makes long-term patterns for science harder to judge.

One of the proxy indicators used as a measure of pupil's poverty is eligibility for free school meals (FSM) (Shuttleworth, 1995, Gorard, 2003, Hobbbs & Vigoles, 2007, Chowdry, 2013). As stated in DfE guidelines, pupil eligibility for FSM is assessed based on certain criteria, such as parent/guardian being in receipt of one of the following:

i. Income Support,
ii. Income-based Jobseekers Allowance,

iii. Income-related Employment and Support Allowance, Support under Part VI of the Immigration and Asylum Act 1999,
iv. the guaranteed element of State Pension Credit
v. Child Tax Credit (provided you're not also entitled to Working Tax Credit and have an annual gross income of no more than £16,190)
vi. Working Tax Credit run-on - paid for 4 weeks after you stop qualifying for Working Tax Credit
vii. Universal Credit

School level data categorises information for FSM pupils as the percentage of all those pupils who are known to be eligible for and/or are claiming free school meals according to school census and performance tables. These FSM values are the main measure of pupil SES and background used for calculations contextualising the attainment figures.



Source: National pupil database, 2009-10

Figure 5.1 % pupils achieving A*-C in maths by % FSM pupils in school

In addition, the gender of each pupil was used to create the percentage of boys in each school, and the same was done for each major ethnic group (listed in NPD as White British, Asian, Black, Chinese, and any other ethnic group)

Special schools, which are expected to have lower attainment, were excluded from the study as the attainment data of these schools is not always available. However, all schools in England have a certain share of pupils with learning challenges, with or without SEN statement, and the level in each school could be an important contextual variable. But it was found that all included schools had no more than 1-2% of SEN pupils.

The Income Deprivation Affecting Children Index (IDACI) tool was considered as a possible measure of disadvantage. However, the choice of schools is driven by several factors other than proximity, such as peer group, school status, religious denomination of school, oversubscription of popular schools and schools offered during admission process. Since students do not always attend the nearest school, and the index is not about an individual characteristic, FSM was favoured as a measure of disadvantage over the IDACI tool.

5.2.2 Analysis using school level data

All analysis for this study was carried out using SPSS version 20. The first phase of the study explored the possible impact of STEM initiatives on school GCSE performances, using the 'ever intervention' group. The means of school performances in terms of percentage of pupils achieving 5+ A*-C including English and Maths in schools were compared. The percentage point difference in achievement between intervention and comparator groups was assessed. The achievement gap was estimated using Newbould and Gray's approach (Gorard, 1999). They define the achievement gap as the difference between performances of intervention and comparator relative to the performance of all entries, minus the entry gap (difference between number of entries for GCSEs for various groups). Since these calculations are from snap-shot data, the entry gap has been taken as zero. The number of schools in comparator every year is 2000+ and intervention schools around 500+. Thus, for calculating achievement gap the following formula was used here:

$$\text{Achievement gap} = \frac{\text{Mean attainment}_{I} - \text{Mean attainment}_{C}}{\text{Mean attainment}_{P}}$$

In addition to the performance tables, school census includes details such as percentage of pupils eligible for free school meals (FSM) in each school. FSM eligibility is widely used as a proxy indicator of disadvantage. Pupils belonging to families with a lower socio-economic status have been shown to perform not so well academically. Thus school performance is negatively correlated to percentage of FSM eligible pupils in school. The analysis also explores if exposure to STEM activities can break the link between SES and Maths performances. Pearson's R correlation coefficient was used to study the correlation between school maths performances and percentage of pupils eligible for free school meals (FSM) in the intervention group and the comparator group. The population dataset met the basic assumptions of binomial distribution, linear relationships between variables (checked through scatter plots) and homoscedacity (discussed in detail in chapter 5). This was justified because Pearson's R has been shown to be insensitive to extreme violations of the basic assumptions of normality and the type of measurement scale (Havlicek and Peterson, 1977). It was expected that the correlation coefficient would decrease if STEM interventions had been effective, suggesting that the link between poverty and attainment had been reduced.

A set of 300 schools formed the 'longitudinal' intervention group. The same set of schools participated in STEM activities each year from 2007 to 2012. GCSE results in maths and science for this set of schools was followed from 2007-08 to 2011-12. Table 5.1 below shows a breakdown of the various school types included in the intervention group. Results of the intervention group were compared with the comparator group. All other schools excluding these 300 schools in the population of eligible schools constituted the comparator. This was done in full understanding of the fact it is quite possible the comparator included some schools which had participated in interventions but were not known to the researcher as well as had some schools which probably have never participated in STEM schemes for reasons such as geographical location.

Previous work has (Gorard, 2009) shown that schools tend to have similar pupil intakes year on year. That is to say the student population characteristics and backgrounds are broadly similar for every cohort in a particular school. This can be attributed to reasons like housing prices, SES, admission policies, geographical location and so on (Gorard, 2003).

Table 5.1 School types in intervention group

School type 2007-08	Frequency
Academies	2
Community	198
Foundation	38
Voluntary aided	56
Voluntary controlled	5
Total	299

Table 5.2 below shows the number of school at the beginning of 2007-08 who were registered for longitudinal interventions. Number of schools decreased by the end of 2011-12 as there were occasions when two nearby schools were merged to form a new academy. Thus for the first year of analysis the number of schools is higher than the last year.

Table 5.2 Number of schools – longitudinal intervention and comparator

Group	Longitudinal intervention	Comparator
2007-08	299	2720
2011-12	289	2409

Achievement gap

The entry gap was considered for the longitudinal intervention schools. Thus the achievement gap was calculated before and after intervention using the formula:

$$\text{Entry gap} = \frac{\text{numbers}_{\text{Intervention}} - \text{numbers}_{\text{Comparator}}}{\text{numbers}_{\text{Intervention}} + \text{numbers}_{\text{Comparator}}}$$

$$\text{Achievement gap} = \frac{\text{Mean attainment}_{\text{Intervention}} - \text{Mean attainment}_{\text{Comparator}}}{\text{Mean attainment}_{\text{Population}}} - \text{Entry gap}$$

Again, as the entry gap before and after intervention was of a similar order, this value was not substituted in the calculations in chapter 6. This is because number of intervention schools and comparator schools were largely similar before and after intervention.

Correlation coefficients

A range of explanatory school and student population variables are known to be able to predict school attainment. Some of these variables are gender, percentage of ethnic minority pupils, percentage FSM eligibility, percentage pupils whose first language is not English. In order to estimate correlation coefficients of school maths or science performances with these predictor variables, the Pearson’s correlation coefficient R was used. For this coefficient the possible values range from minus one to one. Here, a value of one means strong positive correlation – that is the higher the value of predictor variable the more is the value of outcome variable. If R is zero it denotes no correlation – the factors are not linked. A value of minus one denotes strong negative correlation – which means as the value of the predictor variable increases the value of outcome variable decreases.

Cross-product ratio

The cross-product ratio was estimated for mean maths and science school performances in the longitudinal group. No change was defined as ad=bc or ad/bc=1. Here 'a' was the attainment of intervention group before intervention, 'b' after intervention, 'c' was attainment of comparator at the beginning and 'd' at the end of the study.

5.3 Pupil level attainment data

Amended KS4 data was provided by NPD for the academic year 2011/2012 matched to prior attainment at KS3, KS2 and KS1 and to Census 2012 where a match could be found. A total of 631,757 pupil records were available for those who wrote GCSEs at the end of KS4 (no missing data) in 2011-12, A retrospective tracking showed at the end of KS3 pupil records including name of the school pupil was enrolled in was available for 571947 pupils. This meant KS3 school names were not known for 59810 pupils (missing data = 9.5%). This was either because these pupils were studying in a different country during KS3 or opted for home schooling. Further, 578001 of these pupils had attended a primary school in England and pupil level data including KS2 prior attainment and name of primary school attended was available for them (table 15), however records were missing for 53756 pupils (missing data = 8.5%).

Pupil mobility

It was thus important to track whether a pupil attended only one school from the beginning of KS3 till the end of KS4 or moved secondary schools. Two variables were used for this. First, the binomial variable KS4_MOB1 in the national pupil database stands for pupils' date of joining secondary school were GCSEs were taken. If a pupil joined current school in previous two years (years 10 or 11) NPD allotted a value of one and if pupil had been enrolled in current school since KS3 a value of zero was allotted. 96.8% pupils wrote GCSEs in the same school where they were enrolled since year 9 (table 5.3).

Table 5.3 KS4 pupils' date of joining current school

Indicator	Frequency	Percentage
Attending since year 9	611256	97
Joined in years 10 or 11	20501	3
Total	631757	100

The KS3_MOB1 variable indicates whether a pupil joined current school in year 9 (KS3_MOB1 = 1) or year 7/8 (KS3_MOB1 = 0). Descriptive statistics showed pupil mobility data - details of pupils' exact date and year of joining KS3 was available for 91 per cent of all pupils who wrote GCSEs in 2011-12. About 88 percent pupils continued in the same secondary school were they had joined in year 7 or 8 (table 5.4).

Table 5.4 KS3 pupils' date of joining current school

Cases	Frequency	Percentage
Joined in year 7 or 8	556273	88
Joined in year 9	15645	2.5
Missing	59839	9.5
Total	631757	100

The intervention

Access to official records held by STEM activity providers returned a list of schools registered with them for delivering a range of hands-on activities, ambassador visits, school visits, out-reach programmes each academic year beginning from 2007/08 to 2011/12. Longitudinal records created in the form of a school database suggested a set of 300 secondary schools signed-up with at least one STEM activity provider and a maximum of four for every year for a period of five years. This meant beginning in 2007-08 the year 7 cohort was exposed to a wide range of practical, hands-on STEM activities with the idea of motivating them to like science and developing an understanding of the subject to help them attain higher. There were ambassador led sessions (talks, seminars) and speed-dating events where participants were regularly exposed to the career choices which would be available should a STEM subject choice be made after GCSEs to encourage participate in science and maths beyond compulsory education. This exposure to diverse activities continued from the beginning of KS3 till the end of KS4. The inclusion of all of these activities as intervention was justified because they shared common objectives - improving attitudes towards and an understanding of STEM subjects, raising attainment and improving participation in STEM subjects.

5.3.1 A summary of analytical pupil groups

Scanning through pupil level data it was evident that students mostly continued in the same secondary school where they had transitioned from primary schools or first joined. However, there were occasions when this did not happen. Thus all students from this cohort were divided into several analytical groups based on the duration for which they were known to have been exposed to STEM interventions.

The ever-intervention group

All students who were known to have participated in STEM activities for at least a year to a maximum of five years were included in this group. This group was divided into the following sub-groups depending on the duration of intervention.

KS3 only intervention

Students who participated in STEM activities every year from beginning till the end of KS3 were included here. These students did not participate in STEM activities in KS4 either because their schools chose it that way or because they moved schools.

KS4 only intervention

These students did not participate in STEM activities in KS3 either because their schools were not known to be registered with known activity providers, or were not in England or because they were home-schooled. These students participated in STEM activities every year from beginning to the end of KS4.

The longitudinal intervention group

All pupils who had joined one of the 300 secondary schools registered with STEM activity providers in year 7 or 8 and continued in one of these intervention 300 schools till the end of KS4 formed the intervention group. Occasionally a pupil had completed KS3 in one intervention school and moved on to another intervention school in KS4 such cases were included in the analysis. However, if a pupil did not attend an intervention school in KS3 but attended an intervention school in kS4 the pupil was excluded from this group. Similarly, pupils attending an intervention school in KS3 but who did not attend an intervention school in KS4 were excluded from this group. It was possible to track schools attended by pupils from KS1 to KS5 with the help school unique reference numbers (URN) provided in pupil level data.

Staggered intervention group

Several registered schools enrolled pupils at some point between years 7 and 11, but this was not necessarily for all years across KS3 or KS4. Alternatively, sometimes students completed few years of schooling in a longitudinal intervention school and then moved school all of these were cases were included under staggered intervention.

Comparator group

As mentioned earlier, it was not possible to clearly identify schools which had never registered for STEM schemes. Hence pupils from all those schools whose participation status was not known were put together in the comparator group. This was thus the population of all pupils minus the ever intervention group. The size of all of these sub-groups in terms of numbers and percentages of pupils are summarised in table 5.5.

Table 5.5 Breakdown of analytical sub-groups

Pupil analytical sub-groups	Number of cases	Percentage
KS3 only intervention	13311	2.1
KS4 only intervention	1791	0.3
Staggered intervention	18072	2.8
Longitudinal intervention	43288	6.9
Comparator	555295	87.9
Total	631757	100

5.3.2 Indicators used in the study

The study used a range of predictor variables and outcome measures for educational attainment in science and maths for pupil level data. Pupil background predictor variables used in the analysis are discussed first followed by the outcome measures.

FSM eligibility

An indicator variable for whether the pupil is entitled to free school meals was used. FSM eligibility was used as a measure of disadvantage because to be eligible for free school meals a child's family has to have income below a certain threshold. FSM eligibility details were not available for 11% pupils for state maintained secondary schools (table 5.6).

Table 5.6 FSM eligibility – frequency table all pupils

Eligibility for free school meals	Frequency	Percentage
Not on FSM	481712	76.2
Taking FSM	80337	12.7
Missing System	69708	11
Total	631757	100

Eligibility for free school meals is decided by a range of criteria set out by the Department of Education (DfE). FSM request form submitted by the parent to the school is assessed and if it matches the listed parameters the pupil is allowed free school meals. The basic measure in all of these criteria is the family income. However, if the financial condition of a pupil's family changes the student is no more eligible for free school meals. Thus there are four sub-categories of the FSM variable in the national pupil database – FSM now, pupils currently in receipt of free school meals – for this study it was for the academic year 2011-12; Ever-FSM_6 – pupil was eligible for free school meals at some point during the last six years; Not FSM now – pupil currently not on free school meals, Never-FSM-6 – pupil was never eligible for free school meals during the last 6 years. Thus 'FSM now' pupils are the poorest and 'Never-FSM-6' the most affluent. The analysis for pupil level data thus considers all these four categories for estimating the poverty gradient.

Major ethnic groups

Ethnicity aggregated into seven major ethnic groups was made available as a non-sensitive pupil characteristic and provided with the standard data extract. The seven major ethnic groups considered were Asian, Black, Chinese, Mixed, White, any other ethnic group (AOEG) and unclassified if pupils' ethnicity details were not known (table 5.7). Descriptive statistics are summarised below.

Table 5.7 Major ethnic groups - frequency table for maintained mainstream schools

Major ethnic groups	Frequency	Percentage
Missing data	69708	11
AOEG	7022	1.1
Asian	44819	7.1
Black	26247	4.2
Chinese	2343	0.4
Mixed	20189	3.2
Unclassified	5469	0.9
White	455960	72.2
Total	631757	100

Major language groups

Educational research considers speakers of English as an additional language at a position of disadvantage in England (Cummins, 2000; Cline, 2002; Ofsted, 2005). Research suggests bilingual children are often bullied and face academic problems in trying to deal with course content, instructions from educators, peer-group interactions and perhaps are not able to attain their full potential putting them thereby at a position of disadvantage. According to the primary language spoken by pupils they are aggregated into three major language groups English, other than English and unknown (table 5.8) by NPD. Summary statistics for this group are below.

Table 5.8 Major language groups - frequency table

Groups	Frequency	Percentage
Missing data	69708	11
English	490724	77.7
Other	69897	11.1
Unknown	1428	0.2
Total	631757	100

Outcome measure – attainment –

STEM intervention in the form of educational programmes was delivered to the same cohort for five consecutive years throughout KS3 and KS4. The impact of these initiatives if any was evaluated on participating pupils from known registered schools. The outcome measures considered were a) attainment in science and maths GCSEs and b) post-16 participation in STEM subjects (assessed through subject choices made by participating pupils beginning of key stage 5). This section focuses on indicators of pupil attainment, indicators of participation data are discussed in the next section.

Pupil level data maths performance indicators

KS4_GCSE_MATHAC was the binomial variable marking whether pupil passed maths GCSE at A*-C. The values allowed were zero and one, where one stands for passed and zero for not passed (table 5.9).

Table 5.9 Pupil passed maths GCSE at A*-C

Cases	Frequency	Percentage
No	197970	31.3
Yes	433787	68.7
Total	631757	100

Pupil level data science performance indicators

KS4_LEV2SCI2B was one of the binomial variables chosen to mark science attainment, whether the pupil has achieved two ‘good’ GCSE science GCSEs or equivalent (including the BTECs, OCRs and IGNVQs). The allowed values were zero and one. A value of one indicated pupil achievement while zero denoted two good GCSE science GCSEs were not achieved (table 5.10)

Table 5.10 Achieved two 'good' GCSE science GCSEs or equivalent

Cases	Frequency	Percentage
Not achieved	285072	45
Achieved	346685	55
Total	631757	100

KS4_GCSE_SCIAC was the other binomial variable used in analysis. It denoted whether pupil passed science GCSE at A*-C. The two allowed values were zero and one. Here, one represented pupil met criteria hence passed and zero represented not passed (table 5.11).

Table 5.11 Pupil passed science GCSE at A*-C

Cases	Frequency	Percentage
No	261486	41
Yes	370271	59
Total	631757	100

Achievement gap estimation

As for analysis of school level data, Newbould and Gray's formula was used for estimating achievement gap. The only modification being number of pupils were counted for calculations here,

$$\text{Entry gap} = \frac{\text{Entries}_C - \text{Entries}_I}{\text{Entries}_C + \text{Entries}_I}$$

$$\text{Achievement gap} = \frac{\text{Number achieved A*-C}_C - \text{Number achieved A*-C}_I}{\text{Number achieved A*-C}_C + \text{Number achieved A*-C}_I} - \text{Entry gap}$$

Relative risk ratio

This is defined as the ratio of probability or chances of success in intervention group to that in the comparator. This was used to estimate effect size of the intervention in pupil level data. The formula used was:

$$\text{Relative risk ratio} = \frac{\text{Percentage pupils attaining the target indicator in intervention group}}{\text{Percentage pupils attaining the target indicator in comparator}}$$

A value of 1 indicates that chances of success are similar in either of the two groups with or without intervention. A value less than one means students perform better in comparator and more than one means intervention helps students perform better.

5.3.3 Pupil level data Regression Analysis

Introduction

This section explains the regression analysis approach. The first section describes multiple linear regression analysis used in the study to interpret findings from a continuous variable highest standardised points achieved in GCSE maths and science. The second part describes binary logistic regression analysis carried out for the specified outcome measure, attainment of A* - C in GCSE maths or science. The regression models used pupil background information such as SES, gender, ethnicity, language group, SEN status, participation in STEM initiatives and prior attainment in maths and science as the independent predictor variables for the study. Current eligibility for FSM was used as an indicator of SES.

Multiple linear regression - Objective

Multiple linear regression was used to understand whether attainment can be predicted based on explanatory variables participation in STEM initiatives, Gender, SES, SEN, ethnicity, language group. And also to determine the overall fit of the model and the relative contribution of each of the explanatory variables of the total variance explained. For instance, is participation in STEM activity during KS3 and/or KS4 a good predictor of maths and/or science attainment at the end of KS4?

