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Science for All? School Science Education Policy and STEM Skills Shortages

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ABSTRACT: Whether enough highly qualified STEM workers are being educated and trained in the UK is an important question. The answer has implications not only for educators, employers and policymakers but also for individuals who are currently engaged in, or are considering entering, education or training in this area. Set against a policy backdrop that prioritises students studying more science for longer, this paper considers long-term patterns of participation in STEM education – from school science through to graduate entry into the highly skilled STEM labour market. Using a unique dataset that extends across seven decades and comprises many hundreds of thousands of students, the paper finds that patterns of participation in most STEM subjects have varied little over the period considered; suggesting that efforts to increase the numbers of students studying science in school has had limited impact on the throughput of students who study STEM, including the pure sciences, at university level and, subsequently, on the number of graduates who would be available to undertake highly skilled work in areas for which degree-level skills are a pre-requisite.

Keywords: school science, policy, participation

1. INTRODUCTION

> Science and the pursuit of knowledge are given high priority by successful countries, not because they are a luxury which the prosperous can afford; but because experience has taught us that knowledge and its effective use are vital to national prosperity and international standing. (Thatcher, 1988)

> Our goal is prosperity for all through successful business using excellent science. (Blair, 2002)

> The world is seeing an incredible wave of scientific and technological change . . . the most powerful way to achieve higher growth is to make sure the UK the most innovative economy in the world. (Sunak, 2023)

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As the above extracts show, the importance of science and technology in securing the future prosperity of the UK has been a common theme among policymakers for some time. The current iteration of a discourse that situates science and technology at the cornerstone of 'economic growth, improved public services and strategic international advantage' (House of Lords, 2022, p. 3) aspires for the UK to be a science and technology 'superpower', placed 3rd in the world for scientific research and innovation (Department of Science Innovation and Technology, 2023; HM Government, 2021, p. 4).

To achieve this aspiration, the current UK Government intends to increase the percentage of GDP spent on research and development to 2.4% by 2027 (from 1.74% in 2019), with public investment in this area rising to £20 billion by 2024/5 (from £9 billion in 2017/18) (House of Commons, 2022). These developments, along with (among others) the Government's Industrial Strategy, Innovation Strategy, Integrated Review and Levelling Up Strategy, signal an important and arguably welcome focusing of the UK's STEM agenda post-Brexit. While this emphasis on science and technology as 'the major driver of prosperity, power and history-making events' (Department of Science Innovation and Technology, 2023, p. 6) is not new nor confined to the UK (e.g., CEDEFOP, 2016; Command Paper 1490, 1961), the challenges of implementing this latest ambitious programme of reform have already become apparent. The House of Commons Science and Technology Select Committee's August 2022 report criticises the lack of an overarching plan for the development of science and technology, with few measurable outcomes for its funding plans and its ambitions characterised by poor communication and unclear targets. The Committee notes that although the Government 'recognises the UK cannot be "world-leading" in everything . . . it has not identified the areas of science and technology that it wants the country to specialise in, nor has it been clear about how specific its priorities will be' (House of Commons, 2022, p. 3).

Hand-in-hand with rhetoric about the transformative power of science come claims that a shortage of suitably qualified STEM workers is holding back economic growth and placing UK industry at a disadvantage in relation to international competitor countries (e.g., Command Paper 8980, 2014; Department for Business, Innovation and Skills, 2013; HM Treasury, 2021; House of Commons, 2022; The Royal Society, 2021; Wakeham Review, 2016). According to the Confederation of British Industry (CBI) and other sector skills organisations, employers report widespread difficulties in recruiting people with STEM skills at every level, from new apprentices to more experienced workers (CBI, 2016, 2019; EMSI, 2022; Engineering UK, 2016; The Institute of Engineering and Technology, 2017), with the Royal Academy of Engineering (RAE) estimating that 124,000 engineers and technicians are needed each year to meet current and future demand for core roles (RAE, 2019).

Over at least the last seventy years numerous corporate and government bodies have examined the supply of the STEM workforce and have found it wanting in terms of both quantity and quality (Caprile *et al.*, 2015; Smith, 2017). The reasons provided for this apparent skills deficit have remained remarkably similar over time and tend to centre largely on the shortcomings of the education system (e.g., Command Paper 7980, 2010; House of Commons, 2023; Institute of Physics, 2022; Roberts, 2002; Royal Society of Chemistry, 2008). Consequently, policymakers have responded to calls from industry, government and universities to enact education-specific policies and initiatives – often requiring the investment of considerable amounts of public funds – aimed at remedying the situation (e.g., Command Paper 7980, 2010; Council for Scientific Policy, 1968; DES, 1985).

The aim of this paper is to examine the impact that decades of policy focus on science education have had on long-term patterns of participation in science (biology, chemistry, and physics) and STEM subjects more broadly – from school science to graduate entry into the highly skilled STEM labour market. It addresses the following research questions.

- What are the long-term patterns of participation in school science at compulsory (i.e., GCSE) and advanced (i.e., AS and A) levels?
- What are the long-term patterns of application and acceptance to undergraduate STEM degrees?
- What evidence is there that initiatives to increase the science content of the school curriculum have fed through to graduate entry into highly skilled STEM jobs?

The findings summarised in this paper are derived from a unique data set that has not been presented in this form previously and which sheds light on a key issue in contemporary education policy: the role of the school – and science education in particular – in contributing to the wider economic prosperity of the country. Before describing the main findings, we first reflect on one dimension of this challenge: the relationship between school science education and concerns about STEM skills shortages.

