EDUCATION

WHEN STEM? A QUESTION OF AGE.

Institution of
MECHANICAL
ENGINEERS

Improving the world through engineering

The Institution would like to thank the Ranger Engineering Education Foundation for supporting the WHEN STEM Education Forum event and the Royal Academy of Engineering for funding to help produce and disseminate this report.

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EXECUTIVE SUMMARY

The engineering community spends considerable resources on inspiring and encouraging the next generation of engineers. In doing so it enhances existing STEM education, by dynamically and informatively complementing the STEM curricula.

Currently, the proportion of resources applied increases as children progress through their school education. However, this report seeks to ascertain whether this engagement could produce a greater and longer-lasting effect on the STEM perceptions, interests, subject choices and career decisions of young people. By analysing research outcomes and by seeking the views of experts in this field at the WHEN STEM? forum in January 2010, and conducting post-event interviews, we have identified a range of key factors that affect the motivation of young people to STEM. Importantly, we have identified how these factors and children's motivation can be influenced by age.

There is a marked difference in approach between the teaching of science and mathematics at primary and secondary schools. Typically children of primary school age exhibit a natural enthusiasm for learning and for exploring their world; they demonstrate broadly positive attitudes to STEM subjects. In stark contrast to this, there is a sharp decline in positive attitudes to science and mathematics during the early years of secondary school. Young people, particularly boys, generally expect secondary school science to be exciting (eg 'explosive') but often perceive it to be dry and unrelated to real life. The more transmissive educational approach that young people experience leaves less opportunity for discussion, self-directed learning or practical work. Students at early secondary school who are left uninspired and unenthused by the work undertaken in STEM subjects, lose the momentum in maths and science created at primary. This can disengage them from STEM before the age of 14.

This suggests that the 11–14 age group (Years 7, 8 and 9) is a crucial period for engaging and inspiring students in STEM subjects; this is particularly important as this period influences GCSE subject choice, a decision taken in Year 9.

As students make subject decisions for GCSE and A-level, they can unconsciously pass decision points, beyond which careers in STEM are no longer an option to them. Decisions they make or that are made by others, such as the level for which they are entered in GCSE mathematics or which GCSE optional subjects they select, can preclude them following a STEM pathway.

Engineering is often not identified as a career option until the latter stages of the education process. Awareness at primary school age of STEM careers in general and engineering careers in particular is low. Evidence suggests that engaging young people before they reach secondary school, has the potential to create more positive attitudes towards STEM. Broad choices about whether to follow STEM-related career paths are often made between the ages of 11 and 14. The 7–11 age range is, therefore, a formative period during which positive awareness of broad STEM career paths could be introduced. Of all the STEM occupations, engineering has the lowest proportion of females, and therefore engaging girls under the age of 11 is likely to have a disproportionately positive effect on girls' attitudes to STEM subjects and engineering as a career.

The engineering community should:

1. **Allocate a greater proportion of its resources to influencing the 11–14 age group**. This is a key period during which children's interest in STEM often falls away; this influences their future decisions about whether to study STEM subjects and pursue STEM careers.
2. **Work with the Government and schools to investigate ways that engineering can add value to the curriculum**. Activities that support these early secondary school years should link theory with practical activity and illustrate the real-world relevance of the maths and science curricula.

Government should:

1. **Promote non-transmissive teaching for STEM subjects in both primary and early secondary schools** that encourages *interactive* learning. Teacher training should prepare secondary school teachers to understand how to build on primary school learning and experiences to create a positive response to, and progressive learning in, STEM subjects.

INTRODUCTION

While the debate surrounding existing shortages of engineers in the UK continues, a shortage in the coming years is commonly predicted. With contributory demand-side factors such as the threat of climate change, rapid population growth and the need for major infrastructure investments, added pressure is being put on a workforce already stretched to its limits.

Engineers will undoubtedly play a central role in addressing these and other issues of the future, and so ensuring a long-term adequate supply of engineers is vital for the continued and sustainable health, wealth and security of the UK.

In order to meet the predicted demand for engineers in the future, we need to ensure that sufficient young people elect to study STEM (science, technology, engineering and mathematics) subjects, and through these progress into STEM relevant occupations. While the Institution's focus is on the E (engineering) in the STEM acronym, the science, technology and mathematics elements are all integral to a student's educational path into an engineering career. The engineering community therefore seeks to promote and support STEM in its broadest sense at all stages of education.

ENGAGEMENT AND ENHANCEMENT

The engineering community expends considerable resources trying to engage with and enhance the STEM-relevant education of the next generation of potential engineers. Engineering institutions, independent charitable organisations and employers all make considerable efforts to engage young people and to illustrate the interest of, and opportunities provided by, STEM subjects.

This resource is applied across a range of ages but, broadly, increases as the age of the young people engaged increases. For example, an analysis of the range of activities available and promoted through the STEM Directories (as at December 2009) shows that 65% of the listed activities[1] are listed as being for those aged over 11 years, ie secondary school age or older.

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DECISIONS MADE BEFORE GCSE CAN IRREVERSIBLY DETERMINE FUTURE CAREER OPPORTUNITIES.

A QUESTION OF AGE

If the engineering community applied a greater proportion of its resources on a specific age range, would it have a more beneficial and longer-lasting effect on the perceptions, interests, study choices and career decisions of young people? If so, what is that age range and how should we use our finite resource to best effect? This is the question this report seeks to answer. The report provides some background data on the UK education system and then analyses research data and informed expert opinion, draws conclusions and makes recommendations.

In January 2010 the Institution held an Education Forum, WHEN STEM?, to assess the extent to which age is a factor in attitudes and aspiration towards subjects and careers. The view was that this is an important issue which has a significant impact, but that it is not sufficiently understood. The Institution, therefore, undertook a process of research and consultation with a wider rage of subject experts; this process was guided by the issues raised at WHEN STEM?