Missing data

Regression findings do not prove anything but only provide an estimate in making judgements (Gorard, 2013). However, as a first step towards performing the analysis correctly descriptive statistics were used. Frequency estimation of all independent and dependent variables showed missing data in the range of 9 to 11%. For KS2 prior attainment in maths and science all missing data was excluded list-wise. This was because using mean for missing data imputation rendered the data biased between the groups. However, for all other predictors missing data was treated as ineligible. For instance, all missing FSM were treated as FSM ineligible, missing data for SEN was treated as not SEN (table 5.12).

Table 5.12 Missing data

Missing data	FSM eligible now	FSM_6	Major language group	Major ethnic group	Gender	SEN	KS2 prior attainment	
							Maths	Science
Percentage	11	11.1	11	11	0	11	9.3	9.2
Treatment	FSM ineligible	FSM ineligible	Excluded cases list-wise		NA	Not SEN	Excluded cases list-wise	

Pre-analysis data estimation

In order to ascertain the data can actually be analysed using multiple regression the following parameters required for multiple regression were checked

Scale

The dependent variable used for the multiple regression analysis - highest standardised points achieved in maths and highest standardised points achieved in science were both measured on a continuous scale.

Explanatory variables

Eight independent variables were considered to start with. Of these FSM eligibility, language group, ethnicity, gender, SEN and participation in STEM activity were categorical variables. KS2 prior attainment in maths and science were both interval variables.

Linear relationship

There was a linear relationship between (a) the dependent variable and each of the explanatory variables, and (b) the dependent variable and the predictor variables collectively. In order to check whether the relationship is linear residuals were checked, that is the observed value of the dependent variable minus the value predicted by the regression equation for each case. Here Y axis represents number of cases.

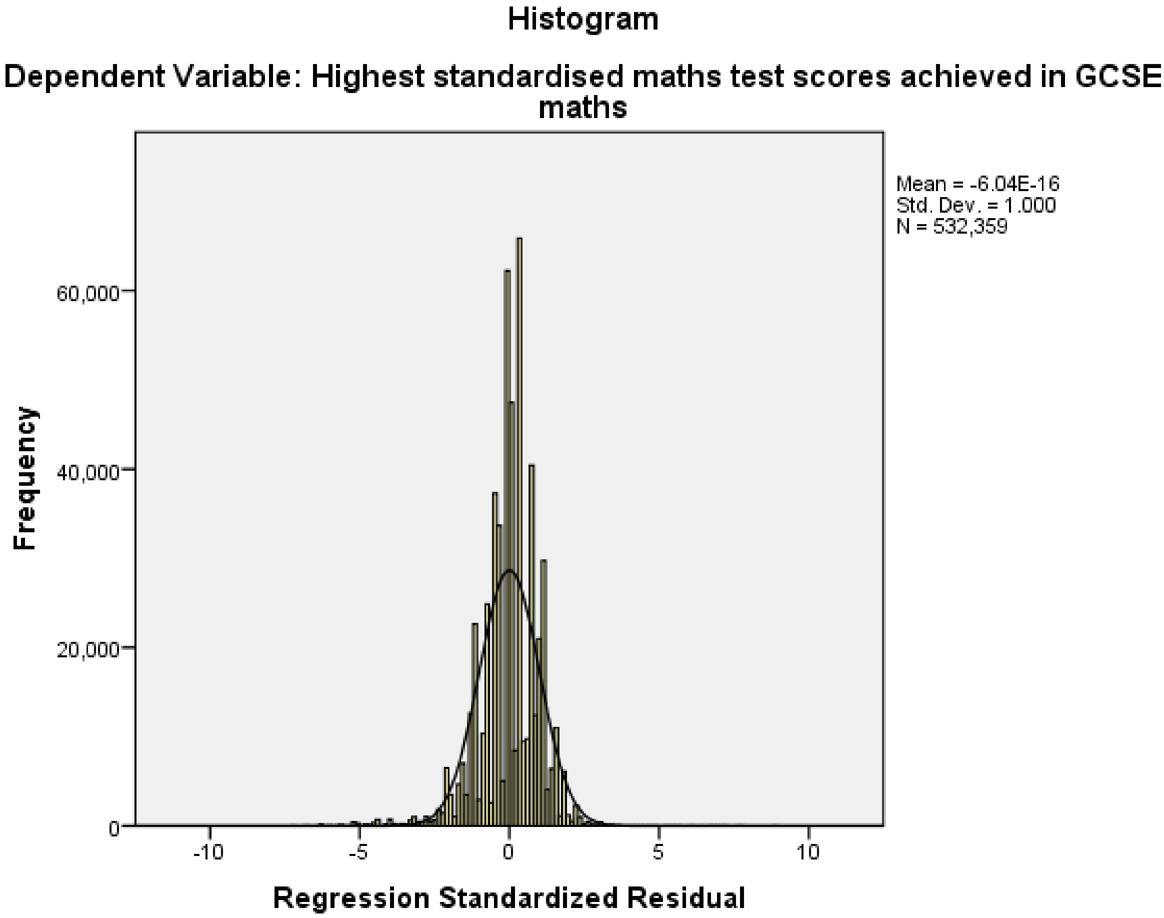


Figure 5.2 Residuals in regression

Multicollinearity

A major precondition for doing and interpreting regression model is the predictor variables must not be too strongly correlated with one another. This is because it leads to serious problems in estimating the relationship between dependent and independent variables, as it becomes difficult to calculate the individual contribution of each variable. Strong correlation among predictor variables might mean they are measuring the same thing, for example FSM eligibility and ever FSM eligibility status during last six years.

In order to rule out this problem of multicollinearity, collinearity diagnostics was estimated. Tolerance, the amount of variance in one predictor variable not explained by other predictors was checked. This value varies from 0 to 1, where a value close to 1 suggests other predictors do not explain the variance in that variable. A value close to 0 indicates almost all the variance in the variable is explained by other variables. For the predictors considered in this analysis all the variables had a tolerance higher than 0.8 (table 5.13)

Table 5.13 Collinearity statistics for regression analysis for maths test score prediction

Predictor variables	Tolerance
KS2 maths prior attainment	0.79
SEN	0.79
FSM eligibility	0.94
Gender	0.97
Language group	0.98
Ethnicity	0.99
STEM intervention	0.99

Similarly, for science test score prediction all explanatory variables considered had a tolerance higher than 0.8 (table 5.14)

Table 5.14 Collinearity statistics for regression analysis for science test score prediction

Predictor variables	Tolerance
KS2 science prior attainment	0.82
SEN	0.82
FSM eligibility	0.94
Gender	0.98
Language group	0.97
Ethnicity	0.99
STEM intervention	0.99

Homoscedasticity

The assumption of homoscedasticity simplifies mathematical and computational treatment. Assuming data distribution homoscedastic when in reality it is heteroscedastic leads to overestimation of the goodness of fit as measured by Pearson's coefficient.

Logistic regression

The outcome variable considered for logistic regression analysis was attainment of A*-C in GCSE maths or science. Predictor variables considered were same as for multiple regression analysis. The underlying premise for this analysis was to look at the probability of achieving or failing to achieve the outcome measure given different levels of explanatory variables. For instance, are students more likely to achieve an A*-C in maths and/or science if they participate in STEM interventions? Results of this analysis are discussed in chapter 6. Data analysis approaches, measures and indicators used for post-16 participation data are discussed in the next section.

5.4 Post-16 pupil level STEM participation data

At the time when data request was submitted and approved for the study, amended KS5 data for the specified year was not available. Approved KS5 unamended data for the cohort being followed up had a total of 796192 cases. Unamended data meant the file had duplicate entries for some cases. In this file 22 such cases were identified. It was impossible to ascertain which of these was a primary case was and which the duplicate. This is because NPD allocates an anonymised pupil matching reference number (PMR) to each case. However, for these duplicate cases though the PMR was exactly same, the school names, attainment and participation data differed. In order to reduce ambiguity all of these 44 cases were deleted. Thus pupil records for 796148 were available for those who were expected to take A-levels in 2013-14.

Similarly, KS4 attainment data files had 631757 cases. 245 duplicate cases were identified for which KS5 data was not available. Hence 490 cases were deleted. This could be because these pupils took a gap year, dropped out of education or moved to a school type whose performance data was not available with NPD, or perhaps possibly left the country. Thus, 631267 cases were available from the cohort being followed up.

A longitudinal record was now created by merging KS5 variables with the original KS4 attainment file for this cohort who took GCSEs in 2011-12 and A-levels in 2013-14. A total of 76406 cases (12%) from this cohort were exposed to STEM interventions at some point in secondary school from the beginning of year 7 till the end of year 11. For analysing continued post-16 STEM participation of pupils, the intervention group was further split up into various sub-groups depending on the point of delivery of the intervention (table 5.15).

Table 5.15 Number of cases in intervention sub-groups and comparator

Sub-groups	Frequency	Percentage
Comparator	554861	88
Participated in KS3	13290	2
Participated in KS4	1784	0.3
Participated every year in KS3 and KS4	43275	7
Staggered participation in KS3 or KS4	18057	3
Total	631267	100

The year 7 cohort of 2007-08 comprising of 631267 pupils was followed up. Key stage5 (KS5) data was available from the national pupil database for 55% of these pupils either because only these pupils took a qualification route and cashed in on their qualifications in

2013-14 or perhaps because some had moved out of England or even equally probably some had dropped out of education.

Qualification routes

Several qualification routes are available for those aspiring to study a STEM subject beyond compulsory education. However, as table shows beyond compulsory education the biggest share was of those students from the cohort for whom attainment data was not available. This was followed by A-levels. A very small percentage of pupils pursued other qualification routes. Also, A-levels remain the most popular choice amongst people wanting to study at the university (Smith, 2011). Thus the analysis presented here focusses on AS/A level STEM participation.

Table 5.16 Qualification routes taken by 16-18 year olds, England

Qualifications	Frequency	Percentage
International Baccalaureate	2580	0.4
Applied A level	6200	1.0
BTEC/OCR	2652	0.4
NVQ/VRQ	111569	17.7
A level	222506	35.2
Missing	285760	45.3
Total	631267	100

Pre-requisites

According to the organisation of the National Curriculum in England a range of subjects are studied across key stages 3 and 4. A student then takes GCSEs in three core subjects English, maths and science and other optional subjects. Students require at least five A*-C including the core subjects English, maths, to meet the pre-requisite to start A-levels. Typically, AS levels are taken in four subjects in year 12 from amongst those in which a GCSE was taken. Thereafter, a pupil drops down to three or four subjects for A-levels. Also pupils achieving a higher grade at GCSE are more likely to go to enter the same subject at AS and A-level than those attaining a lower grade. Thus arguably, an achievement of five A*-C is one of the most essential criteria for pursuing A levels and was tracked first in order to map STEM participation.

5.4.1 Indicators used in the study

The trigger variable in NPD files identifies students who are 16-18 years old at the start of the academic year and have been entered for a GCE/GCE Applied A level or a GCE Applied Double Award in Summer 2011 or a Level 3 qualification equivalent in size to at least one GCE/GCE Applied A Level during the 2013/2014 academic year. A value of one is allocated if pupil meets any of the criteria listed in table 5.17 below

Table 5.17 Trigger variable

Conditions/Exceptions	Description
Condition A	Student entered for GCE/GCE Applied A level or double award in Summer 2014
Condition B	Student entered for other level 3 approved qualification with an A level equivalent size greater than or equal to 1 in 2013/2014 academic year
Condition C	Student is at the end of advanced level study- E flag
Condition D	Student is from a Menorah school and has entries in Winter 2013
Condition E	Student was aged 16-18 at the start of the 2013/2014 academic year
Condition F	Student does not have an amendment flag of TO, CL, NR or Z (see below)
Exception A	Student is 16 and has a single A level or single equivalent qualification (size equal to or greater than an A level) in 2014 and no other level 3 qualification in the 2013/2014 academic year

Amendment flags:
TO: Transfer out- student on student listing but not on roll at the school or college at the time of the tests.
CL: Claimed internally- transfer of result to another student in the cohort.
NR: Not on roll- student not on roll at the time of the tests and has not had results claimed by another school or college.
Z: Student is not at the end of Key Stage 5 (forced out).

NPD Coverage at KS5 included all students with the criteria KS5_TRIGGER=1. This data was available for 58% of the cohort being followed, while only 55% of the population met the trigger criteria.

Table 5.18 Trigger criteria

Trigger criteria met	Frequency	Percent
No	20928	3
Yes	345511	55
Data unavailable	264828	42
Total	631267	100

Progression from GCSE to AS/A levels

This analysis considers the progression from GCSE to AS/A levels; the proportion of students who go on to take an AS or A level in the same subject. A student's decision to study a GCSE subject further may depend on a variety of factors (Vidal Rodeiro, 2007) such as enjoyment of the subject, ability, career plans school/college based constraints – whether the subject is offered, GCSE attainment. Participation in STEM enrichment and enhancement activities earlier in life thus may arguably have a very insignificant role to play if all of these parameters were added up. This thesis does not attempt to credit/discredit STEM initiatives for continued participation in science and maths subjects. However, it was taken up only to see the participation pattern in post-16 education of this cohort – with particular focus on two most disadvantaged groups – those currently in receipt of free school meals and black ethnic minority pupils.

Data from the National Pupil Database was used to calculate progression rates from GCSE (A*-C grades pupil level data) to AS level for the cohort who completed key stage 4 in 2012 for various science and maths subject choices. The analysis then follows up this cohort to look at the progression rates from AS to A level and also from GCSE to A levels. Thus the three progression routes being considered here are GCSE to AS level, AS to A level and GCSE to A level based on unamended data available from NPD at this point of time for the cohort being followed up.

The key stage 4 database for 2011-12 was used to obtain GCSE results for all students in year 11 in 2012 (regardless of when they had been taken). Records for these pupils were then extracted from the KS5 database 2013-14 which had results from any AS/A levels they went on to take. A student was deemed to have progressed to A level if an A level result for them in the same subject was available for them in the database. Progression to AS level was recorded if the student had results for either AS/A levels (because all students do not have their cashed in AS level results reported separately)

Maths and science GCSEs are not offered in the same form at AS/A levels. Thus specific matching had to be used. For GCSE most students take the Core and additional science qualifications or the separate sciences, while only separate sciences are offered at AS/A levels. Progression was thus recorded for subject pairings as GCSE science (either or both of Core science or additional science) to any of AS/A level biology, human biology, chemistry, physics, psychology, science, electronics, environmental biology, geology, science for public understanding, computer science and ICT). Progression was also reported from mathematics GCSE to any of AS/A level maths, maths mechanics, pure maths, applied maths, statistics, further mathematics and additional maths. The results of this analysis are discussed in Chapter 6.

Chapter 6 Results and discussion

This chapter presents the results from the study as described in the preceding chapters. The results of systematic review are discussed first followed by results for maths attainment are presented first followed by science. These have been grouped as separate sections by subject. Though the approach and findings are largely similar, this organisation was adopted for easier interpretation. They are followed by the results for post-compulsory participation. The next chapter considers their implications as a whole.

6.1 Results of systematic review

Summary of searching and screening

A total of 402,773 reports were identified. This review at the outset was initiated as a part of this thesis by a single researcher.

Table 6.1 Preliminary search results

Dissertations and theses	332781
Scholarly journals	67485
Reports	2173
Working papers	166
Conference papers and proceedings	155
Government and official publications	13

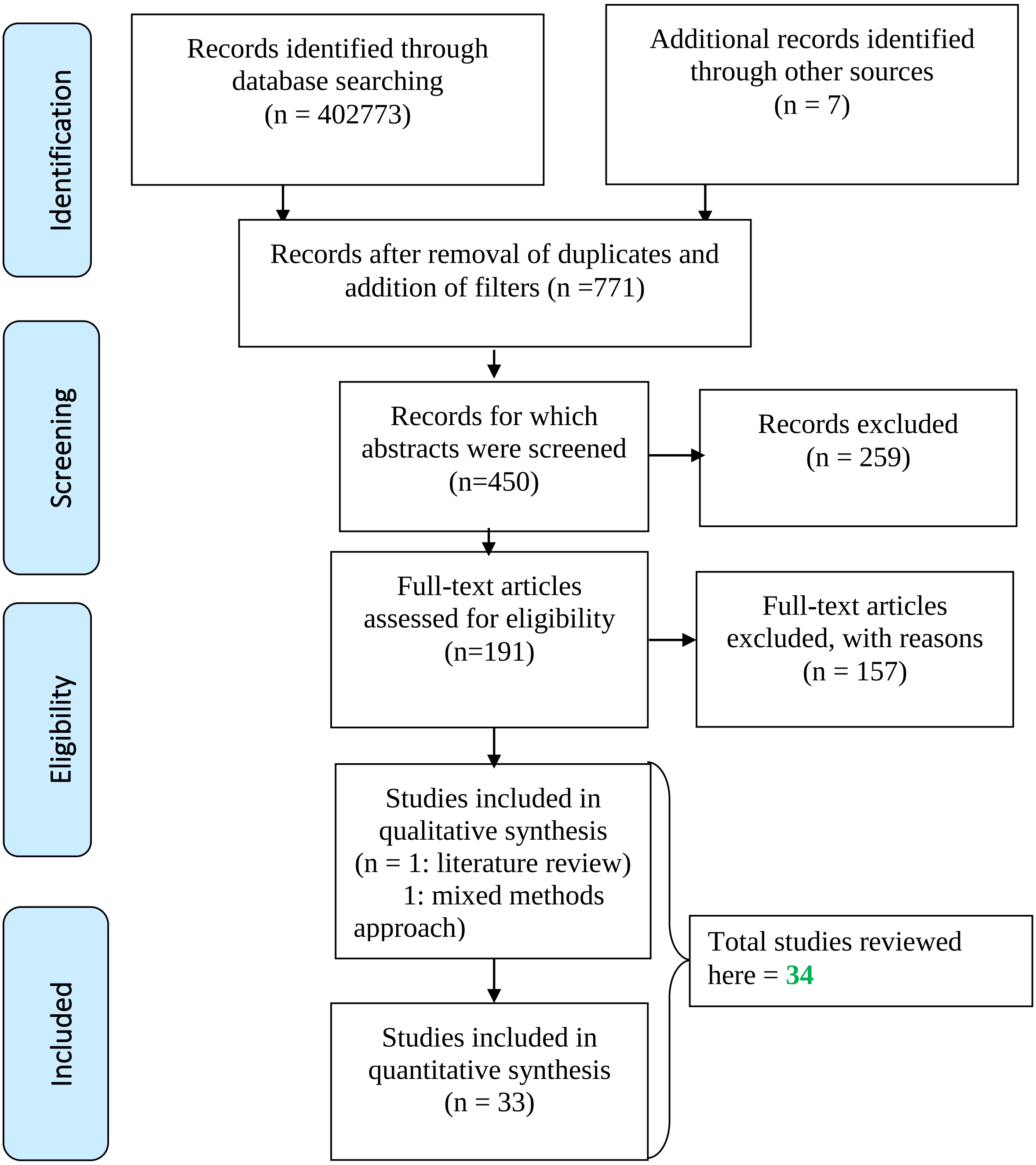
During initial screening exclusion of official reports, books and conference papers brought down the number of reports to 400,266. Adding filters for relevance to the research question identified 16108 reports. Preliminary screening was conducted by scanning titles and abstracts and found 771 relevant reports. Their breakdown in terms of retrieval from various databases is in table 6.2

Table 6.2 Electronic search from databases

<table>
<tr><th>Database</th><th>Syntax</th><th>Retrieved</th></tr>
<tr><td>ERIC</td><td rowspan="4">(Secondary school OR upper school OR high school OR ISCED2 OR ISCED3 OR ISCED level 2 OR ISCED level 3 OR Year 10 OR GCSE OR Key stage 3 OR KS3 OR KS4 OR key stage 4 OR Grade 10) AND (low attainment OR under achievement OR academic achievement OR poor performance) AND (scien* OR math* OR physic* OR Biolog* OR chem* OR STEM NOT “stem cell”) AND (lower socioeconomic class OR SES pupil OR disadvantage* OR poverty OR fsm pupils OR free school meal OR reduced price lunch OR depriv* OR achievement gap) AND (Correlat* OR Associat* OR link*)</td><td>222</td></tr>
<tr><td>ProQuest</td><td>151</td></tr>
<tr><td>PsycINFO</td><td>215</td></tr>
<tr><td>SSCI</td><td>183</td></tr>
<tr><td colspan="2">Total</td><td>771</td></tr>
</table>

Of these 450 reports were retained based on their relevance to the research question being addressed. Second stage screening of abstracts and titles brought down the number of relevant papers to 191. A thorough screening found 34 potentially relevant papers with convincing studies. Four causal, 28 correlational, one mixed methods and one descriptive study was shortlisted after quality assessment. For a classification of all research reports reviewed by study design see appendix

Figure 6.1 PRISMA flow diagram (Based on Moher, 2009)



These research reports established links with constructs which appear to be possible candidates for explaining the achievement gap of underprivileged pupils. The studies suggested implications for government educational policies, school policies and steps which could be taken up locally and at a national level to help dampen some elements linked to underachievement of unprivileged pupils such as risk behaviours, perceived discrimination, low expectations and teacher perceptions'.