2. STEM SKILLS SHORTAGES AND SCIENCE EDUCATION

> …the subjects that keep young people's options open and unlock doors to all sorts of careers are the STEM subjects: science, technology, engineering and maths (former Secretary of State for Education, Nicky Morgan, 2014)

The STEM skills shortage narrative tends to rest on three key assumptions (e.g., Salzman and Benderly, 2019; Smith, 2010). The first is that there are insufficient numbers of students studying STEM subjects at school in particular, a situation that is not helped either by the perceived low status of engineering and technology in the UK school curriculum (Command Paper 117, 2019; Royal Academy of Engineering, 2019), or by the perceived poor-quality of careers advice which 'is patchy at best and perpetuates misconceptions about STEM careers' (DfE, 2017; House of Commons Committee of Public Accounts, 2018,

p. 3). The second assumption is that a shortage of specialist science teachers results in low-quality instruction that is exacerbated when teachers are required to teach outside their area of expertise and when they are supported by poor quality professional development (Royal Academy of Engineering, 2019; The Royal Society, 2021). The final assumption is that those who do study STEM subjects leave education with skills that are insufficiently strong to meet the requirements of employers, resulting in key industries suffering from inadequate supply of suitably qualified graduates, coupled with a university sector slow to respond to the changing demands of the labour market (e.g., Chartered Institute of Personnel and Development, 2017; Royal Academy of Engineering, 2019).

That STEM skills shortages are inextricably linked to the failings of the education system has become accepted widely, and uncritically, by many policy-makers, industry leaders, journalists and researchers. As Salzman and Benderly argue ‘these claims of education failure have become so prevalent that many cite them without much empirical assessment of whether they are true or applicable to the problem being examined’ (2019, p. 9, see also Smith, 2017; Teitelbaum, 2014). The narrative that the responsibility for creating economic prosperity and reducing inequality through scientific and technological innovation, lies primarily in the classroom is so well embedded that any perceived failure of education – and schools in particular – to meet industry’s demand for suitably qualified workers tends to result not only in critique of the education system as a whole, but in a raft of new policy ideas and initiatives (e.g., House of Commons, 2023; Leitch Review of Skills, 2006; The Royal Society, 2011; see also Salzman and Benderly, 2019).

One consequence of the perceived failure of the education system to adequately prepare the next generation of professional scientists has been huge government investment in STEM initiatives. In 2004, for example, the STEM Mapping Review (DCSF, 2006) revealed over 470 STEM initiatives run by government departments and external agencies; all were designed to engage young people, and in particular underrepresented groups, in STEM subjects. And between 2007 and 2017, UK Government departments spent about £1 billion on programmes to encourage greater take-up of STEM subjects (House of Commons Committee of Public Accounts, 2018; see also Banerjee, 2017).

Much more recently the current British Prime Minister, Rishi Sunak, announced plans to move towards all young people studying ‘some form of maths to 18’ (Sunak, 2023). This policy sits alongside recent initiatives such as the STEM Ambassadors, the Advanced Maths Support Programme, the Stimulating Physics Network, and the Institutes of Technology. All these programmes aim to further embed STEM into the school curriculum, support uptake in schools and colleges and enhance ‘the next generation’s mathematical and scientific skills on which the STEM sector will depend’ (Department of

Business, Energy and Industrial Strategy, 2021, p. 56, also; Royal Academy of Engineering, 2019).

The resultant 'stem-ification' (Sharma, 2016) of the education system is an outcome of decades of concerns raised by industry partners and responses by policymakers to perceived shortfalls in the number and quality of STEM workers produced by our education institutions. Many of these initiatives have required fundamental change to the school curriculum, affecting many hundreds of thousands of students. The purpose of this paper is to a) examine the policy context around school science reforms and b) consider the extent to which they have impacted on patterns of participation in STEM courses and careers over the long term: from GCSE science through to graduate entry to the labour market.

3. RESEARCH APPROACH

This paper charts the educational trajectories of students studying STEM subjects in the UK (with a specific focus on England and Wales). It is based on evidence for hundreds of thousands of individuals each year, which allows us to examine patterns of participation in STEM education in a series of snapshots across the educational life course – from school science to early STEM careers. The findings are presented in life order, beginning with education up to the age of 16, post-compulsory secondary education, higher education participation, and finally the first career destinations of STEM graduates.

Before describing the data sources that inform the empirical part of this study, it is important to reiterate that the stance taken in this paper is not 'anti-science'. There are many good reasons to encourage young people to study science: there is an intrinsic value to learning about science and a social benefit to having a scientifically literate, reflective, and socially aware population (Sjöström and Eilks, 2018). However, the impetus behind the policies and many of the programmes to promote science education that we have mentioned here do not stem from these concerns; instead, they are driven by the discourse of a skills shortage of STEM workers: 'the future workforce relies on many more children and young people being encouraged to take STEM subjects and enter STEM careers' (House of Commons Committee of Public Accounts, 2018, p. 3). It is that presumed relationship that we seek to problematise here, not the benefits of studying science for its own sake.

Datasets Used in the Analysis

Complete data that span the extended timescales examined in the study are only available in aggregate form. Therefore, all analysis is restricted to a comparison of the participation of different groups rather than affording a more complex modelling of individual characteristics. Nevertheless, the strength of these aggregate data comes with its potential for providing an overview of long-term trends in participation. This longitudinal overview is important and one which is rarely considered in this context. Recruitment to STEM subjects is a contemporary issue of high political status. If we are to understand how we have arrived at this perceived recruitment crisis, then it is important to take the long view and consider the extent to which participation has been influenced by past social, political and educational events. The focus of the analysis is at five points in the education trajectory: GCSE qualifications, which are typically awarded to students at the end of compulsory formal education; AS-levels taken by some students in the 1st year of sixth form; leading to A-levels (the most common qualification for university entry); followed by entry to higher education undergraduate programmes; and finally the first destination of graduates upon completion of their degree.