Our conclusions are shaped by data and expert opinion through both processes. The recommendations are our own and do not necessarily represent the views of any particular individual consulted.

Annex A lists the WHEN STEM? attendees and those who contributed as part of the post-event research. We are grateful for the contributions of all those listed; in particular we are grateful for the research carried out by Dr Ruth Graham.

The Institution would also like to thank the Ranger Engineering Education Foundation (REEF) for its contribution to the WHEN STEM? Event, and the Royal Academy of Engineering for help in disseminating this report.

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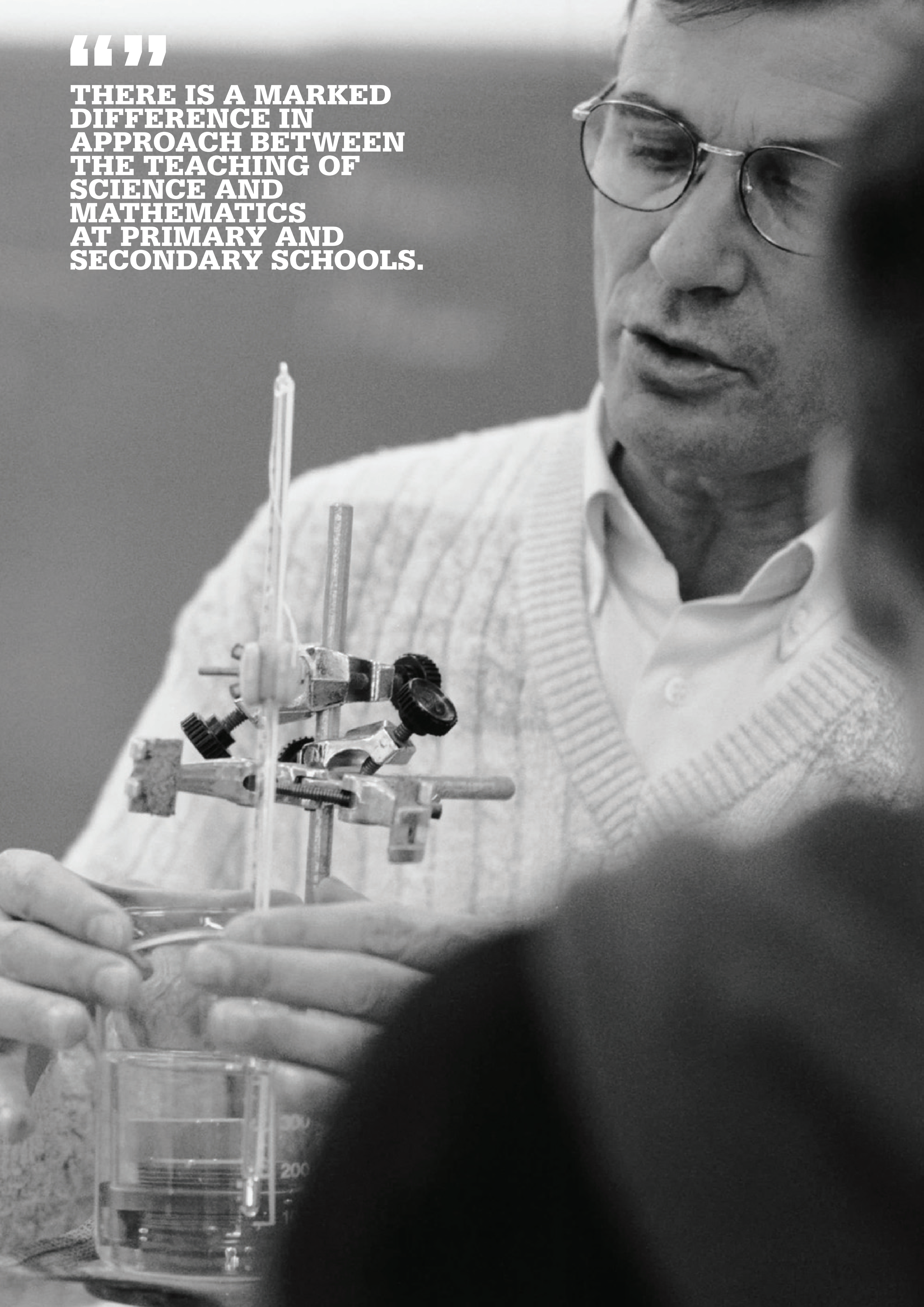
THERE IS A MARKED DIFFERENCE IN APPROACH BETWEEN THE TEACHING OF SCIENCE AND MATHEMATICS AT PRIMARY AND SECONDARY SCHOOLS.



At a young age, children enter the education system and progress through a series of phases and transition points. When they leave they move into either work, training, an additional period of education, or a combination of these. They will have been through a formative period of personal development during which they will have been exposed to a range of social influences and educational experiences. At the same time they will have passed through key gateways; the decisions they make can irreversibly determine their future life and career opportunities.

The UK school system can be divided into three broad periods: up to age 11 (primary), 11 to 16 (secondary) and 16 to 18 (sixth form or further education). School structures and examination systems vary depending on a range of factors such as whether the school is in England, Scotland, Wales or Northern Ireland.

During these stages, children's exposure to STEM-related learning varies; however, the National Curriculum requires that mathematics, science and ICT are all provided up to the age of 16, while design and technology is provided up to the age of 14.

Age	Year	Key Stage
3–5	Reception	1
5, 6	1	
6, 7	2	
7, 8	3	2
8, 9	4	
9, 10	5	
10, 11	6	
11, 12	7	3
12, 13	8	
13, 14	9	
14, 15	10	4
15, 16	11	
16, 17	12	
17, 18	13	

Table 1: Relationships between age, year group and key stages

PRIMARY

There are three stages within the primary years; education providers are required to follow the curriculum framework appropriate to each stage and assess children in relation to standardised learning goals.