Cohen's Kappa

The percentage of relevant papers finally shortlisted for data extraction was actually very low (4.4%) from the shortlisted 771 reports. The inter-rater agreement was very high (κ=0.65). Hence the second person was not required to double screen all research reports. Table below shows inter-rater reliability assessment using Cohen's Kappa.

Table 6.3 Inter-reliability assessment

Screener A	Screener B		
	Include	Exclude	Total
Include	3	2	5
Exclude	1	73	74
Total	4	75	79

Number of observed agreements = 76 (96.2% of the observations)

Number of agreements expected by chance = 70.5 (89.25% of the observations)

K = 0.647

It has to be mentioned that the list of studies identified may not be exhaustive. The keywords used and the databases searched as well as the application of the inclusion and exclusion criteria meant that some relevant papers may have been missed. This did not matter much as the purpose was to set the background and identify those factors known to be associated with the achievement gap of disadvantaged groups.

Candidate modifiable factors associated with underachievement of disadvantaged pupils

All examined evidence primarily hinted at an association of factors, except two which made a causal claim. Collectively the studies addressed the same outcome - educational attainment in science and/or maths and used one of the predefined measures of disadvantage – poverty/lower SES, ethnic minority status/race.

Literature shows the snowballing effect of a number of familial (teen mother, low maternal education), social (homelessness, maltreatment), school related and biological (inadequate prenatal care, pre-term, low birth weight, lead exposure) risk experiences on both academic and behavioural outcomes (Rouse, 2011).

Neighbourhood effects and high risk behaviours

Neighbourhood economic hardship was identified as an important predictor of children's lower mathematics academic outcomes (Hanson, 2011). Children residing in disadvantaged areas do not attain higher in STEM subjects. This is partially because of lack of role models in close vicinity and perhaps equally importantly because teaching work force and learning resources available in schools in such areas are not as good as those in posh/urban schools.

Similarly, cigarette and marijuana use, stealing, participating in group against group fight has been linked to lower SES pupils residing in deprived localities. One of the arguments for such behaviour could be to try to fit amongst other children in neighbourhood. It is easier to fit into neighbourhood community by acting like the majority rather than being branded as too idealistic and being a trend setter. Research shows significant benefits of value added education in preventing the link between SES and these high risk behaviours (Tobler, 2011).

Familial factors - parental academic involvement, authoritative parenting, maternal education and family background

An important role is played in the lives of children by their families – academic or otherwise. However, families living in high poverty, high unemployment and low-education neighbourhoods are known to employ fewer education-oriented practices with their children. Research suggests the effect of such parental practices on children's maths achievement is extremely encouraging. Parental academic involvement has a strong effect on children living in disadvantaged localities (Greenman, 2011).

Parental interest in their offspring's studies may in fact have shielding effects on academic achievement brought about by deprivation. An explanation offered for this is perhaps it camouflages the effect of a range of risk involving factors - low socioeconomic position, psychological and physiological stress, negative emotions. In particular, parental interest in their children's studies during the last year of compulsory education was found to better predict adult allostatic load, which is merely the physiological outcome of chronic exposure to stress or negative emotions. Parental academic involvement also increased life course academic and occupational achievement in their children. Parental involvement has been held as more definite a predictor as opposed to parent's social class or availability of practical academic support by Westerlund (2013).

Children whose mothers have less than a high school education have lower cognitive skill scores at three years of age (Ayoub, 2009; Hanson, 2011). Teen mothers and mothers who are illiterate or unemployed are more likely to raise academically underachieving children as compared to those who have a primary or tertiary level of education despite belonging to the same socio-economic status.

Authoritative parenting has been shown to be a significant predictor of self-efficacy and resilience and positively correlates with academic achievement. A justification available for this is perhaps by acting as influential role models parents add a shield against deprivation by mitigating risk factors. This further lessens the achievement gap (Speight, 2010).

A direct influence of parental support on at-risk status, academic performance, hopelessness, explanatory style and depression has also been established by a study of non-clinical sample of 213 African-American students by Bryant (2007).

Using PISA data from more than 40 participating countries, Nonoyama (2005) in a cross-national study tried to understand the effect of family background on student achievement. The study concluded family SES and background effects had a larger bearing on student achievement than SES alone or school effects across countries.

Just as parental support and involvement sometimes the conditions under which children thrive affects their educational outcomes. Pinder (2010) using a causal comparative design administered survey questionnaires on 87 high school students to explore the impact of family background on science achievement. He concluded family backgrounds such as arrival status of immigrants impacts their achievement. First generation immigrants who choose to migrate (voluntary immigrants) perform much better academically compared to those individuals whose ancestors were forced to migrate.

Teachers' expectation

Discipline gaps, achievement gaps and attendance (Alsace, 2009; Graber, 2010) have all been found to be very strongly correlated. Analysis of 10th grade sample of Educational

Longitudinal Study shows student perceptions of teachers and teacher's attitudes can predict academic performance and discipline. Using SES as a measure of disadvantage the study provides evidence that students' relationship with teachers, perception of teacher sensitivity and the reasons for attendance are the strongest predictors of scholastic achievements. Students in the lowest SES quartile very often did not attend school because of their teacher's expectation of success and for the fear of humiliation in class (Whitehead, 2007).

Student's higher perception of negative teacher feedback predicts more devaluing of academics and greater perceived teacher care at classroom level predicts less devaluing (Strambler, 2010). A lower regard for academics consistently predicts poorer maths test scores. Positive teacher expectations, support and motivation quite expectedly have progressive effects on students regardless of their risk status and particularly for lower income students (Gregory, 2013; Sorhagen, 2013).

School contextual factors – organisation model, size and climate

Transition age pupils are quite divided in their perceptions – to some stepping up to the secondary school is an opportunity and to others a challenge. Vaz (2014) concluded from a prospective longitudinal study the primary school organisation model significantly influences post transition academic competence (AC) in secondary schools. Students attending independent and mid-range sized primary schools had the highest concurrent AC; students from kindergarten-year7 report the lowest scores while attending a school with the kindergarten-year 12 with middle school structure was associated with a reduction AC scores across the transition.

The study however concluded that the contribution of social contextual factors was relatively minor as individual level background factors account for majority of variability in post-transition AC. Similarly, lower SES pupils have been shown to have significantly lower drop-out rates in small sized schools as opposed to large sized schools (AliMohamed, 2011). School climate constructs have been shown to be related to student achievement (Smith, 2008) by some research. Brown (2014) using the population of all 11th grade students in West Virginia shows school size, rural location affect test scores. Children from larger schools perform better. Similarly, the more rural a school the poorer the performance compared to an urban and sub-urban school.

Futility culture – temporary immigrant status

Apart from individual factors, children of temporary immigrants/guest workers have an additional layer of disadvantage to deal with. Multilevel analyses of data based on a survey of 2,845 pupils (aged 10-12 years) in 68 Flemish primary schools (Agirdag, 2012) revealed that a higher proportion of immigrant and working-class pupils in a school is associated with lower levels of math achievement in both immigrant and native Belgian pupils. The study found that the ethnic composition of the school no longer had a significant effect on pupils' achievement, while the SES composition did.

A possible explanation could be immigrant status demands a lot of social and cultural adjustments. If the transition is temporary most parents and children look forward to going back to their native education system and perhaps do not value current education as much as they would normally have. Equally importantly immigrants are faced by a lot of challenges some of which are linked to basic survival. Child's education then perhaps takes a lesser priority within the family. One of the most important conclusions drawn from the study indicated that the remaining impact of SES composition can be explained by pupils' sense of futility and schools' futility culture. Pasztor (2008) suggests institutional factors can impact on school-related integration and help alleviate some of the problems.

Oppositional culture

Analysing data from the US Education Longitudinal Study, a nationally representative panel survey of high school sophomores and seniors Wildhagen (2009) showed schools with high levels of Black-White inequality - in terms of number of pupils from each group; discourage Black students with good grades from taking as many advanced placement courses as they would in schools with less inequality.

Greene (2009) using data from the National Educational Longitudinal Study showed racial-ethnic minority students are disproportionately placed into lower level academic courses and programs including vocational education. The young learner's response is lower school engagement as opposed to their white peers. This perhaps is one of the factors leading to unrealised academic potential among black students.

Negative emotionality

Associations between negative emotionality and cognitive performance of children living in poverty have been examined by some research. The Early Head Start is a federally funded early childhood development program aimed at low-income families. EHS research and evaluation project was a prospective study of 3001 children and families living in poverty. Ayoub (2009) found 1-3year old children who had higher levels of negative emotionality evidenced more rapid rates of decline of cognitive skill scores. The protective effect of EHS on such children's cognitive skill performance however was quite evident. Children who were enrolled in Early Head Start (EHS) had higher cognitive skill scores at three years of age than their peers who were not in EHS.

Similarly, children of incarcerated parents were found to be 3.8 times more likely to be raised by a caregiver who had less than a high school education. Such children showed a trend in lower test scores compared to their peers in single parent households and of similar socioeconomic status (Neal, 2009) experiencing similar negative emotionality. Parental incarceration as the author suggests puts a child at risk of lower educational attainment both during and after parent's release – perhaps one of the major reasons being the failure to reintegrate in the society.

Experiencing and exhibiting aggression and violence is strongly associated with lower socioeconomic status. These undesirable behavioural patterns are highly and disproportionately prevalent among school-aged urban minority youth. Basch (2011a) through well documented literature reviews concludes causal pathways through which aggression and violence slow down learning include affected cognition, lack of school connectedness, and absenteeism. Disruptive classroom behaviour is a well-recognized and significant barrier to teaching and learning.

Neuropsychological factors

Evaluating fifth-grade children from low-income urban schools using clinical neuropsychological tests and behavioural questionnaires Waber (2006) wanted to find out if executive functions are selectively diminished in children from poor urban environments and does integrity of executive functions predict test scores. Neuropsychological variables (particularly executive functions) accounted for 30% variance in mathematics scores amongst participants. Waber reports these children were not moderated in terms of their basic information processing or their psychosocial adjustment. However, despite their competence on neuropsychological measures - which are deemed indicative of risk for learning problems, such as working memory and processing speed, these children obtained fourth-grade scores on state mandated standards-based testing. They do, however, exhibit relatively selective impairment of metacognitive skills and behavioural regulation. This is demonstrated in everyday classroom behaviour, which appears to be strongly associated with achievement test performance.

Perceived discrimination

Minority adolescents experience situations in their everyday lives that they sometimes interpret as unfair. The implications of this perception on the educational attainment of these youngsters are expected to be negative but are relatively less researched. Borsato, 2008 examined perceptions of discrimination among early adolescents of Asian American and Latino descent. 409 students (96 Asian Americans, 126 Latinos, and 187 Whites) attending grades 7th and 8th at a public junior-high school located in Northern California participated in this cross-sectional study. Students were asked to complete an anonymous questionnaire which asked questions about having ever experienced stressful events that they interpreted as connected to their race/ethnicity, demographic background. Details of measures of racial/ethnic identity, depressive symptomatology, problem behaviours (drug use, delinquency, and physical aggression), academic motivation and achievement of these pupils were collected.

Despite their young age, minority participants reported having already experienced one or more situations that they perceived as racial/ethnic discrimination. In addition, perceived discrimination by adults was highest for Latino adolescents, while perceived discrimination by peers was high for Asian Americans. Survey data analysis suggested perceived discrimination is a risk factor for psychosocial and academic outcomes. Peer discrimination significantly predicted depression, delinquency and negatively predicted motivation while adult discrimination predicted physical aggression, drug use and negatively predicted student grades. Research findings support the possible mediating role of adult discrimination relative to the academic achievement gap between Whites and Latinos.

A positive connection to one's racial/ethnic group termed – “high private regard” by the author, emerged as a resilience factor for depressive symptoms and academic motivation. Similarly, “public regard” - the extent to which individuals felt that others view their racial/ethnic group positively or negatively was significantly associated with school importance. The perception that one's group is valued in society predicts a stronger belief that school is important.

Organisational citizenship behaviours and measures of student achievement in Biology also showed a significant positive correlation (Tindle, 2012)

Dietary needs and habits

Food insecurity hampers physical growth, health and intellectual development. Belachew (2011) tried to explore the extent to which food insecurity affects school attendance and educational attainment. The study used a stratified random sample to select participants. Data was analysed from 2009 adolescents in the age group of 13-17 years from two consecutive surveys of a five year longitudinal family study in Southwest Ethiopia. School absenteeism and the highest grade attained after 1 year of follow-up in food secure and insecure adolescents were compared using regression analyses. The analysis was adjusted for demographic factors, reported illness and workload. Multivariable logistic regression analyses showed that adolescent food insecurity, severe household food insecurity, illness during the past one month before the survey, the highest grade aspired to be completed by the adolescent and the number of days that the adolescent had to work per week were independent predictors of school absenteeism. Similarly adolescent food insecurity, severe household food insecurity, illness during the last month and rural residence were inversely associated with highest grade attained. Highest grade intended to be completed by the adolescent and residing in semi urban area were positively associated with the highest grade attained. The study concludes adolescent and household food insecurity is positively associated with school absenteeism and a lower educational attainment.

Administering school based surveys (n=1195) Doku (2013) explored the patterns in breakfast, fruit and vegetable consumption among 12-18 year olds in Ghana. The study aimed to study any association between child’s SES, dietary habits, health and educational attainment using logistic regression analyses. The main research findings are the probability of having a regular breakfast is higher in adolescents from more affluent backgrounds than in those from less affluent ones. Further compared to unemployed/illiterate mothers, those with primary or tertiary educational attainment are more likely to have frequent fruits/vegetables intake. Adolescents’ academic performance in high school was positively associated with frequent fruit/vegetable intake. Some research also presents evidence on a negative correlation between poor nutrition/fast food consumption on test scores (Tobin, 2013)

Biological factors

Birth characteristics like optimal term birth, increased growth in head and length and being first born to mothers residing in most educationally deprived neighbourhoods were associated with higher numeracy scores, among disadvantaged children (Malacova, 2008). Poor oral health, depression, asthma have all been linked to impoverished academic achievement of deprived pupils.

Interplay of factors at work

As is evident from the discussion above a child from a deprived background faces a range of obstacles through childhood such as racial and class discrimination, decreased self-esteem, poverty, outdated and/or limited curriculum resources, and less than acceptable facilities, as well as many other problems associated with inner-city life. Rather than one single stumbling block a lot of factors cited above hinder a child's scholastic progress. This is further supported by Bruner (2014) who undertook an international comparison using TIMS 2011 8^{th} grade science data. The main aim of this study was to understand what factors hinder the achievement of low SES pupils using a six country sample. The research findings suggest student, teacher, classroom and school level factors lead to inequities in achievement. Recommendations available from the papers included here are discussed in the next chapter along with conclusions drawn and limitations of the study.

6.2 Attainment in maths

Within each subject, research findings are presented for school level data first followed by pupil level data. For school level data, the description starts with findings from the snap-shot study design, followed by the longitudinal analysis.

6.2.1 School level data

The headline result for KS4 school performance is based on the mean percentage students achieving 5+A*-C GCSEs or equivalent, including A*-C in both English and mathematics. Table 6.1 shows that there was an upward trend with the average for all schools 10 percentage points higher in 2012 than 2008. The average for intervention schools was higher than for all other schools in every year. This reinforces the point that schools willing and able to volunteer for STEM interventions are not some kind of random sub-set of all schools.

They already have higher attainment scores. The gap is probably higher than this in reality since there will have been at least some schools in 2007-0 8 listed in the comparator group but who were participating in a STEM intervention.

Table 6.4 Mean percentage of pupils achieving maths performance indicator

Schools		2007-08	2008-09	2009-10	2010-11	2011-12
Intervention Schools	% attainment	54	55	60	62	62
	Number of schools	390	536	521	601	550
Comparator Schools	% attainment	48	50	55	58	58
	Number of schools	2,720	2,566	2,559	2,422	2,423
All relevant schools	% attainment	49	51	56	59	59
	Number of schools	3,110	3,102	3,080	3,023	2,973

The differences between the two groups were converted to simple differences between percentages, and into proportionate achievement gaps (Table 6.2). The comparator schools, starting from a slightly lower base figure, gradually caught up with the known intervention schools over time. When looked at in terms of achievement gaps, no clear difference was found over time. This means that, on this headline figure, there is no evidence that STEM intervention schools increased their attainment any faster than the comparator. It is important to note that this is not a question of merely dampening the effect size because only some intervention schools were known. Known intervention schools did not improve faster than another large group of schools the majority of which did not undertake STEM interventions. There is no positive effect size.

Table 6.5 Annual achievement gap estimation, intervention and comparator schools

	2007-08	2008-09	2009-10	2010-11	2011-12
% points difference	5.2	4.5	4.8	3.9	3.9
Achievement gap	0.1	0.1	0.1	0.1	0.1

Educational attainment is known to be linked to several pupil background factors such as SES, EAL, SEN, gender and ethnicity. Information about EAL pupils was not available in the approved standard extract for school level data. However, the correlation between EAL and attainment is known to be lower than that for FSM, for example, from other research (Strand, 2014). Special schools were excluded from analysis and the percentage of SEN pupils in schools being considered for analysis was no more than 1-2%. The percentage of FSM pupils was thus the strongest predictor of school maths performances amongst the variables available. The links between attainment and background are here summarised as the correlation (Pearson's R) between the percentage in each school reaching the KS4 indicator and the percentage of this type of potentially disadvantaged pupils.

Table 6.3 shows that the link between the proportion of FSM pupils and attainment is about the same in every year and between the two groups. The more FSM pupils there are in any school, the lower its attainment is on average. This is already well-known. The key points were whether the link was different between groups, and whether there were signs that the intervention groups had somehow reduced the strength of the link over time as a result of the interventions. The answer to both is 'no'. The comparator groups had a slightly higher proportion of FSM pupils, again making the point that the intervention schools were slightly more privileged at the outset. Both groups increased FSM, perhaps as a result of the economic downturn from 2008 onwards. But the link with attainment remained the same in both groups. There is no evidence here that STEM interventions improved outcomes for less advantaged students.