General Certificate of Secondary Education (GCSE)

The GCSE examination was introduced in schools in England and Wales in 1988 following the reforms implemented as part of the 1988 Education Reform Act. Most young people sit these examinations at age 16. Here, participation data for GCSE biology, chemistry and physics were obtained from the Department for Education (and its predecessor Departments) as well as from the Joint Council for Qualifications (JCQ) from 1993 to 2021. As explained further below, GCSE science programmes have been compulsory since 1988 and while there are several variations that schools can offer, most of the GCSE cohort sit the double/combined award, while a smaller group take GCSEs in the three separate sciences (also known as the ‘triple award’). It is this latter group that receives the most policy attention (e.g., House of Commons, 2023) and is the focus of this analysis.

Advanced Subsidiary (AS)-Level

Reform of post-16 qualifications in 2000 resulted in the two-year A-level being split into two stages – a one-year AS followed by a one-year A2. The intention was that students took the AS level in the first year and either chose to ‘cash in’ their AS and have a certificated qualification or continue to the second year of study towards the full A-level (House of Commons, 2003). These Curriculum 2000 reforms, as they became known, were intended to broaden the post-16 curriculum by encouraging students to take four or five subjects during their first year of A-level study before narrowing their studies in the second year. In the sciences, this broadening of the curriculum provided the opportunity for more young people to delay specialisation and remain in the ‘science stream’ for longer. Although the status of the AS has changed significantly since the early 2000s – from 2015, it has been offered as a stand-alone qualification distinct from the A-level (Long, 2017) – it is an interesting bell-weather for post-16 engagement in science programmes and therefore it is useful to examine trends in participation. Data to examine patterns of participation in AS biology, chemistry and physics programmes were obtained from JCQ from the programme's inception in 2002 until 2021.

Advanced (A)-Level

Long seen as the 'gold standard' qualification for entry to Higher Education in England and Wales, the modern A-level was established in the early 1960s when passes were first awarded on a 5-point scale (from grade A to grade E, later A*–E). The number of A-levels being taken each year has increased from 250,000 in 1961 (DES, 1961) to over 820,000 in June 2021 (JCQ, 2021). Data on A-level entries were obtained electronically and as hard copy from a variety of sources including the Department for Education (and its predecessor Departments), the former Qualifications and Curriculum Authority, the Joint Council for Qualification, the Institute of Physics, and the Assessment and Qualifications Alliance. The analysis focuses on patterns of entry to the A-level examination from 1961 to 2021.

Higher Education STEM Programmes

As noted above, increasing the number of entrants to STEM courses in higher education has long been a key goal of those who seek to resolve skill shortage issues through raising education participation. Data retrieved from the Universities Central Admissions Service (UCAS) were used to investigate patterns of participation in STEM undergraduate degree programmes at UK universities. Since 1993, candidates wishing to apply to study at a UK university have had to make their application through the UCAS. Prior to this date, applications to higher education were made through the Universities Central Council on Admissions (UCCA) and the Polytechnics Central Admissions Service (PCAS). Both organisations merged in 1993 to form UCAS. Data from before 1996 were not available electronically and were retrieved from the UCAS/PCAS/UCCA Annual Reports in the UCAS archives. Here we track patterns of participation from 1986 – the first year in which applications were administered through the UCCA/PCAS schemes – until 2019 (to exclude disruption due to the Covid pandemic).

Graduate Destinations

The first job that a graduate takes after leaving university can be crucial for their future employment trajectories (Dolton and Silles, 2003; Mosca and Wright, 2011). Graduates who enter non-graduate employment after leaving university risk being over-educated for their role and of remaining in lower-level occupations throughout their careers (Dolton and Vignoles, 2000). Indeed, research by the ONS suggests that in 2017 around half of recent biological science graduates were overeducated for their current role along with 40% of physical and environmental science graduates (Savic, 2019).

Data on graduate destinations are collected by the Higher Education Statistical Agency (HESA) as part of their Destinations of Leavers from Higher Education (DLHE) survey that gathered data from all students approximately six months after they have left university. Respondents are asked about the type of work in which they are employed and whether they have embarked upon further study. These data are collected through questionnaires sent out to their graduates by Higher Education institutions and response rates are high, typically around 80%. DLHE data were analysed from 1995 until 2017 when it was replaced by the Graduate Outcomes Survey which follows up students approximately 15 months after graduation. Data on occupational destinations are included from 2003 to 2017 as changes to the Standard Occupational Classification schema mean that data before or after these dates are not comparable.

Before presenting the findings, we would like to add a brief note about some of the terminology used to describe STEM. Defining STEM subjects can be problematic and in the absence of a consensus (see House of Lords, 2012), we have sought to differentiate between school science subjects (namely biology, chemistry and physics) and the broader group of STEM subjects, including those which one might study at university. These include ‘shortage subjects’ such as engineering and computing as well as medical STEM. A full list of STEM subjects is given in the Appendix.

4. Findings

The findings from this study are presented in three sections which mirror the research questions posed at the start of the paper. We first report patterns of participation in school science before considering applications and admissions to STEM programmes at university. The final section reports the results of our analysis into gendered patterns of participation in early STEM careers.

The Schooling of Science – The GCSE

> We have spent too long in a state of semi-detachment from science, as though it was something intimidating and remote from our lives. Too many people in our country lack training in science and technology, too many children think STEM subjects are not for them. (Prime Minister Boris Johnson, 2021)

For as long as science has been taught in schools a key area of ‘conflict’ has been the ‘extent to which science teaching should prepare a technical and scientific elite or should be available to and serve the needs of the majority' (Walford, 1985, p. 158, also Hurd, 1991; Jenkins, 2007). Achieving a balance between these competing demands has been an important challenge for policy-makers and educators as exemplified by statutory changes to the provision of science education at GCSE level over the last 30 years.