The stages are[2]:

Early Years Foundation Stage (ages 3–5):	This has six areas of learning and development that are given equal coverage. The maths area is Problem-solving, Reasoning and Numeracy. The science area makes up part of Knowledge and Understanding of the World.
Key Stage 1: and Key Stage 2:	These follow the 12 subject-based frameworks, with maths and science both core subjects. It is usual for children at KS1 and KS2 to receive one hour of numeracy teaching every day and two hours of science per week. Methods of curriculum delivery are largely decided by individual teachers and through school policy. The current curriculum is widely considered to be over-prescribed and over-loaded.

Following the Primary Curriculum Review, the new curriculum for 2011 has been outlined[3]. The three broad aims of the secondary school curriculum (successful learners, confident individuals and responsible citizens) now also apply to the primary curriculum. To achieve these aims, literacy, numeracy, information and communication technology (ICT) skills, together with the associated personal development and interpersonal skills, form the basis of the new curriculum.

Delivery of the curriculum is achieved through six subject-related integrated 'areas of learning'[4]; there are no longer discrete core subjects. The areas of learning include Mathematical Understanding and Scientific and Technological Understanding.

SECONDARY AND SIXTH FORM/ FURTHER EDUCATION

The first major gateway children reach, is their decision about which GCSE (or equivalent) subjects they wish to study during Key Stage 3; this decision is made during the year preceding the start of their GCSE or equivalent course.

Following this, they choose whether to continue with A-levels or equivalent, and if so which subjects, or whether to undertake an occupationally orientated course (often at a Further Education College) or to undertake a programme of work-based learning such as an apprenticeship.

Many of these choices are, however, not 'free' choices. Choice can be limited by practical issues, such as previous performance in subjects or availability of courses (due to school policy or teacher shortages, for example). So children can find themselves in a position where they cannot choose to follow their preferred route due to external barriers; critically these barriers may not be apparent until the gateway has been passed.

GCSE

All pupils are required to study mathematics and science at Key Stage 3. In 2009 about 755,000 students achieved a mathematics GCSE pass; 30.9% of these were at grade B or higher. The picture for science is complicated, however, due to the fact that there is a 'choice' of whether to take:

- Core Science: covers physics, chemistry and biology and is timetabled as **one GCSE**.
- Double Science: covers physics, chemistry and biology and is timetabled as **two GCSEs**.
- Triple Science: separate study of physics, chemistry and biology and is usually timetabled as **two GCSEs**.

The third choice is often not exercised by pupils, as many schools do not offer Triple Science (a key reason for this is the lack of specialist science teachers). Triple Science availability is increasing, however; in 2009 just over 40% of maintained schools offered Triple Science, up from below 20% in 2002[5].

In 2009 just over 493,000 pupils achieved a GCSE pass in science (ie Single Science) with slightly fewer than 400,000 doing the same in Additional Science (ie making up their Single Science to Double Science).

By way of comparison, the most common individual STEM subjects uptake is shown in **Table 2**.

Analysis by the Department for Children, Schools and Families (DCSF) indicates that 19% of pupils studying Double Science progress on to take one or more science A-levels, compared to 45% of Triple Science pupils who progress to take one or more science A-levels[5].

	Entries	% Achieved grade B or higher	% of UK GCSE Double Science and Triple Science passes combined (684,330)
Physics	91,179	75.4%	13.4%
Chemistry	92,246	77.2%	13.5%
Biology	100,905	74.7%	14.8%

Table 2: 2009 GCSE uptake for STEM subjects
Source: Entries data from JCQ; analysis by IMechE

A-LEVELS

A-level uptake in the key STEM subjects of mathematics, physics, chemistry and biology has essentially remained unchanged between 1985 and 2009 at about 200,000, despite short-term variations. This figure accounts for just over 23% of the overall A-level entries for 2009 (846,977[6]); the proportion of the total 2009 entries accounted for by mathematics and science A-levels are shown in **Table 3**.

Mathematics is generally considered to have performed relatively well in the last few years, but it has in fact returned to about the same level of uptake as in 1985. However, the trend is broadly upwards and this is good news. Of concern to engineering, however, is the decline in the uptake of physics A-level, which now stands at 63% of the level in 1985. The only real STEM A-level 'winner' since 1985 is biology, with a 2009 uptake 137% above that of 1985.

	Entries	**Percentage of all UK A-level entries**
Mathematics	72,475	8.56%
Physics	29,436	3.48%
Chemistry	42,491	5.02%
Biology	55,485	6.55%

Table 3: Proportion of 2009 A-level entries accounted for by mathematics and sciences

Source: Entries data from JCQ; analysis by IMechE

KEY ISSUES

INTRODUCTION

In this section we provide an overview of current knowledge on the factors that influence continuation in STEM in general, and engineering specifically. In particular we consider how these vary according to age. We bring together key research literature and input from experts in the field, captured both at the WHEN STEM? forum and through informal telephone interviews held subsequently with targeted individuals.

Between 1999–2000 and 2007–08, total undergraduate student numbers increased from 888,034 to 1,051,911. During the same period, numbers of engineering and technology students dropped from 74,176 to 71,396.

Source: Strategically Important and Vulnerable Subjects; the HEFCE advisory group's 2009 report

THE IMPORTANCE OF MATHEMATICS AND SCIENCE

Awareness of engineering as a possible career option for children in the UK is generally very low, particularly among younger groups. The term 'engineering' does not appear among the subjects to which they are exposed. Careers in engineering, therefore, typically build on early engagement and progression in science and mathematics. An influential US study published in 2006[7] highlighted the clear connection between early interest in science, achievement in mathematics (at age 13–14) and persistence in engineering to degree level.

Much of the evidence discussed in this section, therefore, focuses on engagement and progression in science and mathematics at school level as a precondition for a career path in engineering.