Table 6.6 Correlation between attainment and FSM eligible pupils

Groups		2007-08	2008-09	2009-10	2010-11	2011-12
Intervention	% FSM	13	15	15	17	17
	R	-0.6	-0.6	-0.6	-0.6	-0.5
Comparator	% FSM	15	15	16	17	17
	R	-0.6	-0.6	-0.6	-0.5	-0.5

Very similar results are found using the intervention group of only those schools involved in STEM interventions every year. Again, both intervention and comparator schools improved their attainment in terms of the KS4 indicator (Table 6.4). Intervention schools achieved higher than all other schools, both before and after intervention. However, while the intervention group showed an improvement of nine percentage points after intervention, the comparator improved by eleven percentage points. This also meant the percentage points difference reduced from four to two (actually 3.97 to 2.43).

Table 6.7 Comparison of mean maths performances – longitudinal group

Schools		2007-08	2011-12
Intervention	Mean % attainment	52	61
	Number of schools	299	289
Comparator	Mean % attainment	48	59
	Number of schools	2,701	2,409

The cross-product ratio was also estimated for this table, where no change was defined as ad=bc or ad/bc=1. Here 'a' was the attainment of intervention group before intervention, 'b'

after intervention, ‘c’ was attainment of comparator at the beginning and ‘d’ at the end of the study. An achievement gap was calculated between the intervention group and comparator using Newbould and Gray’s formula. Mean percentage attainment was considered for calculations. The gap lowered after intervention because progress in the comparator’s attainment was higher than the intervention group.
Calculations are below.

Before longitudinal intervention –

$$\text{Achievement gap} = \frac{3.97}{49}$$

Achievement gap = **0.08**

After longitudinal intervention -

$$\text{Achievement gap} = \frac{2.43}{59}$$

Achievement gap = **0.04**

All of these ways of presenting the findings show that the intervention group of schools did not make more progress than the comparator group. If anything, the comparator group appears to be catching up with the intervention group, for maths outcomes at the school level.

Again, using this second definition of the intervention group, the intervention group started with fewer FSM pupils (Table 6.5). Both groups show an increase in the percentage of FSM pupils over time. Both had the same level of negative link between the percentage of FSM pupils in each school and school attainment, and both improved this slightly to the same extent. This improvement is likely to emerge from the higher proportion of FSM pupils, and cannot be attributed to the STEM activities.

Table 6.8 School FSM intakes and correlation with attainment

Sub-groups	SES & R	2007-08	2011-12
Intervention group	% FSM	13	16
	R	-0.6	-0.5
Comparator	% FSM	15	17
	R	-0.6	-0.5

Of course these are quite blunt measures of possible STEM activity impact on maths attainment and disadvantage. The next step is to consider the data in more detail at pupil level.

6.2.2 Pupil level data

Results for KS4 pupil performances were based on the percentage of students achieving an A*-C in GCSE maths. Table 6.6 shows more intervention pupils met the attainment criteria than comparator group pupils. A difference of three percentage points was noted.

Table 6.9 Pupil maths attainment - A*-C in GCSE maths 2011-12

		Students meeting maths attainment criteria	
Sub-group	Total GCSE entries	Numbers	Percentages
Comparator	555,295	378,075	68
Longitudinal	43,288	30,946	71

The achievement gap between the groups was now calculated. Newbould and Gray's approach for achievement gap estimation (explained in Gorard, 1999) was followed. The formula considered total entries and number of pupils achieving the grade in longitudinal intervention group and comparator. The achievement gap was very low indicating there was not a huge difference in the percentage of pupils in intervention or comparator achieving A*-C in GCSE maths. Calculations are shown below.

$$\text{Entry gap} = \frac{\text{Entries}_C - \text{Entries}_I}{\text{Entries}_C + \text{Entries}_I}$$

$$\text{Entry gap} = \frac{555295 - 43288}{555295 + 43288}$$

$$\text{Entry gap} = (0.86)$$

$$\text{Achievement gap} = \frac{\text{Nos. achieved A*-C}_C - \text{Nos. achieved A*-C}_I}{\text{Nos. achieved A*-C}_C + \text{Nos. achieving A*-C}_I} - \text{Entry gap}$$

$$\text{Achievement gap} = \frac{378075 - 30946}{378075 + 30946} - (0.86)$$

$$\text{Achievement gap} = (\mathbf{-0.01})$$

The percentage of FSM pupils in each group were now checked. This was important to understand if the link between maths attainment and SES was different in any of the groups. Percentage of FSM eligible pupils was exactly same in both intervention group and comparator. Correlation coefficients would have been lower if STEM schemes could have successfully reduced the overbearing effect of SES on maths attainment. However, R values were also found to be exactly same for both groups (table 6.7). This means maths attainment for both groups show similar negative association with pupil SES and being in a STEM intervention group does not offer any additional advantage to underprivileged students.

Table 6.10 FSM versus R – pupil maths attainment

Sub-groups	% FSM pupils	R
Longitudinal intervention	13	-0.2
Comparator	13	-0.2

Percentage of pupils achieving an A*-C in various disadvantaged and privileged groups was now compared based on the duration of intervention (table 6.8). SEN and FSM pupils were the lowest attaining disadvantaged groups. Most privileged groups achieved higher than a respective disadvantaged group for the same measure except ethnic minorities. KS3 only intervention had the maximum percentage of students meeting the maths performance indicator (except FSM and SEN), while KS4 only intervention was the lowest attaining sub-group for all pupils. SEN and FSM pupils faired best in staggered intervention sub-groups. Total number of entries, number and percentages of pupils achieving A*-C in GCSE maths for the groups are summarised in appendix, an abridged version of this is table 6.8.

Table 6.11 Percentage students achieving A*-C in maths

Sub-groups	Intervention group					Comparator	All eligible pupils
	Ever	Longitudinal	KS4 only	KS3 only	Staggered		
Ethnic minorities	71	72	57	75	71	71	69
White	71	72	54	73	68	69	69
EAL speakers	70	72	54	73	69	70	69
Native English	72	72	55	73	70	69	69
FSM	51	50	34	49	60	48	48
Non-FSM	75	75	60	76	73	73	73
SEN	39	39	26	38	43	35	69
Non-SEN	80	80	62	81	78	79	81
All eligible pupils	73	71	51	69	81	68	69

A two-way estimation of achievement gap was now carried out. First the achievement gap between the sub-groups and their respective comparators was estimated. Very low values (nearly zero) were noted always (table 6.9). This meant as many students in the intervention groups met the attainment threshold as those in the comparator.

Table 6.12 Maths achievement gap – intervention and comparator groups

Disadvantage measure	Longitudinal	KS4 only	KS3 only	Staggered
Ethnic minorities	0.01	-0.2	0.05	0
White	0.04	-0.2	0.05	-0.01
EAL	0.03	-0.2	0.04	-0.01
Native English speakers	0.04	-0.2	0.05	0.01
FSM	0.03	-0.2	0.01	0.1
Non-FSM	0.03	-0.1	0.04	0
SEN	0.05	-0.2	0.04	0.1
Non-SEN	0.01	-0.2	0.02	-0.01
All eligible pupils	0.04	-0.2	0.01	0.1

Second the achievement gap between a disadvantaged group and a privileged group of the same predictor exposed to the same duration of intervention was calculated. The achievement gap was of a similar order in the various duration based groups. This meant duration of intervention did not have a major impact on improvement of exam grades.

Table 6.13 Achievement gap estimation between advantaged and disadvantaged groups

Groups	Intervention					Comparator
	Ever	Longitudinal	KS4only	KS3only	Staggered	
White-non white	0	0	-0.04	-0.03	-0.04	-0.03
English–EAL	0.02	-0.01	0.02	0	0.03	-0.01
FSM-non FSM	0.3	0.4	0.4	0.4	0.2	0.4
SEN-non SEN	0.6	0.6	0.5	0.6	0.5	0.6

The two-way achievement gap estimation showed a) intervention did not raise attainment of disadvantaged or privileged pupils any higher than comparator, and b) duration of intervention did not have an overbearing effect on improving pupils' GCSE maths attainment.

Effect of STEM interventions on FSM sub-categories

It is well known that higher the poverty level of pupils, lower is their attainment level in maths. Attainment was lowest for the poorest of the four FSM groups - those currently eligible for FSM, followed by those who were FSM pupils at some point during the last six years (Ever-FSM_6) but are ineligible for FSM now most likely because their financial conditions have recently improved. Those who are not eligible for free school meals now (Not FSM now) are similarly slightly less affluent and achieved a little lower than those who have never been eligible for free school meals during the past six years (Never-FSM_6). A comparison of means shows more intervention pupils in all these four groups met the maths attainment criteria than their respective comparators (table 6.11).

The intervention group was split into various sub-groups based on the duration and time of intervention. Maths attainment increased with decreasing poverty level - the poorest group was also the least attaining group in every intervention or comparator sub-group. Lower SES pupils attained higher in staggered intervention groups, while higher SES pupils attained highest in KS3 only followed very closely by longitudinal intervention groups (table 6.11). KS4 only intervention was the lowest attaining sub-group for all FSM categories.

Table 6.14 Maths attainment - FSM and non-FSM pupils

FSM status	Intervention					Comparator
	Ever	Longitudinal	KS4 only	KS3 only	Staggered	
FSM now	51	50	34	49	61	48
Ever-FSM	54	53	36	50	61	50
Not-FSM now	75	75	60	76	73	73
Never-FSM	77	78	65	79	75	75

The achievement gap was estimated between those pupils who have never been on free school meals during the last six years and three categories of FSM pupils – those who are eligible for FSM now, have been eligible for FSM at some point during the last six years, and have never been on FSM during last six years.

Achievement gap was of a similar magnitude for both FSM now and Ever-FSM groups. The comparator had the same achievement gap or lower than the intervention groups except staggered intervention for poorest pupils. This meant intervention pupils did not achieve any higher than the comparator in most cases. The gap was marginally lower for pupils who had a staggered participation and marginally higher for KS4 only intervention sub-group (table

6.12). The attainment gap was much lower for those presently not on FSM (nearly zero), irrespective of their participation in STEM intervention.

Table 6.15 Achievement gap: FSM pupils and non-FSM pupils

Poverty gradient	Intervention					Comparator
	Ever	Longitudinal	onlyKS4	onlyKS3	Staggered	
FSM now	0.4	0.4	0.5	0.4	0.2	0.4
Ever-FSM	0.3	0.4	0.4	0.4	0.2	0.4
Not FSM now	0.03	0.04	0.07	0.04	0.03	0.03

The effect size of the intervention was now estimated as the relative risk ratio. This was the ratio of probability of success in the treatment group to probability of success in the comparator. Relative risk ratio was always nearly 1 for all sub groups despite differences in duration or point of delivery of intervention (table 6.13). Chances of success in KS4 only sub-group was slightly lower.

Table 6.16 Effect size - ratio of probability of success in treatment versus comparator

FSM status	Intervention				
	Ever	Longitudinal	KS4 only	KS3 only	Staggered
FSM now	1	1	0.7	1	1.2
Ever-FSM_6	1	1	0.7	1	1.2
Not FSM now	1	1	0.8	1	1
Never-FSM_6	1	1	0.8	1	1

These various measures of effect sizes show neither the poorer pupils nor their elite peers had any improved maths attainment due to STEM interventions. The impact of STEM interventions on a second measure of disadvantage ethnic minority status was now considered.

Do some ethnic groups benefit more from STEM initiatives than others?

Mean percentage of pupils achieving an A*-C in maths were now compared for the various major ethnic groups chinese, asian, white, mixed, black and any other ethnic group (AOEG). Chinese pupils were always the highest attaining group followed by Asian, white, mixed, AOEG, unclassified and black in the order (table 6.14). Comparison of means shows maths attainment following intervention is always marginally higher than the comparator either for KS3 only intervention or longitudinal intervention group. KS4 only intervention was the lowest attaining for all ethnic groups.

Table 6.17 Percentage pupils in various ethnic groups achieving A*-C in maths

Ethnicity	Intervention					Comparator
	Ever	Longitudinal	KS4 only	KS3 only	Staggered	
Chinese	91	93	68	95	90	93
Asian	73	72	60	77	76	74
White	71	72	54	73	68	69
Mixed	71	70	57	75	72	68
AOEG	70	76	44	71	68	70
Unclassified	68	70	62	67	66	69
Black	67	69	56	67	66	65

Achievement gap assessed between chinese and all other ethnic groups shows duration of intervention did not affect achievement gap. The results from table 6.15 however need to be interpreted carefully. Achievement gap appears to be lowest for KS4 only intervention subgroup. This is because chinese pupils have lowest attainment in KS4 only group. This low attainment gap should not be misinterpreted as higher effectiveness.

Table 6.18 Achievement gap between Chinese and other ethnic groups

Ethnicity	Intervention					Comparator
	Ever	Longitudinal	KS4 only	KS3 only	Staggered	
Asian	0.3	0.3	0.1	0.3	0.2	0.3
White	0.3	0.3	0.2	0.3	0.3	0.4
Mixed	0.3	0.3	0.2	0.3	0.3	0.4
AOEG	0.3	0.3	0.4	0.4	0.3	0.3
Unclassified	0.3	0.3	0.1	0.4	0.4	0.4
Black	0.4	0.4	0.2	0.4	0.4	0.4

In order to estimate how effective STEM initiatives are in raising maths attainment for each ethnic group the relative risk ratio was calculated to estimate the effect size. This was the ratio of percentage of pupils achieving A*- C in an intervention group to the percentage of pupils achieving the same criteria in the comparator group for the same ethnicity. Irrespective of ethnicity the risk ratio was almost always nearly one (table 6.16). This meant the high attaining or low attaining ethnic groups did not have an added advantage by participating in STEM interventions. The ratio was only marginally lower for KS4 only intervention supporting the previous results that students achieve least in this sub-group.

Table 6.19 Ratio of probability of success –intervention group & comparator

Ethnicity	Intervention				
	Ever	Longitudinal	KS4 only	KS3 only	Staggered
Chinese	1	1	0.7	1	1
Asian	1	1	0.8	1	1
White	1	1	0.8	1	1
Mixed	1	1	0.8	1	1
Any other ethnic group	1	1	0.6	1	1
Unclassified	1	1	0.9	1	1
Black	1	1	0.9	1	1

Results from comparison of means, correlations and effect sizes all show STEM interventions have not been able to raise maths attainment for disadvantaged or privileged pupils. The next section presents results from regression analyses.

Multiple linear regression analysis results for GCSE maths attainment

Independent variables linked to maths attainment were included for analysis using the default SPSS method 'Enter'. This means all variables chosen as predictors were entered into the regression equation and contributed to R square. For model one below all explanatory variables excluding STEM intervention were included. The model summary suggests together the explanatory variables KS2 maths prior attainment, SEN, SES, gender, ethnicity, language group can predict the outcome variable of highest standardised point scores achieved in maths with an accuracy of 76.6%. Adjusted R square was 0.6 suggesting that the model is good at predicting maths scores. However, for model two when STEM intervention was added as an independent variable it did not appear to change the R or adjusted R square values (table 6.17).

Table 6.20 Models from multiple regression analysis for predicting of maths test scores

Model	Independent variables included	Additional variables included	R	Adjusted R square
Model 1	KS2 Maths prior attainment, SEN, FSM eligibility gender, language group, ethnicity	None	0.77	0.59
Model 2		STEM intervention	0.77	0.59

Binary logistic regression results for maths attainment

The baseline model with no independent variables suggested the prediction that everyone will attain an A*-C in maths turns out to be correct in 69.8% cases. Statistics for the model with independent variables KS2 maths prior attainment, gender, FSM eligibility, language group, ethnicity and SEN provided measure of pseudo R square as 0.55. This indicates a moderate to strong improvement in fit over the baseline model. A comparison of predicted and actual scores showed 84.1% of the predictions were accurate. Thus there was a clear improvement over the baseline model, where 69.8% predictions were accurate.

A second model was created including all predictor variables as well as STEM intervention. The pseudo R square values and percentage accuracy of predictions was exactly the same as for the model excluding STEM intervention. The regression coefficients for all independent variables are summarised in the table 6.18 It suggests for example an increase of one on the scale for KS2 prior maths attainment increases the probability of achieving an A*-C in maths by 0.38. Thus STEM intervention is inconsequential for maths attainment according to logistic regression output.

Table 6.21 Logistic regression output for maths attainment[1]

Independent variables	Regression coefficients
KS2 maths prior attainment	0.38
FSM eligibility	-0.67
SEN	-1.02
Language group – EAL	-0.07
Ethnic minority	0.001
Gender	0.14
Stem intervention	0.01
Constant	-8.74

The results from multiple linear regression analysis and logistic regression were similar. Despite using different maths performance indicators both outputs deemed the link to STEM interventions trivial compared to other predictor variables. This supports earlier findings from school and pupil level data.

[1] The percentage of cases predicted correctly was 84.2 and the pseudo R square (Nagelkerke) was 0.55

6.3 Attainment in science

Research findings for science were quite similar to that of maths attainment. Within this section, results are presented for school level data first followed by pupil level data. Findings from the snap-shot design are described first followed by the longitudinal analysis.

6.3.1 School level data

School science performances were first assessed on the basis of mean percentage of pupils at the end of key stage 4 achieving two GCSEs at grades A*-C or equivalents covering the KS4 science programme. Attainment improved by 11 percentage points from 2007 to 2010 for the average of all schools (table 6.19). The mean attainment for intervention schools was higher than all schools every year. Thus, rather than being a random sub-sample of all schools, intervention schools were actually schools with higher attainment from the start. This gap between comparator and intervention schools would actually be higher than what is noticed here. This is because the comparator will have at least some more schools registered for interventions.

Table 6.22 Mean percentage of pupils achieving science performance indicator

Schools		2007-08	2008-09	2009-10
Intervention schools	Mean % attainment	56	58	65
	Number of schools	390	535	522
Comparator schools	Mean % attainment	50	54	62
	Number of schools	2,698	2,544	2,558
All relevant schools	Mean % attainment	51	55	62
	Number of schools	3,088	3,079	3,080

Differences between the two groups were converted into simple percentage point differences, and respective achievement gaps (Table 6.20) each year. The intervention schools always achieved higher, however an improvement of nine percentage points is noted between the first and last year for them. Comparator schools on the other hand showed a higher improvement of 12 percentage points. Entry gap was taken to be zero as the set of schools vary for every year of the snap-shot study. Achievement gap was exactly same every year. Thus known STEM intervention schools did not improve attainment at a faster rate than comparator – which was a large group of schools most of which did not do STEM interventions. There was no positive effect size

Table 6.23 Annual science achievement gap estimation, intervention and comparator schools

Groups	2007-08	2008-09	2009-10
% points difference	5.1	3.7	3.9
Achievement gap	0.1	0.1	0.1

Several measures of deprivation in terms of student population of a school were considered for example SEN, SES, EAL, gender and ethnicity. All special schools were excluded from analysis and the percentage of SEN pupils in schools being considered for analysis was no more than 1-2%. Amongst the remaining variables, percentage of FSM pupils was the strongest predictor of school level science attainment. It is well known, that the percentage of lower SES pupils in a school is negatively correlated to school science attainment. First, it was important to understand if the level of poverty was same or different in intervention groups and comparator for all three years. Second, the link between percentage of FSM pupils and the percentage of all pupils reaching the KS4 science indicator.