When science became a compulsory subject with the introduction of the National Curriculum in England and Wales in the late 1980s, the intention was that all students from age 5 to 16 study a 'broad and balanced' science curriculum leading to entry for the GCSE examination. This model of 'science for all' meant that students at the secondary phrase were taught a programme of study that incorporated the three main sciences – biology, chemistry, and physics – to be accommodated within a maximum of 20% of curriculum time (DES, 1985). While schools would be free to teach the three sciences separately, the National Curriculum reforms sought a combined approach with an underpinning emphasis on investigative study and problem-solving (DES, 1985). This model of combined science took shape in the GCSE double award, which quickly became ubiquitous, largely replacing the separate science disciplines in state schools, although not within the independent sector. This move towards double or combined science was not without controversy; there was particular concern about the 'compression' of the three separate science disciplines into two GCSEs and that the double award would not adequately prepare students for post-16 study (The Royal Society, 2008). However, in those state schools where the separate sciences remained popular – usually those with high proportions of higher attaining students or in schools who were in competition with local independent schools and offering the three sciences was seen as desirable in attracting students – they were rarely given enough curriculum time, with practical work and time for discussion greatly reduced (Fairbrother and Dillon, 2009; Millar, 2011; SCORE, 2014).

The double award was eventually replaced in 2006 by a series of single award specifications modelled on the Twenty-First Century Science approach (Burden, 2007) and which included more applied and vocational science options, ostensibly giving schools greater flexibility and a curriculum offer that was both more 'complex' and 'targeted' (The Royal Society, 2008, p. 27). At the same time the Government introduced targets to increase the uptake of the separate sciences, encouraging schools to offer them to all higher achieving students (The Royal Society, 2008). These targets were soon to become formalised requiring that by 2014, 90% of state schools offer the separate sciences (or triple award) and proposing that the number studying for separate GCSEs in chemistry, physics and biology be doubled (Fairbrother and Dillon, 2009). Later, the wide-ranging reforms of the National Curriculum under then Secretary of State for Education, Michael Gove, led to further re-organisation of the upper-secondary core science curriculum, with students currently either being able to take a single GCSE in biology, chemistry and

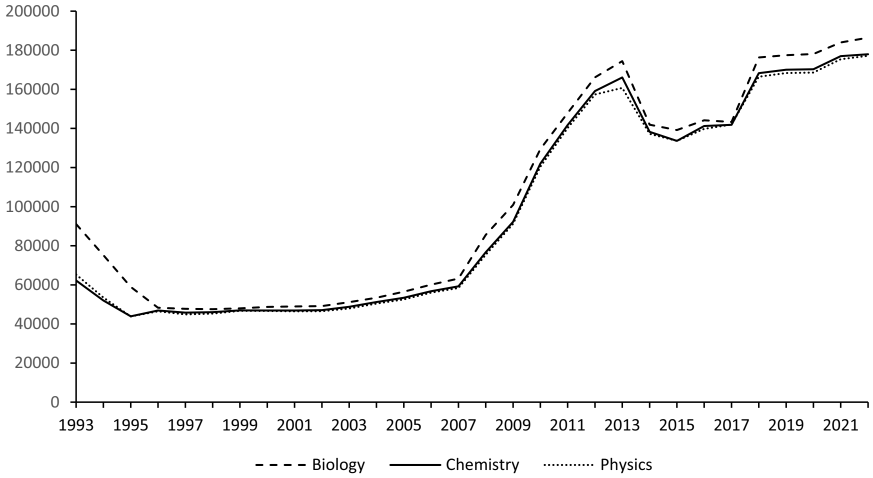

Figure 1. Full course GCSE entries for separate sciences from 1993 to 2022, all UK
Source: DES, DCSF, JQA

physics or a double GCSE award in combined science (DfE, 2017; Jadhav, 2018).

The impact of these various reforms can be seen in the entry data for the separate science GCSEs from 1993, by which time the double award was well established, to the present (Figure 1). After being reasonably stable in the 1990s and early 2000s the number of students entered for GCSEs in biology, chemistry and physics increased rapidly following the end of the double award in 2006. Following a slight dip between 2013 and 2018 – likely linked to uptake to the range of combined and additional science options available at the time – the numbers taking triple science appear to have now flattened out following the re-introduction of the double/combined award in 2018. Even so, the number of students taking the three sciences has almost tripled since 1993; this represents a large increase in the science content of the 14–16 curriculum – comprising 3 out of the typically 8 subjects (DfE, 2019) that students will study at GCSE.

The past 30 years of science education curriculum reform have been characterised by a yo-yoing of priorities between separate science GCSEs and the combined/double award and exemplifies the tensions underpinning the aims of school science education that were highlighted earlier: a model of ‘science for all’ versus a focus on preparing students for advanced study and entry to STEM professions. One key reason for this tension has been the repeated calls over the past century by scientists, policymakers, industrialists and educators for the need to recruit and retain more scientists, mainly for the reasons discussed at the start of this paper (see also Fairbrother and Dillon, 2009; Smith and Gorard, 2011; Tomei *et al*., 2014).

However, as Ogborn (2004, p. 69) notes, only a 'very small fraction of the population has the graduate-level qualifications to meet the demands for highly skilled workers that industry requires'. Making the training of a minority who will eventually become professional scientists a key goal of a general science education is an inefficient means of meeting the perceived demand for STEM skills, a point we will return to later. Advancing a programme of triple science also leads to concerns about unequal access to the curriculum, particularly for students who live in more economically deprived geographical regions (Royal Society of Arts, 2015) where teacher shortages may be more acute, and also among students who are eligible for free school meals (Homer *et al.*, 2013; SCORE, 2014). Nevertheless, as a policy to encourage more students to study science subjects with the sole aim of increasing the numbers available to take advanced level study, the policy of encouraging more science at GCSE has been a success (see also Homer *et al.*, 2013). Whether this translates into increased entries at higher levels will be the focus of the next section.