Children's engagement, achievement and persistence in STEM have been the focus of a significant body of research. It paints a highly complex picture, where a child's desire to follow a career in STEM is influenced by a wide range of interrelated factors. For example, research has shown that 'intrinsic self-interest' can motivate children to persist with STEM, despite finding school science boring[8]. Conversely, negative associations with the identities of scientists lead many children not to continue with STEM study, despite seeing science as important.

It is also clear that perceptions of and engagement with STEM change as children get older, as do the factors supporting or hindering progression in these subjects.

Our research considered attitudes and aspirations related to STEM, factors that support and improve engagement and persistence, and key points at which disengagement occurs. Where possible we looked at how each of these varies with age.

A recent review of the literature[10] identified the three principal factors that influence children's engagement with science as *gender, the quality of teaching and pre-adolescent experiences*. These themes are strongly evident in each of the sections presented below.

ATTITUDES AND ASPIRATIONS IN STEM

Children's attitudes towards and engagement in STEM vary considerably as they progress through primary and secondary schools. Research in the field and the experts consulted for this report both note that overall interest in science changes with age. While the picture is complex, the evidence points to three distinct age-related phases:

1. **Ages 4–10**: throughout early primary schooling and up to the ages of 10–11, attitudes towards science are generally very positive with little gender or socio-economic differences. For example, a survey of UK primary school teachers[11] identified the majority responding positively to the statement "Children love learning science" (89%) and negatively to the statement "Girls are less interested than boys in science" (80%), with no variation in response by the age group taught.
2. **Ages 10–14**: between the ages of 10–11 and 14, there is a rapid drop-off in interest in science, with a particularly sharp decline for girls. For example, a study of 12- to 16-year-olds in England[12] identified a sharp decline in positive attitudes towards science between the ages of 12 and 14, with the female students responding more negatively than their male peers. To the statement "It would be good to have a job as a scientist" 41% of 11-year-olds but only 10% of 13-year-olds responded positively.
3. **Age 14+**: the attitudes held towards science at 14 are largely carried forward into adult life. By this age, the gender differences are very evident, with girls holding particularly negative attitudes towards the physical sciences. For example, a study looking at the attitudes to science held by 14- to 15-year-old students in England[11] found that girls were more likely to identify school science as difficult, less likely to identify school science as interesting, and less likely to consider a career in science or technology than their male counterparts.

Between 2005 and 2009, the proportion of A-level entrants who were female rose from 30.6% to 38.1% in mathematics, 22.0% to 22.2% for physics and 28.6% to 31.3% for further mathematics.

Source: UK Resource Centre for Women in Science, Engineering and Technology.

The research evidence indicates that children make broad career choices at an early stage in their secondary schooling. A recent DCFS study[13] looking at children's education and career choices identified that 85% of Year 7 children (aged 11–12) felt that they knew what career they wished to follow and, of this group, 65% have held this ambition for two years or more. Evidence from the literature and feedback from the experts consulted also strongly suggests that decisions to follow careers in STEM (or not) are largely formed by the age of 14. For example, in 2004, the Royal Society conducted a web-based survey of 1,141 SET (science, engineering and technology) practitioners from the age of 24 through to post-retirement. For the majority of survey respondents (63%), their decision to follow a STEM career was made before the age of 14[14].

The experts consulted also pointed to a strong link between *early interest* in science and *continuing* in STEM education, particularly within the physical sciences and engineering. This finding is clearly demonstrated by a major US study published in 2006[5] seeking to understand how career aspirations in science translate into actual career progression in this field. Using data from the National Educational Longitudinal Study (NELS) from 1988 and 2000, the study tracked 3,359 individuals and analysed the impact of career expectation in science (aged 13–14) on the likelihood of progression to a degree in a science-related field. The results indicated that children who, at age 13–14, expected to enter a science-related career by the age of 30, were 3.4 times more likely to obtain a degree in physical sciences or engineering than children without such aspirations. In a more recent study by the same research team[15], interviews were held with 116 graduate students and scientists to understand the "timing, source and nature of their earliest interest in science". In 65% of those interviewed, their initial interest in science was sparked before the age of 11.

In light of this *early* formation of career interests in STEM, it is particularly interesting to note both the low awareness of *engineering* among the young and the negative correlation between age and perceptions of engineering. For example, a recent study of UK perceptions of engineering[16] found that a positive orientation to engineering declined with age, with only 12% of 11- to 16-year-olds having some knowledge about what engineers do and 49% of 7- to 11-year-olds perceiving engineering as 'boring'. Another UK study[17] identified that "younger people in particular were found to have a much more limited initial understanding of engineering in comparison to other groups". For many children therefore, future career aspirations are being formed before they have developed any real concept of engineering as a future option. This point was strongly underlined by the feedback gathered from experts in the field.

The last decade has seen an increasing emphasis in the research literature on children's identity and how this shapes their attitudes to and progression in STEM subjects. The research identifies a clear distinction between children feeling that *science is important/exciting* and actually *wanting to be a scientist* because a career in this field does not align with the sort of person that they want to be. For example, ongoing research at King's College London[18] highlights this division between enjoying 'doing' science and wanting to 'be' a scientist, arguing that this "disjuncture is particularly likely to occur where science, as an identity discourse, is experienced as clashing with popular hegemonic forms of masculinity and femininity". Early results from this study underline the highly gendered identities associated with both school science and science as a career. It is interesting to note that these conclusions were drawn from interviews with 10-year-old children, where gender distinctions in attitudes to science were already apparent.

Results from the ROSE (Relevance of Science Education) survey of international attitudes to science and technology among 15- to 16-year-old children[19] suggest that the negative associations with science identities is not just a UK issue. The survey found that, although young people across the world view science and technology as "important for society", the general response to the statement "I would like to be a scientist" was negative, particularly among children in more-developed countries. The study's authors suggest that, rather than "What do you want to be when you grow up?", a more meaningful question would be "Who do you want to be when you grow up?", as children in the more-developed countries select career choices that align with their own sense of identity – "young people, especially girls, do not want to have the identity that is seen to be connected with being a physicist or an engineer".