Mean values of percentage of FSM eligible pupils and the correlation coefficients are summarised (table 6.21). Both groups showed an increase in the percentage of FSM pupils, but the comparator had a slightly higher proportion. The intervention schools were slightly more privileged at the start but there was no evidence of their ability to reduce the link between SES and science attainment. On the contrary despite starting with a slightly higher proportion of disadvantaged pupils, the comparator showed a slightly weaker link at the end.

Table 6.24 Correlation between and FSM eligible pupils

Groups		2007-08	2008-09	2009-10
Intervention	% FSM	13	15	15
	R	-0.5	-0.4	-0.4
Comparator	% FSM	15	15	16
	R	-0.5	-0.3	-0.3

Very similar results are obtained when the intervention group includes only those schools which participated in STEM interventions every year. Mean of percentage of pupils meeting KS4 science attainment criteria improved in both intervention and comparator schools. Intervention schools achieved more than the comparator both before and after intervention. However, while the intervention group showed an improvement by 10 percentage points the comparator improved by 12. This also meant the percentage point difference in attainment between intervention group and comparator before and after intervention reduce from four to two (actually 3.98 to 2.23)

Table 6.25 Comparison of mean science performances – longitudinal group

Schools		2007-08	2009-10
Intervention	Mean %attainment	54	64
	Numbers	299	294
Comparator	Mean %attainment	50	62
	Numbers	2720	2558

The cross-product ratio estimated for this table was one. The achievement gap was calculated using Newbould and Gray's formula between intervention group and comparator. Achievement gap decreased from 0.07 to 0.03. Calculations are below.

Before longitudinal intervention –

$$\text{Achievement gap}_B = \frac{3.98}{51}$$

$$\text{Achievement gap}_B = 0.07$$

After longitudinal intervention –

$$\text{Achievement gap}_A = \frac{2.23}{62}$$

$$\text{Achievement gap}_A = 0.03$$

All these estimations show the intervention group of schools did not make any more progress than the comparator schools. In fact, the comparator seems to be catching up with the intervention group.

Again this estimation shows, the longitudinal intervention group started with a lower percentage of FSM eligible pupils. The comparator had a relatively higher share of FSM pupils at the start and end. Both showed similar association between percentage FSM pupils and KS4 science indicator and both improved to the same extent.

Table 6.26 School FSM intakes and correlation with attainment

Sub-groups		2007-08	2009-10
Intervention	Mean % FSM	13	15
	R	-0.5	-0.3
Comparator	Mean % FSM	15	16
	R	-0.5	-0.3

Results from analysis of school level data show STEM intervention schools did not perform any better in KS4 science. On the contrary the comparator group has improved. The next section considers the data in more detail at the level of pupil GCSE attainment. School level data for science attainment did not have matched variables beyond 2009-10. The pupil level database is rich and has clearly matched variables for science attainment from 2007-2012.

6.3.2 Pupil level data

Results for KS4 pupil performances considered percentage of students achieving A*-C in GCSE science as the indicator. Slightly more students from intervention group met the threshold than the comparator. A percentage point difference of four was observed.

Table 6.27 Pupil attainment - A*-C in GCSE science 2011-12

Sub-group	Numbers achieved	Entries	Percentage
Comparator	321682	555295	58
Longitudinal	27002	43288	62

Achievement gap between the groups was now calculated. Rather than percentages, actual number of pupils achieving A*-C in GCSE science and total number of entries were substituted for calculating achievement gap between longitudinal intervention group and the comparator. A very small achievement gap was noted. This supported findings from school level data. Calculations are shown below.

$$\text{Entry gap} = \frac{\text{Entries}_C - \text{Entries}_I}{\text{Entries}_C + \text{Entries}_I}$$

$$\text{Entry gap} = \frac{555295 - 43288}{555295 + 43288}$$

$$\text{Entry gap} = (0.86)$$

$$\text{Achievement gap} = \frac{\text{Nos. achieved A*-C}_C - \text{Nos. achieved A*-C}_I}{\text{Nos. achieved A*-C}_C + \text{Nos. achieving A*-C}_I} - \text{Entry gap}$$

$$\text{Achievement gap} = \frac{321682 - 27002}{321682 + 27002} - 0.86$$

$$\text{Achievement gap} = \mathbf{0.02}$$

Percentage of FSM pupils and links between FSM and pupil science attainment were now calculated. Both values were exactly similar (Table 6.25). This meant the groups were largely similar in their share of lower SES pupils. Also SES was still as good a predictor of science attainment in the comparator as in the intervention group. Put more simply this means STEM interventions have not been able to weaken the link between science attainment and SES.

Table 6.28 FSM versus R – pupil science attainment

Sub-groups	% FSM pupils	R
Longitudinal intervention	14	-0.2
Comparator	14	-0.2

Findings from pupil level data supported those from school level data. Intervention group pupils did not achieve any higher than comparator. Neither did correlation coefficient values reduce for intervention group. Percentage of pupils achieving an A*-C in various disadvantaged and privileged groups were now compared based on the duration of intervention. SEN and FSM pupils were the lowest attaining group. Most privileged groups achieved higher than the deprived groups for the same measure. This difference was notably higher for science than in maths. Most pupils achieved highest in the KS3 only intervention sub-group, followed by longitudinal intervention. FSM pupils achieved most in staggered intervention group followed by KS3. SEN pupils achieved most in staggered followed by longitudinal intervention. Much lower percentage of pupils in KS4 only intervention groups met the maths indicator. This was lower than the comparator for all disadvantaged and privileged sub-groups. Table 6.26 is an abridged version with only mean percentage students achieving A*-C in GCSE science. For total number of entries and numbers meeting threshold see appendix.

Table 6.29 Percentage pupils achieving A*-C in science

Disadvantage measure	Intervention					Comparator	All eligible pupils
	Ever	Longitudinal	KS4 only	KS3 only	Staggered		
Ethnic minorities	60	61	41	70	60	59	59
White	62	63	45	65	57	58	59
EAL speakers	57	59	32	66	56	56	56
Native English	63	63	48	65	61	59	59
FSM	39	37	27	38	49	34	35
Non-fsm	66	67	49	69	61	63	63
SEN	28	28	19	27	32	25	35
Non-SEN	71	72	51	75	67	68	71
All eligible pupils	64	62	41	61	70	58	59

Achievement gap between all intervention and comparator group pupils was estimated. The ratio between the percentage points difference in pupil achievement (for each intervention and respective comparator group) and percentage attainment in population (58.6%). Achievement gap was very low. This meant the intervention group pupils did not attain much higher than comparator.

Table 6.30 Achievement gap – intervention groups versus comparator

Disadvantage measure	Longitudinal	KS4 only	KS3 only	Staggered
Ethnic minorities	0.03	-0.3	0.2	0.02
White	0.1	-0.2	0.1	-0.02
EAL	0.1	-0.4	0.2	0
Native English speakers	0.1	-0.2	0.1	0.03
FSM	0.1	-0.1	0.1	0.3
Non-FSM	0.1	-0.2	0.1	0.03
SEN	0.1	-0.1	0.03	0.2
Non-SEN	0.1	-0.3	0.1	-0.01
All eligible pupils	0.1	-0.3	0.1	0.2

Second, achievement gap was estimated between a disadvantaged and a privileged group for the same predictor variable for the same duration of intervention. Very low achievement gap was noted for ethnicity and EAL subgroups. The gap was relatively larger for FSM and SEN pupils. However, the magnitude of achievement gap between two sub-groups for the same predictor was nearly the same for various durations of interventions. This meant disadvantaged students did not benefit much from a change in point of delivery or duration of intervention.

Table 6.31 Achievement gap- advantaged and disadvantaged pupils

Disadvantage measure	Intervention				Comparator
	Longitudinal	KS4 only	KS3 only	Staggered	
White & non-white	0.03	0.07	-0.09	-0.05	-0.01
English & EAL	0.08	0.2	-0.005	0.09	0.05
Non-FSM & FSM	0.5	0.4	0.5	0.2	0.5
Non-SEN & SEN	0.8	0.5	0.8	0.6	0.7

Effect of STEM interventions on FSM subcategories

Percentage of pupils in each of the four FSM sub-groups attaining A*-C in GCSE science following STEM intervention was estimated. The poverty level of a pupil's family was found to negatively affect their science attainment. Thus higher the poverty level, lower was the science attainment. More pupils from poorer families met the science achievement criteria in the staggered intervention sub-group followed by KS3 only intervention. More pupils from higher SES met the threshold in KS3 only intervention sub-group.

Table 6.32 Percentage of FSM pupils attaining A*-C in GCSE science

FSM status	Intervention					Comparator
	Ever	Longitudinal	KS4 only	KS3 only	Staggered	
FSM now	39	37	27	38	43	34
Ever-FSM	41	41	28	38	43	37
Not FSM now	66	67	49	69	65	63
Never-FSM	69	70	53	72	68	66

Achievement gap was calculated for between the most affluent pupils and the various other FSM sub-groups - FSM now, Ever FSM and Not FSM now. Attainment gap was of a similar order for pupils currently on free school meals and those who were on free school meals at some point during the last six years. However, between group differences were not very large when compared across the same row. This means duration of point of delivery does not make much difference in reducing the poverty gradient.

Table 6.33 Achievement gap between poor pupils and their most affluent peers

FSM status	Intervention				Comparator
	Longitudinal	KS4 only	KS3 only	Staggered	
FSM now	0.6	0.4	0.6	0.4	0.5
Ever-FSM	0.5	0.4	0.6	0.4	0.5
Not FSM now	0.1	0.1	0.1	0.1	0.1

In order to estimate the effectiveness of STEM interventions the relative risk ratio was calculated (table 6.31). All intervention groups offer the same chances of success as the comparator, except KS4 only intervention sub-group which offered slightly lower chances than the comparator.

Table 6.34 Effect size estimates

FSM status	Ever intervention	Longitudinal	KS4 only	KS3 only	Staggered
FSM now	1	1	0.8	1	1
Ever-FSM_6	1	1	0.8	1	1
Not FSM now	1	1	0.8	1	1
Never-FSM_6	1	1	0.8	1	1

All the different ways of analyses show STEM interventions did not offer any added benefit in term of improved attainment to participating pupils than the comparator.

Do some ethnic groups benefit more in terms of science achievement form STEM initiatives? Science attainment varies with ethnicity. The mean performance is much higher than the lowest achieving group's science results. Mean percentage of pupils achieving an A*-C in GCSE science was compared for various major ethnic groups. Chinese pupils were the highest attaining ethnic group in GCSE science and black the lowest attaining. Most ethnic groups achieved highest in a KS3 only intervention sub-group. More unclassified and black pupils met the threshold in longitudinal intervention groups. However, the least percentage of pupils meeting attainment criteria was from the KS4 only intervention sub-group.

Table 6.35 Percentage pupils achieving A*-C in GCSE science by ethnicity

Ethnicity	Ever intervention	Longitudinal	KS4 only	KS3 only	Staggered	Comparator
Chinese	80	80	53	90	78	80
Asian	63	60	40	72	66	62
Unclassified	65	67	46	61	62	60
Mixed	63	63	44	69	63	59
White	63	63	45	65	57	58
AOEG	57	63	28	72	53	57
Black	56	60	43	59	54	52

Achievement gap was calculated between the highest performing ethnic group – Chinese and all other ethnic groups (table 6.33). The highest achieving group was considered for this calculation rather than the national performance. This is because the research project focusses on improvement of attainment. Thus it was thought if participation in STEM activities can help one ethnic group to achieve higher it others could be expected to perform at par. Achievement gap was of a similar order for most intervention groups and comparator. It was lowest for KS4 subgroup. This should not be interpreted as the most effective period of intervention. This is because the low values of achievement gap are simply because a relatively lower percentage of Chinese pupils met the science attainment threshold in this group. Thus STEM interventions did not reduce the attainment gap.

Table 6.36 Achievement gap of various ethnic groups with Chinese pupils

Ethnicity	Intervention					Comparator
	Ever	Longitudinal	KS4 only	KS3 only	Staggered	
Asian	0.3	0.3	0.2	0.3	0.2	0.3
Unclassified	0.3	0.2	0.1	0.5	0.3	0.4
Mixed	0.3	0.3	0.1	0.4	0.3	0.4
White	0.3	0.3	0.1	0.4	0.4	0.4
AOEG	0.4	0.3	0.4	0.3	0.4	0.4
Black	0.4	0.3	0.2	0.5	0.4	0.5

A second way of estimating whether STEM schemes improve chances of success in GCSE science attainment for various ethnic groups was through the relative risk ratio. The relative risk ratio did not vary for various ethnic groups for the same kind of intervention.

Table 6.37 Effect size estimate – science attainment, ethnicity

Ethnicity	Longitudinal	KS4 only	KS3 only	Staggered
Chinese	1	0.7	1	1
Asian	1	0.6	1	1
Unclassified	1	0.8	1	1
Mixed	1	0.8	1	1
White	1	0.8	1	1
Any other ethnic group	1	0.5	1	1
Black	1	0.8	1	1

The various methods of estimation used here correlations and effect size estimates show almost all pupils perform nearly the same well with or without intervention. However, the chances of pupil's success in the KS4 only sub-group is lower than the comparator. The next section summarises results of regression analyses.

Multiple regression analysis results for science attainment

Predictor variables used were SES, gender, language group, ethnicity, SEN and science prior attainment for model 1. Highest point score achieved (GCSE equivalencies) in science (full GCSE, full intermediate or foundation GNVQ and vocational GCSE) was used as the outcome measure for science attainment.

Model summary shows together the explanatory variables can predict the outcome variable of science test scores achieved with an accuracy of 60%. The adjusted R square was 0.35 suggesting that the model is a moderate fit for predicting science scores. However, for model 2 when STEM intervention was added as an independent variable it did not appear to change the R or adjusted R square values (table 6.35).

Table 6.38 Multiple linear regression analysis models for prediction of science test scores

Model	Independent variables included	Additional variables included	R	Adjusted R square
Model 1	KS2 science prior attainment, SEN, FSM eligibility gender, language group, ethnicity	None	0.6	0.35
Model 2		STEM intervention	0.6	0.35

Binary logistic regression results for science attainment

The baseline model with no independent variables suggests the prediction that everyone will attain an A*-C in science turns out to be correct for 59.6% cases. Statistics for the model with independent variables KS2 science prior attainment, gender, FSM eligibility, language group, ethnicity and SEN provided the measures of pseudo R square as 0.46. This indicates a moderate improvement in fit over the baseline model. A comparison of predicted and actual scores shows 76.3% of the predictions were accurate. Thus there was a clear improvement over the baseline model, where 59.6% predictions were accurate.

A second model was created including all predictor variables as above and also STEM intervention. The pseudo R square values and percentage accuracy of predictions was exactly the same as for the model excluding STEM intervention.

The regression coefficients for all independent variables are summarised in the table 6.36. It suggests an increase of one on the scale for KS2 prior science attainment increases the probability of achieving an A*-C in science by 0.33

Table 6.39 Logistic regression output for science attainment[2]

Independent variables	Regression coefficients
SEN	-1.23
FSM eligibility	-0.82
KS2 prior science attainment	0.33
Language group – EAL	-0.2
Stem intervention	0.1
Gender	0.03
Ethnic minority	0.001
Constant	-8.5

[2] The percentage of cases predicted correctly was 76.3 and the pseudo R square (Nagelkerke) was 0.46

Multiple linear and logistic regression analyses used different science performance indicators but the findings were largely similar. Both analyses show STEM interventions are not as important predictors of success as the other independent variables considered here. This supports findings from school and pupil level data.

6.4 **Post-compulsory STEM participation**

The second outcome measure considered was continuation in STEM education beyond compulsory education. Results for participation are discussed under four subheadings. Percentages of pupils meeting the requirements for A-levels are discussed first followed by the actual percentages of those who took A-levels in STEM subjects. The next section discusses STEM participation amongst FSM pupils and lowest attaining ethnic minority – black pupils. These estimations are important as it is the year after interventions have been stopped and reflect pupil attitudes towards STEM subjects

6.4.1 Meeting the pre-requisites

The results considered students who were likely to make STEM A-level entries. Typically, AS levels are taken in four subjects in year 12 from amongst those in which a GCSE was taken. Thereafter, a pupil drops down to three or four subjects for A-levels. It is well known that students achieving a higher grade at GCSE are more likely to go to enter the same subject at AS and A-level than those attaining a lower grade. More intervention group pupils achieved an A*-C in GCSE science than the comparator.

Table 6.40 GCSE attainment by subject

Subject	% taking GCSE		% A*-C in GCSE	
	Intervention	Comparator	Intervention	Comparator
Maths	98	95.8	72.9	68.1
Science	79.4	75.9	63.6	58

At least five A*-C grades including the core subjects English and maths are required to meet the pre-requisite to start A-levels. More pupils who have been in the intervention group attained the threshold and were likely to enter A-levels than the comparator. However, the maximum number of such qualifying pupils were from staggered or longitudinal intervention groups while the least from KS4 only intervention (lower than comparator).

Table 6.41 Percentage pupils achieving five or more GCSE/GNVQs at grades A*- C

Intervention sub-group	Percentage pupils
Ever intervention	63
Longitudinal intervention	60
KS4 only intervention	35
KS3 only intervention	58
Staggered intervention	76
Comparator	56

Thus more intervention group pupil met the entry criteria and likelihood for AS/A level entries. The next section explores the actual share of those who entered for these qualifications.

6.4.2 Progression from GCSE to AS/A levels

Attainment data was used as a proxy indicator of participation data. This is because there was no variable in the files provided which could give an estimate of the number of pupils who had wanted to study a STEM subject for post-compulsory education. Biology, human biology, chemistry, physics, science, electronics, environmental sciences, geology, computer studies and information technology were included under science and technology. While maths, mechanics, pure maths, math discrete AS level, applied maths, statistics, further maths, additional maths were included as indicators of maths participation. The only criteria considered was whether the pupils take an AS/A level examination from this cohort. Hence pupils achieving A to E, Q and U were all counted as having participated in STEM education. Table 6.39 shows participation data individual subject-wise. The letters P, I and C in the table headings below indicate population, intervention group and comparator respectively.

Table 6.42 Number of pupils progressing from GCSE to AS/A levels by STEM subject

Subject		Numbers cashing-in AS level			Numbers progressing to A level		
		P	I	C	P	I	C
Biology	Numbers	8468	1246	7222	47272	6675	40597
	Percentages	1.3	1.6	1	7.5	8.7	7.3
Chemistry	Numbers	6746	1025	5721	39711	5743	33968
	Percentages	1.1	1.3	1	6.3	7.5	6.1
Physics	Numbers	5011	767	4244	27467	3840	23627
	Percentages	0.8	1	0.8	4.4	5	4.3
Environmental science	Numbers	0	0	0	797	107	690
	Percentages	0	0	0	0.1	0.1	0.1
Geology	Numbers	354	45	309	1818	255	1563
	Percentages	0.1	0.1	0.1	0.3	0.3	0.3
Computer studies	Numbers	1059	133	926	3308	394	2914
	Percentages	0.2	0.2	0.2	0.5	0.5	0.5
Maths	Numbers	11139	1551	9588	63017	9142	53875
	Percentages	1.8	2	1.7	10	12	10
Statistics	Numbers	168	13	155	0	0	0
	Percentages	0.02	0.01	0.03	0	0	0
Further mathematics	Numbers	4659	638	4021	10824	1698	9126
	Percentages	0.7	0.8	0.7	1.7	2.2	1.6
From amongst	Numbers	631267	76406	554861	631267	76406	554861

Students taking an A level exam are not counted in the AS level entries by the National pupil database. Thus for AS-level data the table above shows only the number of pupils who had their AS levels cashed in. This meant if a pupil went on to complete an A level in maths this pupil was not counted in the AS level data above. However, as NPD does not provide the number of those who failed an exam it is believed that the actual numbers of those opting for a certain subject would be slightly higher than what is projected here.