Staying in the Science Stream Part One: The AS Level

The number of students taking the three science subjects at AS-level between 2002 and 2021 is shown in Figure 2, with biology recruiting the largest number of

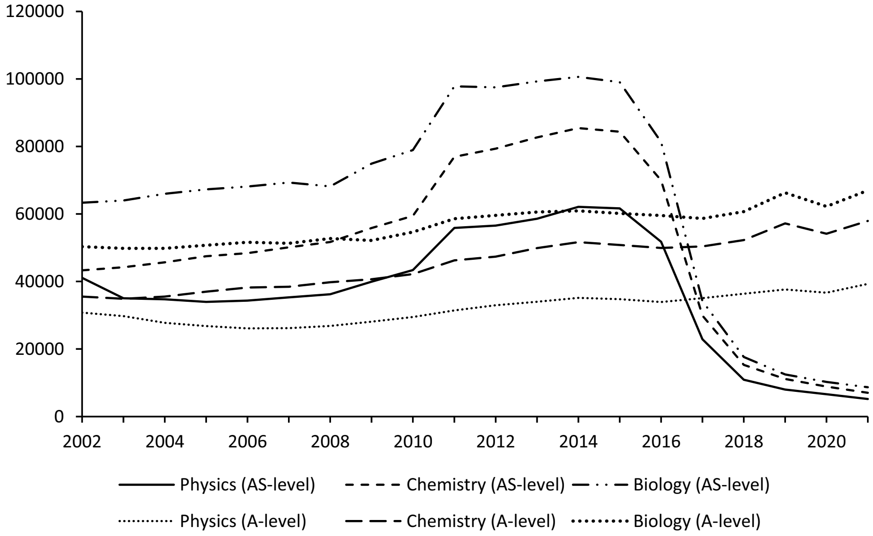

Figure 2. Entries to AS level (and for comparison A-level) sciences, England and Wales, 2002–2021

Source: JQA

students, followed by chemistry and then physics. Participation in all three subjects have followed the same general trend, with very slow increases during the 2000s followed by a sharper increase in the early 2010s, and a subsequent rapid decline in entries as the impact of the 2015 reforms that made the AS a separate qualification to the A-level took place. Also shown, for comparison, are entries to the full A-level courses in the three science subjects. A-levels are discussed in more detail below, but it is worth noting while they share the same relative differences in popularity to AS-levels (biology the most popular, physics the least) there appears to be little similarity between the two qualifications in terms of patterns of participation: for example the increase and rapid decrease in entry to AS-level from 2011 onwards is not replicated in the data for A-level.

While AS qualifications, as originally conceived as a stepping stone to A-level, appear to have been successful in broadening the curriculum experience for students, they do not appear to have had any appreciable effect in increasing take up to the three sciences at A-level. Rather, between 2002 and 2014 the three sciences, alongside modern foreign languages, were among the most ‘dropped’ subjects, with the percentage of students who do not continue to study these subjects between AS and A-level increasing over time (Sutch *et al*., 2015, p. 55).

Staying in the Science Stream Part Two: The A-Level

The organisation of the secondary school curriculum in England and Wales is such that students traditionally reduce the number of subjects they study first at age 14, in preparation for the GCSE, and then at age 16 in preparation for courses which lead to Higher Education, the workplace and so on. For students who take the A-level route into Higher Education, traditionally the most popular option, this would involve retaining only three, or usually no more than four of their secondary school subjects.

Entries to A-levels in the three sciences are shown in Figure 3. Biology is in the healthiest position of the three, with the steady rise in the number studying at A-level biology mainly attributed to the increasing number of female students who opt to study the subject. Physics, on the other hand, has seen little increase in the number of students studying the subject over the period considered. Although entries to physics had been in steady decline since the late 1980s, the recent slight upturn is still relatively modest, returning the number of entries to levels only slightly higher than in the 1960s. Around 5% of all A-level entries in 2021 were in Physics, 7% were in chemistry and 8% in biology, figures that have only varied by a few percentage points since the early 1990s.

The introduction of compulsory GCSE science in 1988, the Curriculum 2000 reforms mentioned above, and the revival of triple science GCSE in 2006, have all provided an opportunity for more young people to remain in the ‘science stream’ and prepare for A-level study. Despite an increase in the amount of science taught as part of the school curriculum and interventions to

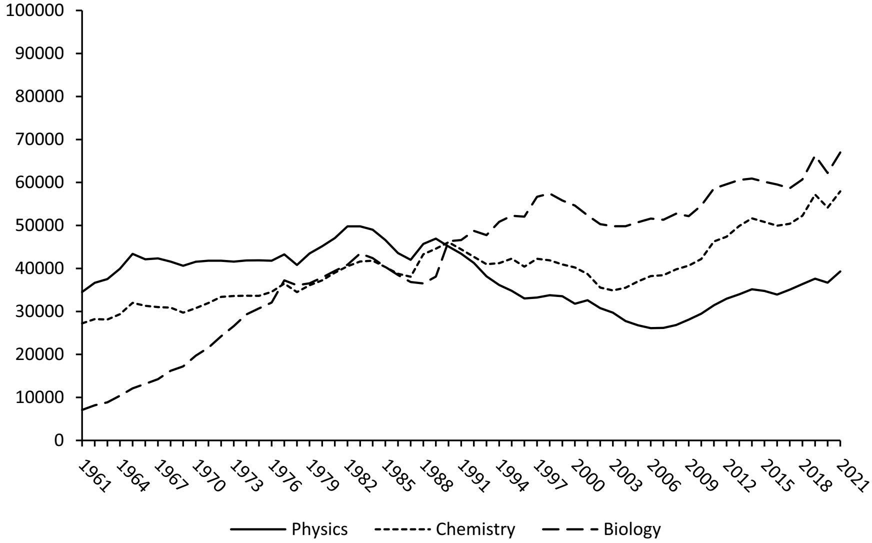

Figure 3. Entries to the three sciences at A-level, England and Wales 1961–2021
Source: DfE, DES, DfES, DCSF, QCA, JCQ, AQA, Edexcel, IoP