These findings suggest that simply increasing a child's *enjoyment* of science may not necessarily increase their likelihood of wanting to *become* a scientist or engineer. This study did, however, identify strong aspirations among young people to follow careers that align with their values, in areas such as creativity, working with others or helping people.

However, science and engineering are often identified by children (particularly those younger groups) as *uncreative* disciplines[16], with little opportunity for autonomy, discussion and design. Indeed, a recent study of US high school children and college students (ages 16–24) identified that "students perceive science and creativity to be essentially opposite", where a career containing one cannot contain the other[20]. These findings echoed points made by the experts consulted, who saw a strong mismatch between children's aspirations to work in a creative, inspiring and supportive environment, and their views of an engineering career.

For many children, there is a also disconnection between *real science*, which is seen as an important vehicle for solving some of the world's challenges, and *school science*, which is often seen as dry, difficult and boring. For example, during her study of post-16 choices in science among high-achieving students, Cleaves (2005) highlighted widespread negative attitudes towards school science, which was seen to be irrelevant, overloaded with content and difficult. Despite these attitudes, however, those students who chose to continue with science were "distinguished by their deeper appreciation of what one might expect in a science career, despite evidence that such understanding had not been acquired in the science classroom". For many children, particularly boys, this intrinsic 'self-interest' in science is the driving force in their persistence in STEM. A study of graduate students and SET professionals found that 57% of men identified the source of their initial interest in science as being *self*[15]. Interestingly, the study also revealed that, of those whose aspirations in science were formed early, the sources of interest were more likely to be identified as an *intrinsic self-interest*. This finding held true for both men and women.

AGES 11 TO 14 – PRIMARY TO SECONDARY SCHOOL TRANSITION

Studies conducted in 2001/02 and 2005/06[21] illustrate a sharp decline in children's positive attitudes to both science and mathematics over the period of transfer between primary and secondary school, which was not replicated in subjects such as English. Children, who typically enjoy primary science, expect secondary science to be 'even more exciting' and often find themselves disappointed. In particular, boys expect secondary science to be *dangerous* and *explosive*, which is not borne out in reality[18].

This decline in interest, or disengagement with STEM, is illustrated clearly in a recent unpublished US survey of children's attitudes to science careers, undertaken by Adam Maltese and Robert Tai. The study tracked two cohorts of children from five states across the USA (2,200 in total) aged 12–14. Outlined in **Figure 1** are the responses given, on a five-point scale, to the statement "Science is something I enjoy very much." The figure presents the students' responses to the statement at six-monthly intervals over three school years. A decline can be seen in positive responses across this age period, particularly among the female students.

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ENSURING A LONG-TERM SUPPLY OF ENGINEERS IS VITAL FOR THE HEALTH, WEALTH AND SECURITY OF THE UK.

Many of the experts we consulted commented that, in comparison to primary science, science teaching at secondary school is often characterised as being dry and unrelated to real-life experiences, with a more transmissive educational approach and less opportunity for discussion, self-directed learning or practical work. All these factors can be seen to contribute to a disengagement from science.

On entering Year 7, children in many secondary schools are told that they will be making a ‘fresh start’ in science, with the assumption either that they ‘know nothing’ or that the science learnt at primary school is ‘oversimplified’ or simply ‘wrong’. Many secondary teachers would argue that this approach is necessary where feeder primary schools offer a wide range of approaches to primary science. However, this ‘fresh start’ alienates many children, particularly high-achievers[21].

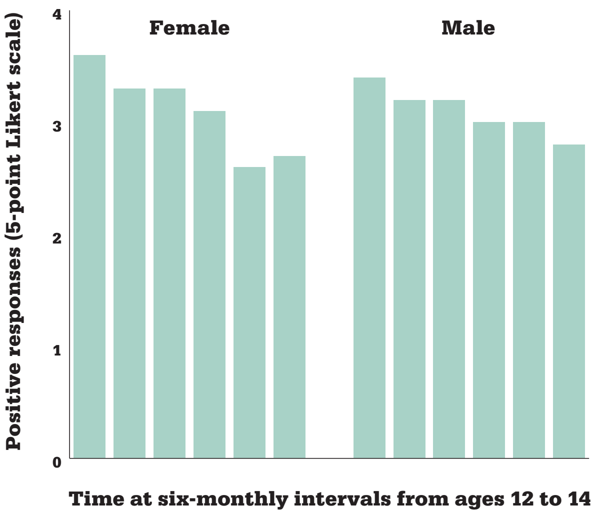


Figure 1: US students’ (ages 12–14) responses over three school years to the statement “Science is something I enjoy very much.”

DECISION POINTS

Children often ‘unconsciously’ pass decision points, typically at ages 14 and 16, beyond which careers in STEM are no longer an option to them.

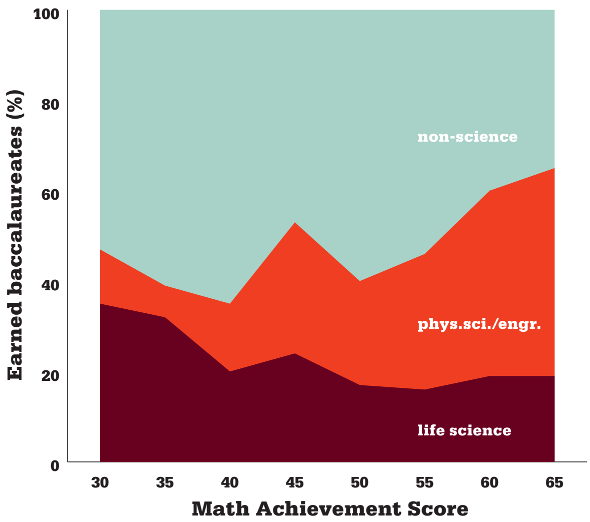
Many experts consulted in the preparation of this report, referred to children looking back on decisions made by themselves or their school, such as the level for which they are entered in GCSE mathematics or which GCSE optional subjects they select, and realising that they are no longer able to follow a STEM pathway. In line with this expert view, a recent study of Bangladeshi girls in London[22] found that many of the interviewees were not aware of the significance of their choices in STEM until after the decision had been made.