For estimating achievement gap rather than individual subjects' participation in any of the above subjects was now considered as – STEM participation. Thus, all students taking up an AS/A level in STEM subjects were counted together. A higher percentage of intervention group pupils participated in STEM education than the comparator (Table 6.40).

Table 6.43 pupils progressing from GCSE to AS/A levels

STEM subjects	Cashing-in AS level			Progressing to A level		
	P	I	C	P	I	C
Numbers	37604	5418	32186	194214	27854	166360
From amongst	631267	76406	554861	631267	76406	554861
% participating	6	7	6	31	36	30

Participation gap was calculated considering the actual number of entries and attainment, for AS/A levels this was zero. Relative risk ratio estimations supported these results. A value of one was obtained which meant STEM intervention does not make any change. Calculations are shown below.

$$\text{Entry gap A-level} = \frac{\text{Entries}_C - \text{Entries}_I}{\text{Entries}_C + \text{Entries}_I}$$

$$\text{Entry gap A-level} = \frac{554861 - 76406}{554861 + 76406}$$

$$\text{Entry gap A-level} = (0.7)$$

$$\text{Participation gap A-level} = \frac{\text{Numbers. participated}_C - \text{Numbers. participated}_I}{\text{Numbers. participated}_C + \text{Numbers. participated}_I} - \text{Entry gap}$$

$$\text{Participation gap A-level} = \frac{166360 - 27854}{166360 + 27854} - 0.7$$

$$\text{Participation gap A-level} = \mathbf{0}$$

All these estimations show the likelihood of continued post-16 STEM for intervention group pupils is thus the same as comparator. Table 6.41 summarises effect sizes.

Table 6.44 post-16 STEM participation – effect sizes

STEM participation	Participation gap	Relative risk ratio
AS level	0	1
A level	0	1

The next discusses results of post-compulsory STEM participation amongst FSM pupils depending on the point of delivery and length of intervention.

6.4.3 Post-compulsory STEM participation of lower SES pupils

The poorest pupils from the cohort who were on free school meals (80289 pupils) during GCSEs were tracked from the census. The actual number of pupils in each of these intervention sub-groups and comparator who were awarded a grade from A to E, Q or U in the KS5 attainment table for STEM subjects were considered (Appendix). Progression rates from GCSE to AS and A levels in STEM subjects was much lower than the national average for 2013/14. Lower SES pupils are known to shy away from STEM education. Neither all pupils in each subgroup took an exam nor did all have a result reported. It was thus difficult to ascertain whether these pupils had failed an exam or dropped out of education between GCSE and AS/A levels. Most students from staggered intervention sub-groups (S) continued with STEM subjects (table 6.42) except computer studies were more pupils from KS4 only intervention group took an AS/A level than any other intervention group or comparator (C). L denotes longitudinal intervention group in the table below.

Table 6.45 Progression rates of FSM pupils from GCSE to AS/A levels by STEM subject

Subject	% progressing to AS level					% progressing to A level				
	KS3	KS4	L	S	C	KS3	KS4	L	S	C
Biology	3.2	3.4	3.1	9.1	3.7	2.4	1.1	2.2	6.6	2.6
Chemistry	2.4	2	2.6	8	3.3	1.8	0.9	1.9	5.6	2.3
Physics	1.1	1.1	1.6	3.4	1.7	0.9	0.6	1.2	2.1	1.2
Environmental science	0	0	0	0	0.03	0	0	0	0	0.03
Geology	0	0	0.1	0.1	0.1	0	0	0.03	0	0.1
Computer studies	0.1	1.1	0.4	0.2	0.3	0.1	0.6	0.2	0.1	0.2
Maths	3.4	3.7	0.04	10.8	4.4	2	1.7	2.98	7.4	3.1
Statistics	0	0	0.01	0.05	0.02	0	0	0	0	0
Maths further	0.2	0	0.5	1.2	0.7	0.2	0	0.4	0.7	0.4

All students from the above table were now marked as having participated in STEM education. The maximum number of pupils participating in STEM at AS/A levels were from the staggered intervention group. The longitudinal intervention groups had a lower participation than the comparator (Table 6.43).

Table 6.46 Number of FSM pupils taking up AS/A levels in STEM subjects

STEM subjects	Cashing in AS level					Progressing to A level				
	KS3	KS4	L	S	C	KS3	KS4	L	S	C
Numbers	39	23	184	204	2961	98	17	510	435	7085
From amongst	1309	352	5657	1945	71026	1309	352	5657	1945	71026
% participating	3	7	3	10	4	7	5	9	22	10

The participation gap between the various intervention sub-groups and comparator was always nearly zero. Calculations have been shown below for the FSM group which has maximum percentage of students taking AS-or A-levels in STEM subjects.

$$\text{Entry gap} = \frac{\text{Entries}_C - \text{Entries}_I}{\text{Entries}_C + \text{Entries}_I}$$

$$\text{Entry gap} = \frac{71026 - 1945}{71026 + 1945}$$

$$\text{Entry gap} = 0.9$$

$$\text{Participation gap} = \frac{\text{Numbers participated}_C - \text{Numbers participated}_I}{\text{Numbers participated}_C + \text{Number participated}_I} - \text{Entry gap}$$

$$\text{Participation gap} = \frac{7085 - 435}{7085 + 435} - (0.9)$$

$$\text{Participation gap} = \mathbf{0}$$

Similarly, the probability of pupils' continuing studying STEM subjects was highest in staggered intervention sub-group for A-level and other sub-groups made almost no difference than the comparator.

Table 6.47 Post-16 STEM participation FSM – effect sizes

Grade	AS-level				A-level			
Subgroup	KS3	KS4	L	S	KS3	KS4	L	S
Achievement gap	0.01	-0.01	0.03	-0.1	0.01	0	0.02	-0.1
Relative risk ratio	0.8	1.7	0.8	1.1	0.7	0.5	0.9	2.2

Thus, the longitudinal intervention was not particularly effective in promoting post-16 STEM participation. The staggered intervention sub-group though had a high success rate, however most students for this group were not exposed to the intervention regularly so their continuation with STEM subjects cannot be directly attributed to the intervention.

6.4.4 Post-compulsory STEM participation of lowest attaining ethnic minority group - Among the various ethnic minorities considered in the study for pupil attainment in science and maths, black pupils are the lowest attaining group. Hence this section tried to asses if black ethnic minority pupils opt for STEM subjects beyond compulsory education following a STEM intervention? The results presented here also tries to address whether the duration and point of delivery of the intervention made any difference to their attitudes towards taking up STEM subjects beyond GCSE.

The 2011-12 GCSE cohort had a total of 26223 known black pupils. All black pupils for whom a result A-E, Q or U was available in the KS5 attainment table were counted as having participated in STEM. The fails were not recorded by NPD hence, it is expected that actual number of participating pupils could be slightly higher than what is being projected below in (appendix)

Percentage of pupils progressing from GCSE to AS levels was calculated by adding up the entries for AS and A levels while GCSE to A level progression was calculated by the number of A level entries (Table 6.45). All STEM subjects offered at AS/A level which was taken up by at least one black pupil was added in the table below. Science, electronics, psychology, science for public understanding, information technology, mechanics, pure maths, maths discrete, maths applied and additional maths were not taken by any black ethnic minority pupil.

Table 6.48 Progression rates of Black pupils from GCSE to AS/A levels

Subject	% progressing to AS level					% progressing to A level				
	KS3	KS4	L	S	C	KS3	KS4	L	S	C
Biology	12.2	8.5	12.5	9.4	9.1	9.4	2.3	9.2	7.2	6.7
Chemistry	9	0	10.3	8.7	8.5	6.8	5.4	7.7	7	6.3
Physics	4.7	18.5	2.7	3.6	3.2	3.6	3.1	1.8	2.3	2.2
Environmental science	0	0	0.1	0	0.01	0	0	0.1	0	0
Geology	0	0	0	0	0.1	0	0	0	0	0.05
Computer studies	0.4	1.5	0.5	0.3	0.5	0.4	0.8	0.5	0.1	0.3
Maths	12.2	13	11.6	12.2	11.3	9.7	9.2	8.3	8.8	7.9
Statistics	0	0	0.1	0.1	0.02	0	0	0	0	0
Maths further	0.4	0.8	0.7	1.02	1.02	0	0	0.4	0.6	0.6

All black ethnic minority students taking STEM subjects for AS-and A-levels were recoded as having participated in STEM post-16. This meant studying one of the above subjects was counted as one for participation. So if a student studied two STEM subjects, the participation was counted twice for the same student. Total number of entries for all sub-groups and the percentages of those taking STEM subjects are summarised below.

Table 6.49 Number of Black pupils taking up AS/A levels in STEM subjects

STEM subjects	Cashing in AS level					Progressing to A level				
	KS3	KS4	L	S	C	KS3	KS4	L	S	C
Numbers	25	23	157	184	2127	83	27	419	509	5394
From amongst	278	130	1499	1960	22356	278	130	1499	1960	22356
%participating	9	18	10	9	10	30	21	28	26	24

Participation gap was nearly zero for all intervention sub-groups. Also, students from the various intervention sub-groups were as likely to continue with STEM subjects as the comparator group students as seen from relative risk ratios which was always one (table 6.47). More students from KS4 only intervention group were likely to take-up an AS level in STEM subjects. However most of them did not go on to complete A levels in STEM and hence the relative risk ratio drops from 1.8 to 0.9 for this group.

Table 6.50 Participation gap and success ratio AS-&A-levels for STEM participation

Grade	AS-level				A-level			
Subgroup	KS3	KS4	L	S	KS3	KS4	L	S
Achievement gap	0	0.01	0.01	0	-0.01	0	-0.01	-0.01
Relative risk ratio	0.9	1.8	1	0.9	1.2	0.9	1.2	1.1

Post-16 STEM participation results support research findings from school and pupil level attainment data. The longitudinal STEM intervention group did not do any better than the comparator in terms of continued STEM participation. This was true for all pupils as well as black ethnic minority pupils. More students from staggered intervention group of FSM pupils were likely to continue in STEM. However, this cannot be held as a direct outcome of participation in STEM activities. This is because this sub-group comprised of a large share of pupils who had not regularly been in an intervention school. Thus it is likely that they might have had other exposure/experiences which might have motivated them to take up STEM subjects at AS/A levels. Conclusions drawn from these results are discussed in chapter 7.

Chapter 7 Conclusions and implications

This chapter summarises the research findings described so far, and then considers the implications. The latter includes the limitations of the study, recommendations arising from the study for policy and practice, suggestions for further research.

7.1 Research findings

STEM enrichment and enhancement activities were conceived and designed to motivate by increasing knowledge and raising curiosity. The informal STEM education sector has thus been supported by government, private agencies and educational charities with the belief that they can raise science and maths achievement and STEM participation in the long run. However, the results reported in the previous chapter suggests the outcome does not meet the expectations. The findings provoke the question why is this happening? It also tries to understand why the results obtained are what they seem. Has there been any error in implementation? If so what can be done to ameliorate the situation.

Conclusions drawn here summarise findings from evaluation of both outcome measures chosen for the study – educational attainment measured through achievement in standardised national examinations (GCSE) and continued post-16 STEM participation (AS- and A-levels). The recommendations available from academic literature identified in the systematic review are summarised followed by the research findings from educational attainment in maths, science and post-16 STEM participation. The project had five main research questions to answer. This section answers them one at a time.

7.1.1. Which factors are linked to underachievement of disadvantaged pupils in school science and maths education?

Educational research considers several parameters measures of disadvantage. For example, pupils from lower socio-economic backgrounds identified by their eligibility for free school meals (UK) or reduced price lunches (US), speakers of English as an additional language, ethnic minority status, and statement of special educational needs. Disadvantaged pupils face several challenges in their day-to-day life, each one of which could be quite unnerving for a child individually. Acting together these factors lead the child to a position of distress affecting their academic performances.

The review identified factors within the family. For example, limited resources in terms of money, parental education, care and even dietary needs. High poverty neighbourhoods only add on to the negativity around these children as adversities often lead to increased crime rates and lack of role models. All of these negative emotions lead to decreased self-esteem and a sense of futility within young minds which gradually become unfathomable as the young person finds it difficult to give them up.

This persistent lack of academic motivation and peer pressure often leads to increased aggression and violence among disadvantaged youth. Often this is a psychological response or outburst which such children do not know how to deal with. Research evidence shows an earlier intervention can often curb such behaviour not only preventing their dropping-out from education but also by helping them reach for a better life.

7.1.2. Does continued participation in enrichment and enhancement activities raise school attainment levels?

Mean maths and science attainment for all schools increased from 2007 to 2012. Higher percentage of students achieved 5+A*-C or equivalents including A*-C in both English and mathematics GCSEs in intervention schools every year than the comparator for both study designs. Similarly, percentage of pupils achieving two GCSE grades at A*-C or equivalents covering the KS4 science programme was higher for the intervention group than the comparator. Attainment gap was however exactly the same each year for the repeated cross-sectional design. This meant the improvement in school performances was of a similar order in both intervention and comparator groups. However, the achievement gap between intervention and comparator narrowed down significantly after intervention for the longitudinal design. This was because comparator schools had more improved attainment than intervention schools after intervention.

In most analysis intervention and comparator schools had a similar or slightly lower share of lower SES pupils – a school level deprivation measure. A strong negative correlation of similar order was seen in intervention schools as well as the comparator group. This suggests correlation of school attainment in maths with percentage share of FSM pupils was not affected by STEM intervention. If STEM interventions were able to negate the effect of school level deprivation factors such as SES it would be expected that the values for correlation coefficient would be lower for intervention groups as opposed to the comparator.

A slightly different trend was however noticed for science attainment. Values for correlation coefficients decreased over the years more for comparator than intervention group. This means the effect of poverty on school science attainment had been slightly ruled out for the comparator. This suggests there are perhaps other factors linked to this improvement and need to be investigated.

7.1.3.Can STEM activities effectively reduce attainment gaps between underprivileged pupils and their peers?

Findings from the longitudinal cohort study supported those from school level data. 76,462 students registered for STEM intervention from the beginning of KS3 (year 7 for the cohort) were tracked to assess the impact of STEM initiatives on pupil maths and science GCSE attainment. The results were matched to a comparator group of 555,295 students. Achievement gap was very small after longitudinal intervention (0.01). The percentage of FSM pupils were same in intervention and comparator group (13%) and exactly similar were the correlation coefficients (-0.2). Thus, pupil participation in STEM activities did not show any weakening of link between FSM and maths attainment.

From amongst the various disadvantage measures considered, SEN pupils were the lowest attaining group, followed closely by FSM eligible pupils. Compared to SEN and FSM pupils, ethnic minorities and EAL pupils did relatively better in GCSE science and maths.

A two-way estimation of attainment gap was now carried out for the various disadvantaged groups with varying time periods of exposure to intervention. Amongst the various disadvantage measures considered, FSM eligibility and ethnic minority status were considered in some more detail. First, achievement gap between intervention groups and comparator was always nearly zero. Second, students from privileged backgrounds did not gain any higher than disadvantaged pupils when exposed to similar duration of intervention. The probability of success when a student was placed in either of these groups was the same. This meant science or maths attainment of students is not affected if they are in an intervention group or comparator. Students participating in STEM interventions only during KS4 were however the lowest attaining sub-group. R values for intervention group and comparator were exactly same (-0.2). This means just as maths attainment, STEM interventions could not rule out the effect of FSM or ethnicity on maths or science attainment any more than the comparator.

Multiple linear and logistic regression models were created using different maths and science attainment variables (outcome). Independent predictor variables shown in literature to affect educational attainment were included in analysis. The findings were similar for science and maths. Regression models confirmed STEM interventions were not a deciding factor for science/maths GCSE attainment. Other independent variables like prior attainment, SES, gender, ethnicity, SEN, language groups are able to predict science attainment. Inclusion or exclusion of STEM intervention did not make any difference to the models and the R or adjusted R square values remained unchanged. This supports previous findings that STEM interventions have not had a major impact on GCSE maths and science attainment.

7.1.4 What is the impact of STEM initiatives in widening STEM participation of students from disadvantaged backgrounds?

Key stage5 (KS5) data was available from the national pupil database for 55% of the cohort being followed up. Beyond compulsory education A-levels was the most popular qualification route for the cohort.

Achievement of five A*-C is one of the most essential criteria for pursuing A levels. More pupils who have been in the intervention group met the criteria and were expected to enter A-levels than in the comparator. However, results from post-16 STEM participation data did not meet these expectations and were rather similar to attainment results.

Achievement gap was very small between intervention group and comparator for STEM participation for both AS- and A-levels. Also participation in intervention group did not increase the likelihood of a student continuing in STEM education. Thus as many intervention group students participated in STEM subjects at AS- and A-levels as comparator group pupils.

Achievement gap between all intervention groups of varying duration for lower SES pupils and comparator was negligible. Staggered intervention group pupils had the highest likelihood of continuing studying STEM subjects for A-levels. Most students for this group were not exposed to the intervention regularly so their continuation with STEM subjects cannot be directly attributed to the intervention. However, the longitudinal intervention group did not have many students studying STEM subjects' post-16.

Black ethnic minority pupils were the lowest attaining group for GCSE science and maths. Post-16 STEM participation of these pupils was mapped. Achievement gap for black pupils in intervention group and comparator was zero. Also the chances of their studying STEM subjects was similar in any intervention group or comparator.

7.1.5. What recommendations are available from literature for improvement?

Academic literature shows several factors could be used for levelling the playfield for those from disadvantaged backgrounds with the possibility of extending some of these to all pupils. These could help raise their educational attainment for a better overall life. Lower levels of negative stress, high physical comfort and good health of pupils have been shown to have positive effects on teacher connectedness, school engagement and academic achievement. Negative emotions such as bullying, aggression and violence adversely affect these outcomes (Forrest, 2013). Similarly, positive self-perceptions about academic abilities (Burrichter, 2006), high educational aspirations, empathic understanding, an internal locus of control and hope for the future have been deemed as protective factors contributing to the academic resilience of students living in poverty (Gizir, 2009). Robust studies screened in the systematic review showed developing the factors below could go a long way in improving pupil performances.

Self-concept, equality and academic achievement

Academic self-concept has been shown to be correlated to scholastic achievement. An equally important role is believed to be played by people who matter most to a child - such as teachers, parents and peer group. For instance Gregory (2013) shows positive expectations of students, parents and maths teachers in 10th grade students had positive impact on academic performance irrespective of student's risk status (N=15,000). Significant relationships in a child's life could influence and even raise performance in school and reduce dropout rates. The most prominent ones as pointed out by Burrichter are structure imposed by teacher in the classroom and student's perception of degree of trust and communication with mother. Thus, pupil's perception of what others think about them could make a difference to academic achievement (Burrichter, 2006) of disadvantaged pupils.