increase participation, there appears to be only modest evidence that these reforms have had any notable impact on the number of students studying the sciences at A-level. Although there has been some increase in uptake from around 2009/2010 – these increases, except for biology, look less robust than is often claimed (e.g., Education Hub, 2021). Particularly when set against an expanding sixth form population which has increased by around one third since the mid-1980s, and also when compared with trends across the life of the qualification.

Participation in Undergraduate STEM Programmes

> Why is it that 30,000 vacancies for students in science and engineering in our universities and polytechnics were not taken up last year while the humanities courses were full? (Prime Minister James Callaghan, 1976)

We now turn to patterns of entry in STEM programmes in higher education, specifically recruitment to first degree courses. As with school science, concerns over recruitment to STEM programmes at university are not new as is evident from the above extract from Callaghan's Ruskin College speech on the nature of and purpose of the national education system. Indeed, the general expansion of Higher Education in the UK during the 1960s was less apparent in recruitment to the sciences, with falling entries to university science programmes prompting concerns about a ‘swing from science’ and fears that if things continued as they were, university science faculties would find themselves ‘increasingly recruiting rather than selecting candidates’. (Council for Scientific Policy, 1968, paragraph 6)

Despite the move towards mass higher education from the late 1980s, and as former Prime Minister Tony Blair’s target of 50% higher education participation among the 18–30 age group became closer to being reached (Blair, 1999), the 2000s saw a continued focus on providing additional support to university STEM programmes which ‘meet strategic skill needs’ (DIU, 2009, p. 45). For example, the then Labour government designated some university STEM subjects as ‘strategically important and vulnerable’ (HEFCE, 2008) meaning that they were eligible for ‘enhanced’ financial support, even at a time when funding for other courses was to be reduced (DIU, 2009). This policy continued through the austerity-focused budget cuts of the subsequent Coalition Government (Department for Business, Innovation and Skills, 2010) with the 2010–15 Parliament providing £185 million to support the teaching of high-cost STEM subjects in higher education and committing £7.2 million to provide support to science teachers through the National Science Learning Network between 2014 and 2016 (HM Treasury, 2014).

More recently, successive government-sponsored reviews continued to place an emphasis on the need to promote the development of higher-level STEM skills (e.g., Shadbolt Review, 2016; Wakeham Review, 2016). Support was provided via enhanced funding for the sector (HM Treasury, 2021), the development of university/industry partnerships (NCEE, 2021), as well as new types of institutions – such as University Technical Colleges and the more recent Institutes of Technology (DfE, 2021). Along with a renewed impetus to encourage the uptake of apprenticeships (House of Commons Committee of Public Accounts, 2016), the focus of reform at the post-compulsory level has been to encourage more young people to continue with the study of STEM subjects with a view to increasing transition to the STEM labour market. The impact of these initiative on uptake to STEM courses at university can be seen in the data on applications and acceptances to first degree programmes, which are described below.

Figure 4 provides some insight into how the expansion of higher education over the last three decades has been reflected in changes to the proportion of students interested in studying STEM subjects at university. Over the period considered, the share of applications to all STEM programmes, broadly defined, has gradually increased and, in 2020, just under half of all applications are in this area (see Smith and White, 2019 for a consideration about how this varies with non-STEM programmes). However, much of this increase can be attributed to rise in applications to medical STEM programmes, in particular nursing. Among the non-medical STEM subjects the largest increase in applications has been to the biological sciences, where the share of applications has almost

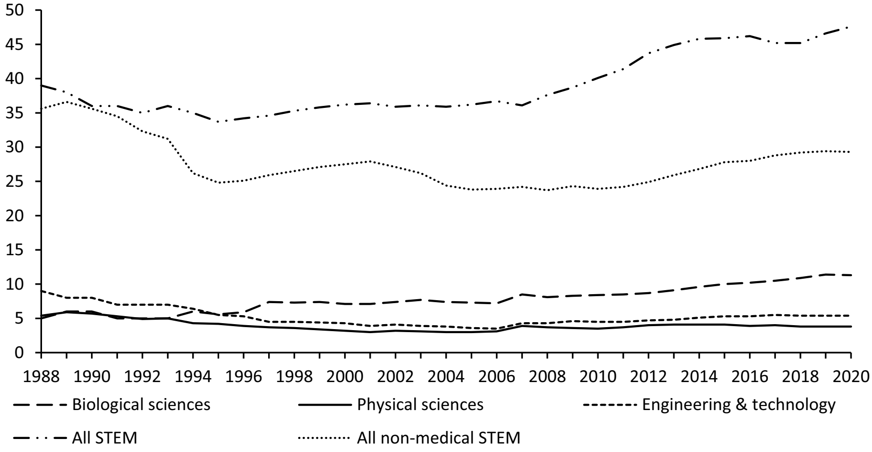

Figure 4. Applications for the largest non-medical STEM groups. As a percentage of all applications