FACTORS THAT SUPPORT AND IMPROVE ENGAGEMENT AND PERSISTENCE

Outlined below are some of the key factors that are seen to support and improve engagement/persistence in STEM in general, and engineering in particular.

- A number of studies have highlighted children's enjoyment of the **practical aspects** of science at school[22,11] and how such hands-on activities can engage children with STEM. As Osborne and Collins (2001) note from their focus group study of 16-year-olds "without exception, pupils expressed a greater interest in work that included opportunities for experimentation and investigation". The study also highlighted that, for children who continue in science, a sense of control and autonomy increases the positive impact of such practical experiences. However, opportunities for practical work in science are seen to decrease through schooling[8]. Many of the experts consulted in the preparation of this report (see Annex A) commented that design and technology (D&T) offered a possible vehicle for offering more hands-on opportunities that could be integrated across the various STEM subjects.
- Girls are particularly motivated by **ethical, environmental and 'people' issues** in STEM when choosing careers in science. For example, a study of 704 UK children aged from 11–21 years[23] found that "Girls who would be interested in a job related to science are less interested in technological developments and 'hardware' investment, and are much more focused on ethics and with awareness of the dangers and responsibilities of science." The study, however, also indicated that such themes often had a negative impact on boys' engagement, which indicates that there is not a 'one-size-fits-all' solution to the issues of STEM engagement and progression.
- **Teaching quality** is a major determinant of both success and engagement in school science. A study of SET professionals[15] identified *school* to be the single most significant (52%) source of initial interest in pursuing science among women (among men, this figure was 33%). The significant influence of *teachers* was also underlined in a review of the literature on children's attitudes to science from 2003[24] where the authors concluded that the research provided "strong confirmatory evidence for children's and adults' anecdotal stories about the influence of teachers on students' attitudes to school science and on subject choice". Despite their significant influence on STEM persistence, however, most teachers do not view themselves as qualified to provide careers advice[25].
- **Roles models** can play a valuable role in influencing children towards STEM. For girls, in particular, a close personal connection with these role models was an essential part of their engagement with STEM. A US study into the formation of scientific role models among 13- to 14-year-old girls[26] concluded that "…the girls in our study sought a personal connection of intimacy and care. To them, a role model was someone who cared about them and shared common interest/experiences. It was only after they made connections with scientists that they started to see scientists as possible role models." A number of experts consulted during the preparation of this report also spoke about the important positive influence of parents, particularly among younger children. A study looking at how young people generally (aged 11–12) in the UK make decisions about their future[27] identified *parents* as the most important influence, regardless of social background.
- **Aptitude in mathematics** has been correlated positively with an increased likelihood of progress/continuation in engineering and physical sciences to degree level; see **Figure 2**. This study[7] revealed that, among those children who expected to enter a science-related career, the probability of gaining a degree in engineering and physical sciences was 51% for those children with above-average mathematics achievement scores, compared to 34% for children with average mathematics achievement scores. More recent research conducted by the same group[28] found that students switching into the STEM pipeline at a later stage in their schooling had consistently higher mathematics and science scores than those students who dropped out of the pipeline.

8th graders expecting a science degree



8th graders NOT expecting a science degree

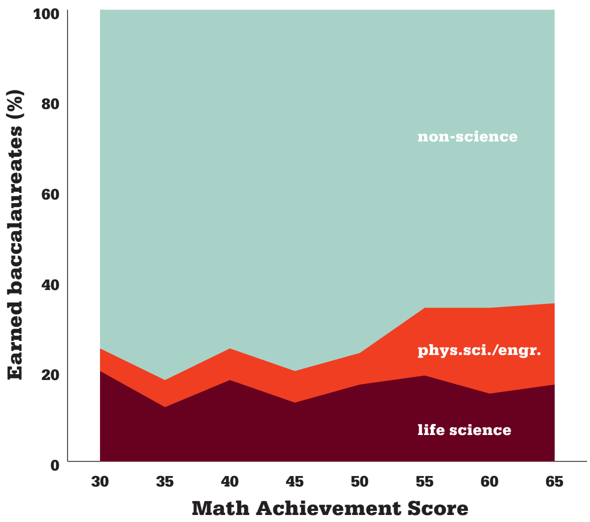


Figure 2: Correlation of mathematics ability with likelihood of achieving a STEM degree, for both 13- to 14-year-olds with and without an expectation of following this path, USA, 2006.

Figure reproduced with lead authors' permission from RH Tai, CQ Liu, AV Maltese and X Fan, (2006). Planning early for careers in science. Science 312: (5777), 1143–1144.

FACTORS AFFECTING ENGAGEMENT AND PERSISTENCE

Outlined below are some of the key experiences and conditions that are seen to hinder engagement and persistence in STEM in general, and engineering in particular. Many of the factors described are interconnected and relate to the pedagogy[29] and overall approach to school science.