Wildhagen (2009) suggests from analysis of large scale national datasets, disengagement from school accounts for relatively higher unrealised potential among blacks than whites. Similarly, lack of school values has been shown to leave disadvantaged children further behind (Blake, 2012). Using data from the Educational Longitudinal Study, Boccanfuso

(2009) suggests a link between presence of school membership within disadvantaged students with high levels of academic performance and effort. Promoting equality in academic opportunities in schools and sustaining high levels of engagement throughout school could be a step towards raising pupil's self-concept and raising attainment.

Motivation

Absence of role models and mentors from social environment among young people and their families in disadvantaged areas are often thought to explain their poor education levels and jobs (Bricheno, 2007). Disadvantaged pupils are thus thought to have lower aspirations and lack motivation. However, a clear causal relationship between attitudes, aspirations and children's educational outcomes is not established in literature in the absence of robust evaluations (Gorard, 2012)

Motivational similarities and differences have been shown by analysis of student survey responses within subgroups of race and gender (Zelei, 2005). Examining student survey responses related to motivational conditions between and within race, gender, high school academic course level the study concluded in order to reduce disparities and support student achievement teachers and school administrators need to understand the differences and similarities which exist between pupil motivational conditions and establish appropriate academic expectations for students by improving instructional strategies.

In perhaps what could be termed as an assessment of efforts to motivate, Anderson (2012) investigated the relationship between academic achievement and participating in a high school debate program on college-readiness in the Chicago Public School district over a 10-year period. Study participants were at-risk school students - identified using an index including prior attainment in grade 8, poverty status, and enrolment in special education. Regression analyses were used to assess the association between debate participation and graduation and science performance. Overall, debaters were 3.1 times more likely to graduate from high school than non-debaters, and more likely to reach the college-readiness benchmarks on the English, Reading, and Science. Debate intensity was positively related to higher scores. Anderson suggests debate participation is associated with improved academic performance for at-risk adolescents. A possible explanation could be deciphered by the science involved during the preparation the child makes for preparing the text for the debate, Equally importantly perhaps the cumulative effects of the positive thought process and the confidence which is instilled while standing up to speak.

Teacher effect

The impact of teacher's intentional or unintentional classroom actions, expectations (Gregory, 2013) and beliefs on students' success (Burrichter, 2006) has been shown. Teacher's understanding of student perceptions and appreciating the importance of favourable relationships for better classroom dynamics can contribute to setting the grounds right for improved attainment of lower SES pupils (Whitehead, 2007; Archambault, 2012). Schools giving more instructional time to reading and math have had a positive effect on high poverty students' scores (Chatterji, 2005)

Dell'Angelo (2010) shows when teachers perceive a high degree of obstacles to student learning, then, in fact, students' achievement level is lower. Conversely, when teachers perceive a lower degree of obstacles to student learning, then, students have higher achievement even when poverty levels are high.

Teacher quality in high poverty school settings remains an important policy target for reform and improvement (Hogrebe, 2010). The role of teacher led classroom management and student behaviour has been correlated positively with student achievement (Marsden, 2006). There is some evidence in maths that teacher effects are more pronounced in high minority schools (Konstantopoulos, 2011). Teacher support acts as moderator for lower SES pupils and may even help change the negative trajectory found between poverty and academic achievement (Liu, 2008; Little-Harrison, 2012, Casper, 2013). Convincing research conducted by Freitas (2013) shows a dedicated teacher cadre with high level of self-efficacy, cultural competency and those who can identify with the students either due to similar ethnicity, language, upbringing or socio-economic status, poverty or hardships help to make learning environment congenial. High poverty schools with such teachers are high achieving schools and offer vital lessons for implementation.

Encouraging parental involvement

Parental involvement in their child's studies, particularly in terms of academic socialisation has been shown to improve academic achievement and impact the overall health and cumulative well-being of lower SES pupils (Westerlund, 2013). Educating parents and providing them with strategies that promote academic achievement is a way to increase achievement of high poverty kids. This has the long-term potential of changing the generational poverty cycle (Boggess, 2009) Parental support has been shown to act as a buffer between SES and academic achievement (Liu, 2008; Little-Harrison, 2012).

The under representation of minority female students has been addressed by some research. Some studies have shown the positive impact of familial support and students decisions of continuing with STEM majors (Parker, 2013). These results are important as they suggest how verbal persuasion and parental support can beat the odds through encouragement Dowey (2013)

Early intervention

Research shows children with high parental expectations for education and maternal years of education are better able to benefit from typical teacher facilitated opportunities in learning basic mathematics skills improving their readiness to learn in kindergarten and beyond (Wang, 2013). Children from deprived families are thus at an increased risk for early and prolonged academic and social difficulties. An effective intervention suggested for these children is attending pre-kindergarten programmes (Tucker, 2012).

Analysing Early Head Start (EHS) data Ayoub (2009) concluded children who received lower levels of cognitive and language stimulation at home, belonged to families receiving government assistance, had unemployed parents and less than a high school maternal education level had lower cognitive skill scores at the age of three. However, children who were enrolled in (EHS) had higher cognitive skill scores at three years of age than their peers who were not in EHS. Formal childcare could thus offer a preventive means of attenuating deprivation effects on children's early academic trajectory (Geoffroy, 2010)

Verdugo (2011) suggests by year 12 a large percentage of students leave school without graduating. These findings are further supported by Vaz (2014). The longitudinal study shows transition to secondary schools impacts academic competence of several groups of pupils. An early intervention is thus definitely required to extend support to disadvantaged pupils as is also supported by the multilevel cohort analysis of Singh (2012) which found a significant and dominant effect of academic performance in grade 3 on maths performance at 5^{th}, 8^{th} and 10^{th} grades.

Coordinated school health and breakfast programmes

Conducting a stepwise regression analysis on data from 50 states, Vinicullo (2009) shows students in states promoting students' health demonstrated higher academic scores and higher rates of high school completion. High-stakes achievement testing suggests executive functions account for variance in maths attainment between children from poor urban environments and their elite peers (Waber, 2006). Efforts to improve children's academic achievement thus need to consider developmental factors and pupil health in addition to curriculum.

Basch (2011b) explored the causal pathways between disparities of breakfast consumption among school-aged urban minority youth and their adverse academic achievement. On any given day a substantial proportion of American youth reported skipping breakfast. Neuroscience research has identified the processes by which dietary behaviour influences neuronal activity and synaptic plasticity, both of which influence cognitive functions. Participation in School Breakfast Programs has also been associated with reduced absenteeism. Universal School Breakfast Programs and allowing youth to eat breakfast in the school cafeteria are some approaches known to increase participation. Developed countries already offer reduced price lunches (US) and free school meals (UK). The added costs of breakfast program to the governments need to be investigated, while evidence supports the benefits.

De-tracking & implementation of focussed research based instruction materials

A combination of research-based instructional materials from the University of Chicago School Mathematics Project with a multi-tiered teacher support system of sustained professional development and in-class coaching led to the evolution of Talent Development (TD) Middle School Model's mathematics programme. The main objective of the programme was to develop comprehensive and sustainable mathematics education reforms in high poverty middle schools (Balfanz, 2006). Outcome evaluation on various measures of achievement found TD students outperformed students from control schools on multiple measures of achievement with an effect size of 0.24, by the end of middle school. Similar programmes with the mission of improving the academic achievement of students who are often in the middle or average range and who are typically minorities and are economically disadvantaged have been shown to bring about significant improvement in mathematical achievement (Peak, 2011)

Ineffectiveness and inequities of ability grouping has long been debated. Burris (2008) conducted a longitudinal study at a diverse suburban American high school in order to examine the long-term effects on the achievement of students. All students were given accelerated mathematics in a de-tracked middle school as well as ninth-grade "high-track" curriculum in all subjects in heterogeneously grouped classes.

The quasi-experimental study analysed a pre- and post-reform success in the earning of the New York State Regents diploma and the diploma of the International Baccalaureate of the cohort. Binary logistic regression analysis showed a post-reform increase in the probability of students earning diplomas as summarised in table 7.1

Table 7.1 Impact of reform on diploma attainment summarised from Burris, 2008

Pupil identifier	Probability of diploma attainment
De-tracked cohort	70% greater chances
White/Asian students	3-fold increase
FSM eligible - African American/Latinos	5-fold increase
FSM ineligible - African Americans/Latinos	26-fold increase

The programme helped increase enrolment in International Baccalaureate classes and the average scores remained higher. The authors conclude that if a de-tracking reform includes high expectations for all students, sufficient resources and a commitment to the belief that students can achieve when they have access to enriched curriculum, it can be an effective strategy to help students reach high learning standards (Burris, 2008)

Daw (2012) suggests increase in the amount of homework may increase the socioeconomic achievement gap in maths and science in secondary school. It can be anticipated that the child may not have enough support at home. This further supports the use of focussed instructional materials in school.

Checking aggression and violence in school

Criminal justice, aggression and violence are now recognized as hindrances to learning and teaching. They form an important focus of the education and public health systems. Implementing evidence-based school policies and programs to reduce aggression and violence must be a high priority to help close the achievement gap (Basch, 2011)

Evidence suggests emotional intelligence plays a significant role in predicting academic achievement for all students but more specifically for at-risk students (Nelson, 2009). Perhaps higher the emotional intelligence of a child at-risk the more sensitive he is and this can often serve as a protective cover against negative behaviour. The author argues using instructional strategies that develop emotional intelligence could help alleviate attainment gap for at-risk students.

Group counselling approach

Bruce, 2009 evaluated the impact of a group counselling intervention on African-American students' achievement rates during the spring administration of high-stakes testing at a rural high school in Georgia. All participants had a pass score on Maths section of the Georgia High School Graduation Tests (GHSGT). Additionally, the achievement gap between African-American students and White students on the Enhanced Math narrowed during the 2007-2008 testing period, with 63.2% of African-American students achieving pass rates as compared to 70.5% of White students. The pass rate increased from the 38.7% pass rate among African-American students from the previous school year, indicating that the intervention was successful in improving pass rates on high-stakes testing. The study offers evidence base for professional school counsellors for utilizing the practice of group counselling to promote achievement among underachieving student subgroups (Bruce, 2009). Similarly, Pearson (2014) analysing factors that contribute to the success of minority students in maths, using a large longitudinal dataset shows school size and academic emphasis on a school level are important predictors of success.

Extracurricular activities

Kelepolo (2012) using a sample of (N=654 participants, 1107 non-participants) shows the positive impact of participation in school sponsored extra-curricular activities on academic success. The outcome measure for the study- performance in Utah's criterion-referenced tests (CRT), include assessment of maths and science. Successful high achieving high poverty schools have been shown to take steps to involve all students in some kind of extracurricular programme. These activities were found to be an incentive that gave students the initiative to remain in school rather than dropping out (Killigo, 2012). Also perhaps spending an extra hour on training beyond school teaching with a responsible adult instils positive values in the young learner thereby raising attainment.

7.2 Limitations of the study

The quasi-experimental design used here is perhaps the most practical option for conducting outcome evaluations in the social sciences. By using pre-existing groups, such as individuals already enrolled in STEM enrichment and enhancement activities provided by others, it makes an evaluation possible and avoids the potential ethical concerns involved in withholding or delaying treatment or substituting a less effective treatment for one group of study participants. The significant limitation of this design is that without randomization, the study groups may have already differed in important ways that account for some of the group differences in outcomes after the intervention, and which cannot be controlled for by the analysis. In other words, this design provides practical but comparatively weaker evidence of program effects than one that uses randomization.

As is true with any longitudinal study it is difficult to attribute outcomes solely to the intervention. This is because every child is exposed to a range of societal, familial and school related factors during the years in secondary school, apart from these STEM enrichment and enhancement activities. Some of the former might ignite a passion for STEM and some others may turn students away. Owing to the long time period involved in this prospective longitudinal study, it is difficult to ascertain with certainty that the educational outcomes in terms of attainment and participation are solely due to the intervention. It is quite possible a good of several factors have led to raised/impoverished attainment and continued/discontinued STEM participation. Of course, this only matters if such other factors are biased in terms of intervention and comparator schools.

In the absence of randomisation, a matched comparator group can provide a good estimate of the effect of the intervention. A range of effect size estimates were used in the study, showing the difference between the intervention group and the comparator.

An ideal matched group for this study would have been schools and pupils from schools who have definitely not participated in any STEM schemes, and such schools clearly exist (STEMNET, 2010). However, it was not possible to identify such schools, and so the compromise selected was to compare the known intervention schools with all other mainstream schools. This is likely to reduce the estimated effect size for the intervention, but should otherwise provide an unbiased estimate of whether the intervention was effective or not.

7.3 Recommendations for practice

Research findings suggest STEM enrichment and enhancement activities have not been phenomenally successfully in improving school performances, raising pupil attainment or increasing STEM participation of students. These schemes require huge investment of resources – in terms of staff engagement, time and money. Given the high priority STEM agenda, if these schemes are not working perhaps the money should be saved and used elsewhere. For example the systematic review has identified a range of schemes and programmes such as early head start and use of tailored instruction materials which have been shown to work through large scale studies.

There are indications that school and student performances are gradually improving over the years. A range of factors could affect student's subject choices, attitudes and aspirations in secondary school. As is true for all longitudinal studies it is difficult to attribute the entre success of improved educational outcomes to STEM activities. It is expected that a good mix of several factors can bring in a change by improving attainment widening participation of disadvantaged pupils and all pupils in general.

The duration and point of delivery (key stages) of intervention was considered in the study. Research findings suggest that different groups marked by several school or pupil level identifiers did not benefit any differently. The basic presumption that all pupils could be enrolled in the same intervention is perhaps unfair.

KS4 only interventions were found to be least effective. On certain occasions the comparator group schools and students performed better than this sub-group. This calls for further research to investigate if these interventions produce any damaging effects. Similarly, KS3 only and longitudinal interventions were found to be most effective. Previous research shows educational interventions early on in the life of students are often more effective (Ayoub, 2009; EIF). The research findings from this thesis support these claims. This study has focussed only on secondary school students it would be worth replicating a similar study on primary school children to offer more insight.

Reducing tuition fees for STEM courses or perhaps a Harvard like pattern with reduced tuition for the third year could be an important consideration in the light of growing STEM demand. There is no evidence to explain why disadvantaged pupils are less likely to attain higher and continue participating in STEM. Research needs to explore this avenue.

Attainment and participation in STEM qualification routes other than those addressed here need to be explored in other research. The limited availability of secondary data such as details of participating schools or names is very difficult to obtain for research. It is important to encourage research in this area and hence make such data easily available. Two issues highlighted in the Science and Innovation Framework (2004) have been explored here. Several other issues were highlighted. For example, it needs to be assessed how effective have the teacher focussed initiatives been in supporting the teaching work force.

Conclusion

While their journey on educational trajectories and life in general is harder compared to those from privileged backgrounds there are students who despite qualifying for several measures of disadvantage embody resiliency. Equally important are the measures adopted by high attaining schools with a high percentage of disadvantaged pupils. With educational policies like widening participation, Education for All and No child left behind there is hope that all children will reach their full potential, both academically and in other life-long pursuits. The systematic review has identified a range of factors linked to underachievement of disadvantaged pupils in school science and maths. The review has summarised literature that examines current practices and then offers practical solutions for the arduous task of improving educational attainment of these pupils.

The evidence-base from evaluation of STEM initiatives combined with it answers the research questions. Continued participation in STEM enrichment and enhancement activities did not raise school attainment levels. These activities were not effective in reducing the attainment gap between underprivileged pupils and their peers. Thus there was not a direct noticeable positive effect of participation in STEM interventions on educational outcomes of disadvantaged pupils or all participating schools and pupils in general.

While STEM skills are valuable and it is certainly important to encourage more students to study these subjects post-16, despite channelizing huge resources STEM enrichment and enhancement activities are not working. The systematic review identifies several potential areas from academic literature based on robust studies which have been clearly effective in improving cognitive development of disadvantaged pupils. Resources should rather be directed on similar programmes which have been shown to work in UK and elsewhere for raising academic achievement and sustaining pupil interests in STEM. This will ensure with a similar or reduced investment better results are obtained.

Rigorous evaluations are required to understand what works. Some under-researched areas have been highlighted here which deserve more attention.

7.4 Suggestions for further study

Experimental Design

Evaluation studies using an experimental design are considered to be more sophisticated. The gold standard of this design is randomisation. This is because randomisation reduces the likelihood of differences between intervention and control groups before the intervention, which can be a potential determinant and drawback. To put it more simply in randomised controlled trials the intervention and control groups are better matched. For example, in this study pupils could have been matched on the basis of similar geographical location of schools in an area of disadvantage, pupil FSM eligibility or pupil residence. Following randomisation one of the groups could have been registered for STEM activities and the other held back.

However, randomization by itself cannot guarantee the absence of group differences. To confirm that the randomization was effective, groups must be tested after randomization for demographic or any other pre-existing differences that may affect outcomes. This step helps to ensure the groups are comparable. Data collection in an experimental study resembles that of quasi-experimental studies, but with the addition of random assignment.

Table 7.2 Experimental design

Group	Pre-test	Treatment	Post-test
Intervention group (Randomisation)	O	X	O
Control group (Randomisation)	O		O

X = Intervention; O = output measured

Benefits and Challenges of Experimental Design

An experimental design offers the best evidence whether the intervention has brought about any change in outcomes. Physical sciences use this design because lab environments can be controlled and experiments can be repeated, to determine causality. However, implementing valid experimental designs in human settings is much more difficult.

Ethical concerns render experimental evaluation of human services unfeasible. First, parents and schools are more often unwilling to allow participants to be randomly assigned to experimental and control groups, as they believe it denies treatment to individuals who need it (although wait-list control groups can remedy this issue). Second, it is difficult to convince most STEM activity agency directors to work with an evaluator to implement experimental design. Unsurprisingly, this is because they know it is the best way to determine whether the program to which they are committing resources is achieving its intended outcomes.

Cost-benefit analysis

Cost–benefit analysis (CBA), is a systematic approach to estimate the strengths and weaknesses of activities or schemes. It is a technique that is used to determine options that provide the best approach for the adoption and practice in terms of benefits in labour, time and cost savings. This can be an extremely useful activity for calculating and comparing benefits and costs of a project to inform government policy. Thus CBA can help with:

1. Justification for employment of resources
2. Feasibility of running the project for a longer term
3. Providing a basis for comparing projects, in terms of the total expected cost of each option against the total expected benefits, to see whether the benefits outweigh the costs, and by how much.

In CBA, benefits and costs are expressed in monetary terms, and are adjusted for the time value of money, so that all flows of benefits and flows of project costs over time (which tend to occur at different points in time) are expressed on a common basis in terms of their "net present value." Cost–benefit analysis is often used by governments and other organizations, such as private sector businesses, to appraise the desirability of a given policy. CBA helps predict whether the benefits of a policy outweigh its costs, and by how much relative to other alternatives. For example, alternate schemes could be ranked in terms of the cost–benefit ratio. Generally, accurate cost–benefit analysis identifies choices that increase welfare from a utilitarian perspective. Assuming an accurate CBA, changing the status quo by implementing the alternative with the lowest cost–benefit ratio can improve efficiency.