Source: UCCA, PCAS, UCAS

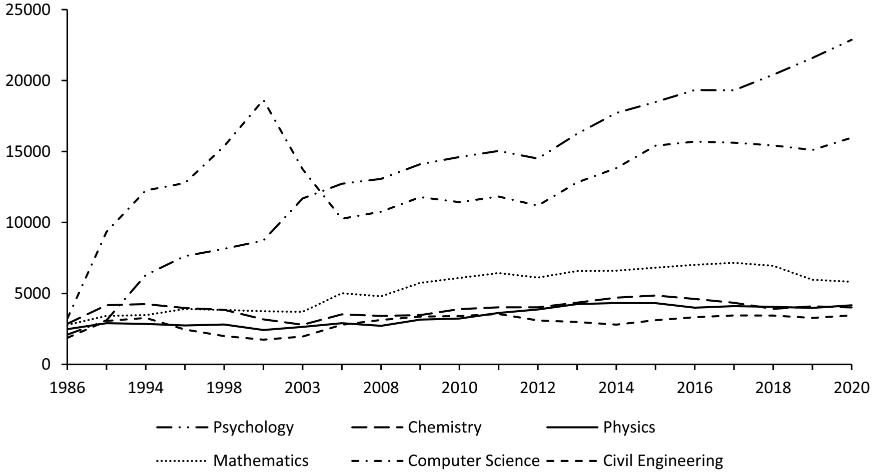

Figure 5. Number of students accepted to selected STEM subject areas, 1986–2020

Source: UCCA, PCAS, UCAS

doubled over the period, largely because of a rise in applications to psychology and sports science programmes. The physical and engineering sciences – usually the areas where shortage claims are most pronounced – have seen little relative change in terms of their share of the pool of potential undergraduate students.

Unsurprisingly, similar patterns can be seen in the data for students who take up their places at university (Figure 5). This graph shows the number of undergraduate students accepted to study several of the key STEM shortage subjects, as well as psychology – a subject which continues to see sustained growth. What is notable about these data is the relative stability in the number of students who have studied subjects like chemistry, mathematics, physics and civil engineering. This stability comes despite large increases in the numbers of students who are attending university as well as the raft of policy and other initiatives which seek, either directly or indirectly, to increase the number of well-qualified entrants into STEM programmes at university.

This long-term view of the Higher Education participation data shows that although participation in STEM subjects appears to have risen, any increase can be largely attributed to psychology and medical STEM programmes rather than in the shortage subjects that have been the focus of so much policy attention over the last several decades. It is also worth noting that patterns of entry to computer science programmes – a key STEM shortage subject – appear to follow a somewhat different trajectory: the sharp rise in entries during the late 1980s and early to mid-1990s was followed by a sharp fall following the end of the 'dot.com bubble' in the early 2000s. While entries have since stabilised and appear healthy, employment opportunities, at least in terms of graduate occupational outcomes, are less positive for computer science graduates than for those from many other STEM subject areas (Smith and White, 2020).

In all, this suggests that compulsory school science has had a limited impact upon the throughput of students studying many of the STEM shortage subjects, including the pure sciences, at university level and, subsequently, on the number of graduates who would be available to undertake highly skilled work in areas for which degree-level skills are a pre-requisite.

The Graduate Labour Market

> . . .success in the sciences is one of the biggest drivers of social mobility, enabling young people from a range of backgrounds to access highly paid careers and opportunities. (former Secretary of State for Education, Nicky Morgan, 2014)

As noted earlier, most of the proposed solutions to the apparent STEM recruitment crisis have tended to focus on the supply side, urging action to increase the numbers of students pursuing degrees in science and engineering and so meeting employers' demands for highly skilled-STEM graduates. This final section of the paper therefore considers the early destinations of STEM graduates six months after leaving university.

Upon leaving university, most STEM graduates either directly enter employment or remain in some type of further study – such as postgraduate research or taught programmes (typically about 4% of biological science graduates enter PGR programmes each year). While levels of unemployment for recent

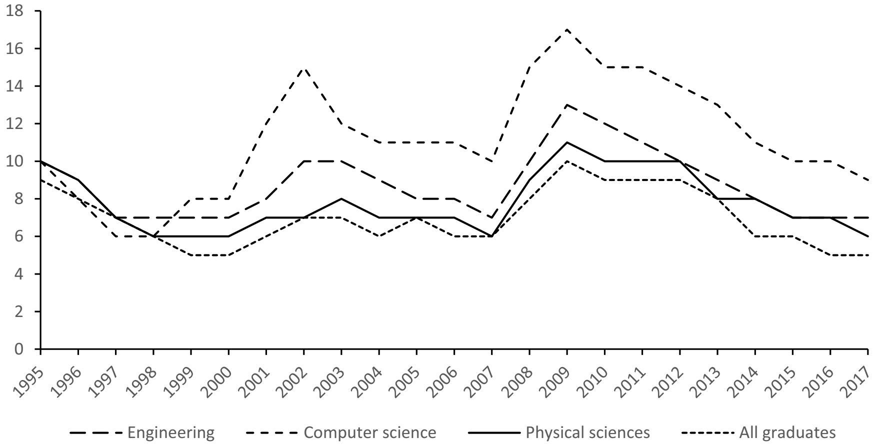

Figure 6. Percentage of graduates who were unemployed 6 months after graduation, selected subjects 1995 to 2017

graduates are relatively low and have remained reasonably stable over the past twenty years, they are among the highest, at around 10%, for graduates from computer science and engineering degrees – two of the main subject areas in which shortages have been claimed (Figure 6). Additionally, around 20% of computer science graduates who do enter the workforce do so into low-skilled 'routine' occupations. The figure for engineering graduates is slightly lower, at