- The **transmissive**[30] nature of current UK science education appears to alienate students and often adds to a perception of science as a 'difficult subject' (see below). A number of experts consulted during the preparation of this report identified this pedagogy as a particular trend in UK secondary schools and weaker primary schools. A review of children's experience of school science across three different countries – Sweden, England and Australia – concluded that perceptions of science as a difficult subject stemmed from "frustration associated with passive learning, memorization, or the irrelevance of the content, rather than from any intellectual challenge"31. This issue is also highlighted in a recent Ofsted review of science education in the UK32 where they found that "in many lessons, teachers simply passed on information without any expectation of pupils' direct engagement in the process". Science teaching involving opportunities for discussion, debate and autonomy is seen to have particularly positive impacts on students' engagement.
- Children often do not see the **real-world relevance** of school science, a factor that promotes disengagement. A recent study of primary school science teachers in the UK identified that "…making science more relevant to pupils' experience was considered to be the best way to improve the teaching and learning of primary science"[11].
- **External summative assessment** at school is also seen to have a negative impact on engagement and persistence in STEM. A consultation study looking at science and mathematics secondary education in the UK[33], for example, identified "a strong perception that assessment has become the 'tail that wags the dog' of the education system and that the assessment process has been inadequate in the testing of students' depth of subject knowledge and understanding of key concepts".
- The **recruitment and retention** of science teachers (particularly in physics) is a significant problem in the UK. A study published in 2005 highlighted that about a third of UK physics teachers for the 14–18 age group did not have physics as their main subject of qualification[34]. International evidence indicates that teacher shortages and lack of teacher qualifications both adversely affect pupil performance. For example, a US study[35] identified that the proportion of students scoring 'below basic' on the South Carolina state tests was strongly correlated with both the percentage of teachers on substandard certificates and the percentage of teaching vacancies open for more than nine weeks. Data collected by Ofsted[36] reveals a strong correlation between teaching quality and whether the teacher holds qualifications in the subject. Recent data from the *Graduate Teacher Training Registry*, however, suggests signs of improvement, with a significant recent increase in applications to initial teacher training in STEM subjects. For example, physics applications increased by 43% from 2009 to 2010.
- Many experts consulted in the preparation of this report identified a limited understanding among educationists and policymakers of the need for **cohesion and coherence across STEM subjects** in secondary schools. This lack of integration of STEM across the curriculum is seen to reinforce a view of the STEM subjects as disconnected from the wider school curriculum. They also saw primary school teachers as currently holding insufficient knowledge of mathematics and its application to design and technology (D&T) to be able to bring mathematics and science together. Remedying this is feasible, as primary school teachers teach across the curriculum.

- **Self-efficacy**, or self-confidence in your own ability, in STEM plays an important role in children's perceptions of and persistence in these subjects, particularly for girls. For example, in their study of 16-year-old science pupils in England, Osborne and Collins[37] identified a connection between children's *enjoyment* of and their *levels of achievement* in science. This connection was particularly strong for girls, with science becoming more interesting to them as their self-confidence grew with higher achievement. A study of younger children's attitudes to school subjects (ages 5–11) indicated that gender differences in self-efficacy in the physical sciences became apparent around the age of 9–10[38]. A recent longitudinal study of 160 US engineering undergraduate students has also found that, for those girls who do continue in engineering to degree level, confidence levels are seen to be lower than for their male counterparts[39].
- Science is widely viewed as a 'difficult' subject and the impact of this perception appears to vary with age. The perceived difficulty of science can be a motivating and challenging factor for children of primary school age, but such positive attitudes decline with age[40]. For secondary school children, the perceptions of science as *difficult* often alienate them from science and reduce their self-efficacy, a pattern particularly evident among girls[40]. The identification of STEM as 'difficult subjects' appears to have some basis in fact. An analysis of the 2006 examinations in England[41] concluded that "STEM subjects are not just more difficult on average than the non-sciences, they are actually without exception among the hardest of all A-levels." Evidence from the USA similarly indicates that, even at degree level, science and engineering schools grade more harshly than other discipline areas, which, it suggests, may be the cause of lower retention levels[42].

WHAT CONSTITUTES SUCCESSFUL ENGAGEMENT IN STEM?

Research evidence and feedback from experts in the field indicate that there is not a 'one-size-fits-all' approach to engage children successfully in STEM. A complex range of factors, including age, gender, mathematical ability and their broader schooling experience, all shape a child's view of STEM and their likelihood to continue in these fields.

However, there are factors specific to the approach to STEM interventions/ activities that are also important. For example, a recent study into different STEM interventions[43] concluded that the most effective activities "have a clear focus; a 'real-life context; a competitive element for students; some freedom for students to experiment and think for themselves; practical and interactive aspects to the activities; and a good balance between all STEM subjects".

The experts consulted during the preparation of the report were invited to comment on how best to design a successful engineering 'intervention' and, in particular, how approaches should change with the age of the target audience.

A summary of the feedback is given below.

- In line with children's changing attitudes to and experiences of STEM, recommended interventions/approaches to engineering engagement should be age-specific. For younger children (pre-10), the focus should be on *sparking* interest, through fun, and through energising activities that involve play. For older children (10–14), the focus should be on *sustaining* interest through challenge, competition and collaborative experiences that underline the positive real-world application and the creative and sometimes uncertain nature of engineering.
- Many experts talked about the need for continuous support and encouragement throughout and beyond compulsory schooling for developing and maintaining engagement in STEM. Some of those consulted, however, also identified one particular age group that should be prioritised in STEM intervention. Although there was some small variation in the exact age range, there was a clear agreement that key interventions must initially engage children before positive attitudes to science start to decline (at the age of 10) and continue beyond the point where many children formulate their broad career choices (ages 12–14). A number of experts also commented that a particular priority should be the primary to secondary transfer.
- Results from a study by Maltese and Tai[7] identified mathematical ability as a key determinant of continuation in engineering and physical science. A number of experts commented that, if one were *able to target only one audience* for an engineering intervention activity, directly targeting high-achievers in mathematics would be the most effective way of improving the quantity and quality of those entering the future engineering pipeline. A number of those consulted also pointed to some key characteristics of these 'high-achievers' that should be considered in the design of any intervention activity. This group was identified as being 'easily bored' by school science, and therefore interventions/activities should be intellectually challenging and energising, and portray STEM as worthwhile, challenging and a subject for which there is not always a 'right answer'.