For example, a generic cost–benefit analysis could involve:

1. Listing alternative STEM projects/programs.
2. Listing all possible stakeholders.

3. Selecting measures for all cost/benefit elements.
4. Predicting outcome of cost and benefits over relevant time period.
5. Converting all costs and benefits into a common currency.
6. Applying discount rate.
7. Calculating net present value of project options.
8. Performing sensitivity analysis.
9. Making recommendations for adopting/rejecting choices.

CBA attempts to measure the positive or negative consequences of a project, which may include effects on users or participants, effects on non-users or non-participants, other social benefits. The guiding principle of evaluating benefits is to list all parties affected by an intervention and add the positive or negative value, usually monetary, that they ascribe to its effect on their welfare. However, perfect appraisal of all present and future costs and benefits is difficult, and while CBA can offer a well-educated estimate of the best alternative, perfection in terms of economic efficiency and social welfare are not guaranteed.

STEM specialist schools

The specialist schools programme was a UK government initiative which encouraged secondary schools in England to specialise in certain areas of the curriculum to boost achievement. The Specialist Schools and Academies Trust was responsible for the delivery of the programme. When the new Coalition government took power in May 2010 the scheme was ended and funding was absorbed into general school budgets. It could be worth exploring if the specialist school system or dedicated funding help improve STEM attainment and participation.

Different school types

A range of schools currently exist in England. There are faith schools, independent schools, grammar schools and academies in addition to state maintained secondary schools. It will be worth exploring what the approaches for encouragement and patterns of STEM participation are like in these different types of schools. Best practices from across these schools could be encouraged and publicised.

Other progression routes

This research has focussed only on one progression route. GCSE attainment and AS/A- level STEM participation has been mapped. It would be worth investigating how pupils in other progression routes fair.

Attitudinal scaling surveys

Program evaluation approaches currently being addressed across the UK are mostly self-reported testimonials. For a broader coverage attitudinal scaling could be done. For example, pupil responses in large scale studies could be collected before and after participation in STEM activities. These participants could be routinely exposed to similar activities and followed up over a period of time to see if there is a positive or negative attitude towards STEM and is it any different from what it was in the first place to start with.

Different designs

A range of study designs addressing the same or similar research question add to the credibility of research findings. For example, most reported studies focus on association of factors as seen in the systematic review. A range of causal studies trying to answer similar research questions might help to picture the undercurrents better while also suggesting which kind of activities and schemes should be promoted and when.

Earlier intervention

This study has focussed only on secondary school students it could be worth replicating a similar study on primary school children. Similarly, STEM schemes are very popular across developed countries and STEM education almost always tops the education agenda. Similar studies in different population settings across different age groups can provide more insight.

Labour market returns

An interesting investigation could be to see how the returns to qualifications vary by subject area, focusing particularly on the wage return to STEM subjects. This is an under researched area though it has been shown that literacy and particularly numeracy is highly valued in the UK (De Coulon et al. 2010; Bynner and Parsons 1997a, 1997b, 2005; Grinyer, 2005), as is A level mathematics (Dolton and Vignoles, 2002).

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Appendix A Data extraction

Factor	Bibliographic details	Disadvantage measure	Design, sample, age-group	Outcome variable	Results/Conclusions drawn by author	Reliability rating, Gorard (2014)
Societal factors - Oppositional culture	Wildhagen, 2009	Race	ELS*, a nationally representative panel survey of high school sophomores and seniors. SEM and Hierarchical linear modeling	Participation and attainment in advanced placement (AP) courses	High achieving black students do not realise their full potential because of lower school engagement relative to high achieving whites.	3*
Societal factors - Oppositional culture	Greene, 2009	Race, ethnicity	National Educational Longitudinal Study	Academic achievement and career outcomes	Disproportionate academic placement of ethnic minority pupils into lower academic courses/vocational education impact their test performances, eventual employment status and occupational placement.	3*
Social factors - Neighbourhood disadvantage	Greenman, 2011	Poverty, neighbourhood disadvantage	Prospective longitudinal design, large, nationally representative database of American elementary school students, ECLS-K+ and contextual data from the 2000 US Census	Maths achievement end of 5^{th} grade	Effect of higher levels of early education-oriented parental practices on children's mathematics achievement was stronger for children who live in disadvantaged neighborhoods.	3*

Familial factors – parental involvement	Bryant, 2007	Ethnic minority status, economic disadvantage	Survey administration, N=213 representing 65 schools in northeastern part of US from grades 6-12.	at-risk status, academic performance, hopelessness, explanatory style and depression	Parental support directly influences risk status, academic performance, explanatory style, hopelessness and depression.	2*
Familial factors – Parental academic involvement	Westerlund, 2013	Socio-economic disadvantage	Prospective population based cohort study, n= 365 women & 352 men, survey followed by linear regression analysis (stepwise) and testing for mediation	Academic achievement	Parental interest in their offspring's studies may have protective effects by decreasing the likelihood of a chain of risk involving low academic achievement, low socioeconomic position and high accumulated physiological stress.	3*
Familial factors - authoritative parenting	Speight, 2010 (full-text not available)	Ethnicity, cultural groups, SES	Correlational design, multiple regression analyses and analysis of variance. *(Thesis abstract doesn't discuss sample size)*	Self-efficacy, resilience and academic achievement	Strategies and interventions developed to support and promote resilience and authoritative parenting are likely to have implications for positive outcomes, which may also mitigate risk factors and contribute to lessening the achievement gap among cultural groups.	3*

Familial factors – maternal education	Hanson, 2011	Poverty, Disability, English language learners	N=1006 four year old children	Maths achievement, social skills	Economic hardship, low maternal education and language isolation in children's neighbourhood communities influence children's developmental outcomes on academic measures (lower maths achievement) and social skills.	3*
Familial factors – background	Nonoyama, 2005	SES	PISA data 200, 2003 from 40+ participant countries. Causal design	Student achievement as a measure of equality of educational opportunities.	1. A multi-dimensional SES has stronger effects on achievement 2. Family effects are not acclimatized by the level of economic development, and are consistently larger than school effects across countries.	4*
Familial factors – background	Pinder, 2010	Immigrant status, ethnicity	N=87 high school students, survey questionnaires, Causal-comparative design	Science achievement, US test scores	Voluntary immigrants outperform involuntary immigrants. This offers a possible explanation for achievement gap between ethnic minorities and their native peers.	2*

Teachers' expectation	Alsace, 2009	Speakers of English as an additional language (Puerto rican), poverty	7th grade cohort from a low-achieving high poverty bilingual school & archival data from achievement tests, attendance records, and cumulative records	Academic achievement in Maths	Attendance correlates to maths performance.	2*
Teachers' expectation	Graber, 2010	poverty	Entire population of mainstream 9-12 public high schools in a mid-west state, correlational study	Student achievement (math scores)	Attendance (more) and teacher quality were predictive of math student achievement in high poverty school setting.	3*
Teachers' expectation	Whitehead, 2007	SES, gender, ethnicity	ELS (2002), US, 10th grade sample, secondary data analysis: multiple linear regression and correlation	Academic performance, discipline, student perceptions	Student's relationships with teacher and students feelings regarding teacher sensitivity are significant predictors of academic achievement.	4*
Teachers' expectation	Gregory, 2013	SES	Longitudinal design (4 years); ELS 2002-2006, cross-classified multilevel modeling, n=15,000 10th grade students	Postsecondary education status	1.Positive expectations are additive and promotive irrespective of student risk status 2.Teacher expectations are protective for low income students	4*

Teachers' expectation	Sorhagen, 2013	Poverty	Prospective longitudinal design, 1364 families	Students' high school academic performance	Teacher's expectations have implications for understanding the complexities of self-fulfilling prophecies and for understanding achievement gap between disadvantaged and advantaged students	3*
Teachers' expectations	Strambler, 2010	Ethnic minority status	High poverty urban elementary school in northern California, administration of 15-item student questionnaires, n=111	Standardised maths test scores for achievement (psychological engagement mediated academic achievement)	Highlights the importance of close student-teacher interactions in the link between psychological disengagement from learning and achievement among ethnic minority children	2*
School contextual factors	Vaz, 2014	SES, gender, disability	Cohort study using prospective longitudinal design, n=395 transition age pupils	Academic competence (AC)	1. Personal background factors account for majority of the variability in post-transition AC 2. Potential opportunity for schools to provide support to disadvantaged students before the transition to secondary school, as they continue to be at a disadvantage afterwards.	3*

School contextual factors	Johnson-Brown, 2014	SES	11th grade students in all schools in counties of West Virginia. School size measured by student enrolment, family SES by eligibility for free and/or reduced lunch, rural/urban location by the codes assigned by the Economic Research Service (ERS). ANOVA, post hoc analysis	scores of mastery or better on the WESTEST for the 2010-2011 school year	1. Students in larger schools obtain better results. 2. Students from higher family SES perform better. 3. Students in rural schools have a poorer performance than those in urban or sub-urban schools	3*
School contextual factors	AliMohamed, 2011	Poverty	Common Core of Data (for school enrollment) and the South Carolina State Department of Education (school dropout) for 2004–05 and 2005–06 school years, n=200 matched high schools	Student achievement measured in terms of students' passage rate on HSAP tests, and graduation rates	Dropout and graduation rates of lower SES pupils are impacted by schools size: small-sized schools have lower dropout rates as opposed to large schools	2*
School contextual factors	Smith, 2008 (full-text not available)	poverty	Correlational research design, n=25 low and 44 high poverty schools	Student achievement in tests	District climate impacts school climate and school climate impacts student achievement.	1*
Futility culture	Pasztor, 2008	Children of immigrant/guest workers	Exploratory analysis, PISA 2003 maths achievement of 15 year olds	Maths achievement	Institutional factors can have an impact on school related integration – adding another	3*

					layer of disadvantage on children of immigrants	
Futility culture	Agirdag, 2012	Ethnicity, poverty, immigrant status	Multilevel analyses based on a survey of n=2845 pupils (10-12 years) in 68 Flemish school	Pupil achievement	Pupils' sense of futility and schools' futility culture explains higher proportion of immigrant and working-class pupils in a school is associated with lower maths achievement in both immigrant and native Belgian pupils.	4*
Dietary needs & habits	Belachew, 2011	poverty	5year longitudinal family studies in SW Ethiopia, Regression analysis, N=2009, 13-17 year olds	Educational attainment: highest grade attained	Adolescent and household food insecurity is positively correlated with school absenteeism and lower educational attainment.	4*
Dietary needs & habits	Doku, 2013	SES	Survey administration, southern Ghana, West Africa, logistic regression analyses, n=1195, 12-18 year olds	School performance	Interventions are needed to improve breakfast, fruit and vegetable intake and to increase physical activity to prevent degenerative diseases among Ghana adolescents.	4*

Dietary needs & habits	Tobin, 2013	Poor nutrition	Secondary data from the Food Consumption Questionnaire administered as part of the nationally representative ECLS-K Cohort. Regression analysis using propensity score matching examines relationship between students' reported fast-food consumption and their maths test scores, n=12000, 5th graders	Maths test scores	Relationship between poor nutrition and test scores are negative, schools should consider policies that support students' healthy eating.	4*
Biological factors	Malacova, 2008	Non-aboriginal status	Multilevel approach, population data, W Australia, 8year olds, grade 8 between 1999-2005	Numeracy attainment in nation-wide test	Term birth, increased growth in head circumference and length are key birth characteristics associated with higher numeracy scores among disadvantaged children. Being born first puts disadvantaged children of single mothers in a better position.	4*
Perceived discrimination	Borsato, 2008	Race/ ethnicity	Cross-sectional design, students asked to complete an anonymous questionnaire n=	Academic & psychosocial outcomes,	Perceived discrimination (by peer and/or adults) is a risk factor for psychosocial,	3*

			409 students (96 Asian Americans, 126 Latinos, and 187 Whites) attending 7th and 8th grade at a public junior-high school located in Northern California.		academic outcomes (grades), depression, physical aggression, delinquency, drug use. A positive connection to one's racial/ethnic group is a resilience factor only for depressive symptoms and academic motivation.	
Principal support	Tindle, 2012	SES: eligibility for free/reduced price lunch	N=34schools, all teachers and students of these schools were administered surveys	Student achievement in high schools (Biology & Maths)	SES positive correlates with all measures of student achievement. 1. Principal support has two dimensions; expressive support and instrumental support. Only expressive support was found to have a significant positive relationship with organizational citizenship behavior. 2. OCB correlates to science achievement hence principal support could raise science achievement.	1*

Negative emotionality	Ayoub, 2009	1.Poverty, 2.Maternal education less than high school	Prospective longitudinal design, secondary data analysis of national datasets, n=3001, 1-3 year olds	Cognitive ability	1. EHS has protective and/or promoter effects on children's cognitive skills performance	4*
Negative emotionality	Neal, 2009	Parental incarceration	Quasi-experiment, cross-sectional survey for primary and secondary school data, convenience sample of self-selected participants given incentives for participation, n=174, 6-16 years	Maths test performances	Parental incarceration puts children at high risk; effective intervention programmes need to be formulated for these students.	3*
High risk behaviour	Tobler, 2011	SES	longitudinal group-randomized controlled trial of an alcohol preventive intervention for racial/ethnic minority urban youth (Project Northland Chicago, PNC), repeated cross-sectional surveys, n=2621	High-risk behaviour	Inner city schools can break the links between social disadvantage, drug use and delinquency through value-added education.	4*
Emotional factors - negative emotionality	Basch, 2011	Urban minority status	Literature review	Academic achievement, educational outcomes	1. Aggression and violence hamper learning through causal pathways like cognition, school	2*

					connectedness, absenteeism and disruptive classroom behaviour. 2. Implementing evidence-based school policies and programs to reduce aggression and violence must be a high priority to help close the achievement gap.	
Emotional intelligence	Nelson, 2009 (Thesis)	At-risk students	Correlational study, n=142, 11th grade students	Academic achievement	Emotional intelligence plays an important role in predicting academic achievement for all students but more for at-risk students. Incorporation of instructional strategies that develop emotional intelligence can promote social change and academic success.	2*
Risk factors	Rouse, 2011	Multiple risk factors that threaten child development.	Grade 3 cohort in a large, urban public school system, N=10,000	Academic and behavioural outcomes	1. Low maternal education is strongly associated with third grade reading and math achievement, attendance, and school suspensions. 2. Classroom behavior is significantly influenced by familial and social risks (teen	4*

					mother, low maternal education, homelessness, and maltreatment), but not biological risks (preterm or low birth weight and high lead).	
Neuropsychological factors	Waber, 2006	SES	Administration of clinical neuropsychological tests and behavioral questionnaires and scores on state mandated standards-based testing, n=91 fifth grade children from low-income urban schools	Academic achievement in maths	Efforts to improve children's academic achievement should consider developmental factors as well as curricular content.	2*

Appendix B Classification of all thirty-four research reports reviewed by study design

Causal	Correlational	Mixed methods	Descriptive
Ayoub, 2009	Agirdag, 2012	Alsace, 2009	Basch, 2011 Literature review which tries to outline causal pathways from existing research reports
	AliMohamed, 2011		
	Belachew, 2011		
	Borsato, 2008		
	Bryant, 2007		
	Doku, 2013		
	Graber, 2010		
Brown, 2014	Greene, 2009		
	Greenman, 2011		
	Gregory, 2013		
	Hanson, 2011		
	Malacova, 2008		
	Neal, 2009		
	Nelson, 2010		
Nonoyama, 2005	Pasztor, 2008		
	Rouse, 2011		
	Smith, 2008		
	Sorhagen, 2013		
	Speight, 2010		
	Strambler, 2010		
	Tindle, 2012		
Pinder, 2010	Tobin, 2013		
	Tobler, 2011		
	Vaz, 2014		
	Waber, 2006		
	Westerlund, 2013		
	Whitehead, 2007		
	Wildhagen, 2009		

Appendix C Number of students achieving A*-C in maths & total entries

Sub-groups	Count	Intervention group					Comparator
		Ever	Longitudinal	KS4 only	KS3 only	Staggered	
Ethnic minorities	%	71	72	57	75	71	71
	Achieved	9210	4464	255	1211	3280	62033
	Entries	12946	6238	449	1617	4642	87674
White	%	71	72	54	73	68	69
	Achieved	36777	26250	630	7710	2187	277447
	Entries	51533	36531	1176	10597	3229	404427
EAL speakers	%	70	72	54	73	69	70
	Achieved	6303	2936	228	680	2459	42461
	Entries	9017	4067	426	932	3592	60880
Native English	%	72	72	55	73	70	69
	Achieved	39908	27968	659	8266	3015	299668
	Entries	55786	38978	1202	11322	4284	434938
FSM	%	51	50	34	49	60	48
	Achieved	4760	2837	118	636	1169	33742
	Entries	9270	5658	352	1312	1948	71067
Non-FSM	%	75	75	60	76	73	73
	Achieved	41563	28099	775	8351	4338	309187
	Entries	55700	37429	1286	11001	5984	426012
SEN	%	39	39	26	38	43	35
	Achieved	5225	3406	89	882	848	38856
	Entries	13443	8777	341	2342	1983	112430
Non-SEN	%	80	80	62	81	78	79
	Achieved	41098	27530	804	8105	4659	304073
	Entries	51527	34310	1297	9971	5949	384649

Appendix D Number of FSM pupils taking up AS/A levels in STEM subjects

Subject	Numbers cashing in AS level					Numbers progressing to A level				
	KS3	KS4	L	S	C	KS3	KS4	L	S	C
Biology	10	8	50	49	741	32	4	127	128	1869
Chemistry	7	4	40	46	650	24	3	108	109	1668
Physics	3	2	21	26	343	12	2	69	41	835
Environ. Sc.	0	0	0	0	0	0	0	0	0	23
Geology	0	0	1	1	13	0	0	2	0	36
Computer stud.	1	2	9	2	84	1	2	14	1	149
Maths	17	7	52	68	920	27	6	169	143	2233
Statistics	0	0	1	1	17	0	0	0	0	0
Maths further	1	0	10	11	193	2	0	21	13	272
From amongst	**1309**	**352**	**5657**	**1945**	**71026**	**1309**	**352**	**5657**	**1945**	**71026**

Appendix E Number of Black pupils taking up AS/A levels in STEM subjects

Subject	Numbers cashing in AS level					Numbers progressing to A level				
	KS3	KS4	L	S	C	KS3	KS4	L	S	C
Biology	8	8	49	43	518	26	3	138	141	1506
Chemistry	6	5	40	35	483	19	7	115	136	1410
Physics	3	3	13	25	220	10	4	27	46	502
Environ. Sc.	0	0	0	0	0	0	0	1	0	2
Geology	0	0	0	0	2	0	0	0	0	11
Computer stud.	0	1	1	4	42	1	1	7	2	70
Maths	7	5	49	68	760	27	12	125	172	1762
Statistics	0	0	1	1	5	0	0	0	0	0
Maths further	1	1	4	8	97	0	0	6	12	131
From amongst	278	130	1499	1960	22356	278	130	1499	1960	22356

Appendix F

Ethical approval Durham University

From: SMITH J.C.
Sent: 15 January 2014 14:35
To: BANERJEE P.A.
Cc: GORARD S.A.C.; TORGERSON C.J.; ED-PGRSTUDENTS E.
Subject: RE: Ethical Review

Dear Pallavi
I am pleased to inform you that your application for ethical approval has been granted by the School of Education Ethics Committee in respect of 'Impact assessment of STEM Initiatives in widening participation'.

May we take this opportunity to wish you good luck with your research.

Sheena Smith
Research Office
School of Education
Durham University

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I work part time Monday - Thursday