We also note the finding of the evaluation report, Best Programmes for Pre-University Students"[44] that engagement and enrichment schemes could be "extended with a follow-up reflection period to gain maximum understanding for engineering development and higher order thinking and interpersonal skills".

CONCLUSIONS

We have identified a range of key factors that affect the motivation of young people to STEM. Critically, we can see clear evidence that these factors vary *according to age*.

Primary school (up to age 10–11)
Primary school children exhibit low awareness of STEM in general and engineering in particular; this offers an opportunity to raise early awareness of broad career paths at a formative age. Young people are likely to respond more positively when their values (eg creativity, working with others and helping people) are reflected in the roles that engineering and engineers are seen to play in society. It is, therefore, important to understand how the identity and values associated with engineers can be better aligned with those to which young people aspire. This is likely to have a disproportionately greater effect on girls' attitudes.

Typically, up to the age of about 10 or 11 years, young children exhibit a natural enthusiasm for learning and for exploring their world. During this period they demonstrate a broadly positive attitude to STEM subjects.

Evidence suggests that attitudes to STEM formed during early years are typically carried forward into adult life. Creating a more positive attitude towards STEM during formative years may well not only affect the study and career decisions of the children, but provide them with more positive adult attitudes towards STEM. This could, in the longer term, contribute to a greater pro-STEM attitude in the wider community.

Secondary school (from age 11)
At the age of 11 the majority of children transfer from primary to secondary school. During this period a sharp decline occurs in children's attitudes to both science and mathematics, which is not evident in subjects such as English. Compared to primary level, science teaching at secondary school is often thought of as dry and unrelated to real-life; it is often more transmissive. When starting at secondary school most children make a 'fresh start' in science; many, particular high-achievers, find this alienating.

This is a critical period, as it immediately precedes the choice of GCSE subjects. It also therefore offers a unique opportunity to engage children, so that more of them retain a higher level of interest in STEM as they approach a key decision point. It is reasonable to suggest that more positive attitudes to STEM during the ages 11 to 14 could result in greater interest in and demand for double and triple GCSE sciences in school. Similarly it is reasonable to expect this to translate into a greater STEM uptake of A-level and 'vocational' qualifications with consequential impact on apprenticeships and degree applications.

Efforts in this age group are likely to have a disproportionately greater effect on girls' attitudes to STEM; this is particularly relevant to engineering, as it is the STEM occupation that attracts the lowest proportion of female entrants.

We note the evidence that achievement in mathematics offers a way to identify those children most likely to persist in studying STEM subjects and the importance of role models as key influencers.

The Institution therefore believes that the engineering community would have a greater effect when engaging young people if it:

- Better understands the identities and values to which young people aspire and highlights those relevant to engineering. Use of role models is particularly important, as young people often focus on *who* they want to be rather than *what* they want to be. This is a particular issue for girls and so female engineers as role models are vital; this could help address the current gender imbalance in the profession.
- Works with the design and technology community to add value to and use primary school D&T as an opportunity to introduce engineering concepts to younger children.
- Works with the mathematics community to investigate ways in which children between the ages of 11 and 14 with an aptitude for mathematics, can be introduced to engineering as a potential career path that demands and values mathematical ability.
- Creates activities at all ages that provide interest and stimulation to *both* girls and boys.

- Provides activities at all ages that illustrate:
  a) the wide range of subjects embraced by engineering;
  b) how engineering addresses 'real-world' challenges;
  c) how engineering and engineers help people;
  d) how engineering is, above all, a creative activity.
- Provides activities in support of the primary school curriculum (ie up to age 11) which are *hands-on* and designed to stimulate and maintain an existing interest in STEM.
- Engages teachers to help develop a better appreciation of engineering.
- Informs and involves parents in exploring the wealth of opportunities offered by careers in engineering.
- Provides activities in support of the transition from primary to early secondary school (ie ages 11 to 14) to help reduce the fall-off in interest in STEM during this period, which:
  a) link theory with practical activity;
  b) are designed to illustrate the real-world relevance of the maths and science curricula;
  c) provide opportunities for follow-up reflection to add value for participants.

We also believe that the Government should:

- Encourage the use of teaching styles that foster discussion and understanding of the real-world engineering applications of science and mathematics, rather than ones based on transmitting subject information without context.
- Create an entitlement for all children in Key Stage 3 to have access to an externally provided, curriculum-linked, STEM enhancement and enrichment activity.
- Use initial and continuing teacher training to help primary school teachers deliver STEM learning that can be built on during early secondary school experiences; similarly early-years secondary school teachers need to better understand how to build on primary school learning and experiences to create a positive and progressive learning experience.

RECOMMENDATIONS

Opportunities exist to inform and inspire young people at all stages of their development so that we increase the number of young people who maintain an interest in STEM through important gateways/decision points. The Institution supports the principle of engagement and enhancement across all age groups to address the key factors that can influence young people's motivation towards STEM subjects and careers.

THE INSTITUTION RECOMMENDS THAT:

The engineering community should:

1. **Allocate a greater proportion of its resources to influencing the 11–14 age group**. This is a key period during which children's interest in STEM often falls away; this influences their future decisions about whether to study STEM subjects and pursue STEM careers.
2. **Work with the Government and schools to investigate ways that engineering can add value to the curriculum**. Activities that support these early secondary school years should link theory with practical activity and illustrate the real-world relevance of the maths and science curricula.

The Government should:

1. **Promote non-transmissive teaching for STEM subjects in both primary and early secondary schools** that encourages *interactive* learning. Teacher training should prepare secondary school teachers to understand how to build on primary school learning and experiences to create a positive response to, and progressive learning in, STEM subjects.

CONTRIBUTORS

We are grateful to the following for their contribution to the report.

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Annette Williams	Director, UK Resource Centre for Women in Science, Engineering and Technology	Consulted during research

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