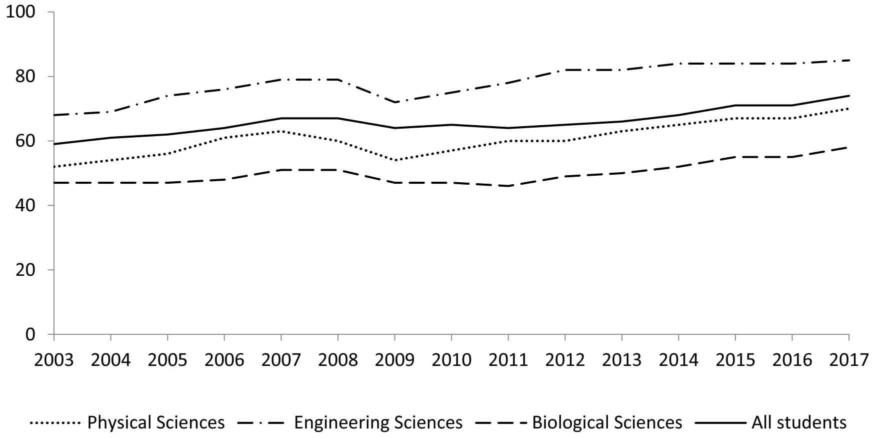

Figure 7. Percentage of graduates entering employment who gain 'graduate' type jobs, selected subject areas, 2003–2017

Source: HESA

18%, but the combined rates of unemployed and underemployed graduates might appear to be somewhat at odds with a sector that is struggling to recruit graduates (see Smith and White, 2019, 2020 for a further discussion of this).

Figure 7 looks more closely at the types of employment undertaken by recent graduates with a comparison provided for selected STEM areas. The designation of graduate job is based on the categorisation developed by Elias and Purcell (2004). As shown below, engineering science graduates are among the most likely to directly enter the workforce after graduation and of these graduates around 80% enter graduate jobs – overwhelmingly in the field of engineering. Among the physical and biological sciences lower proportions enter graduate jobs than graduates overall, a pattern that is particularly noticeable for biological science graduates. In addition, the proportion of all graduates entering graduate jobs has been relatively flat over the period considered for all subject areas varying only by around 10% points.

The final graph (Figure 8) shows the percentage of recent graduates who gain employment and enter highly skilled STEM jobs (as defined by UKCES, 2015). As noted above, the majority of engineering graduates who enter employment go directly to work in the engineering sector and this is reflected in the data shown here. Only around one third of non-medical STEM graduates who enter employment work in highly skilled STEM jobs suggesting that a significant proportion work outside the STEM field.

In general, the biological sciences stand out as relatively weak in terms of employment outcomes: they have lower than average rates of employment and one of the lowest rates of employment in graduate-level jobs.

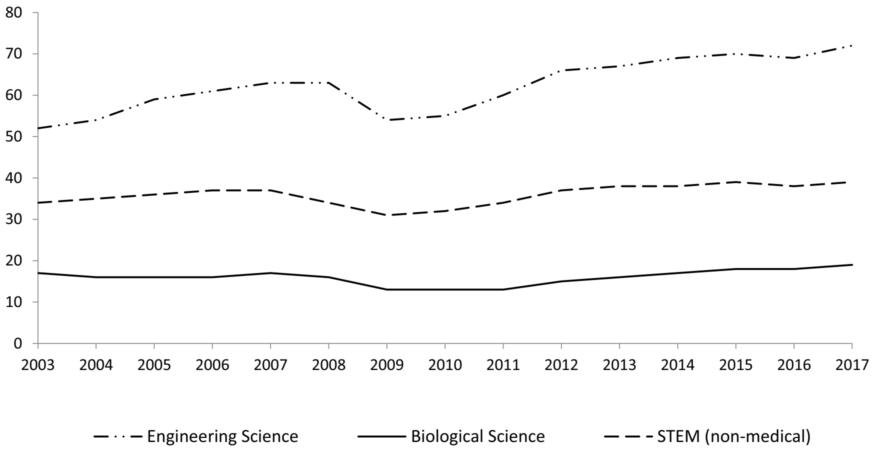

Figure 8. Percentage of graduates gaining employment, entering highly skilled STEM occupations, by subject group, 2003–2017

Source: HESA

What is particularly surprising, however, is the extent to which this subject group supplies the highly skilled STEM workforce. Biological science graduates employed six months after graduation were three times less likely to be in highly skilled STEM jobs than engineering graduates and only half as likely as STEM graduates as a whole. On the other hand, the biological sciences are the largest recruiting non-medical STEM subject group for undergraduate programmes, and biology is the healthiest recruiter among the three science A-levels. While we would not expect a simple linear relationship between studying biology at A-level, entry to biological science programmes at university and working in a highly skilled job in the field – it is worth noting that the subject area which attracts the largest number of students is also the one where employment opportunities appear to be the most limited.

5. DISCUSSION

Over the last seven decades there have been numerous policies and initiatives that have aimed, either directly or indirectly, to encourage a greater number of young people to remain in the 'science stream', subsequently study science subjects at university, and enter the graduate STEM labour market. In very different ways, several major policy initiatives have sought to achieve this goal. These include: the expansion of comprehensive education; the raising of the school leaving age to 16; the introduction of the National Curriculum; Curriculum 2000; an increased diversity of vocational and academic pathways to Higher Education. Some of these initiatives have been implemented gradually and their impact on participation is hard to gauge (e.g., Banerjee, 2017; Tripney *et al*., 2010). Others, such as the introduction of compulsory science at age 14 in the late 1980s, have clearly had a very limited effect on post compulsory participation in the pure sciences.

Nevertheless, further initiatives continue to be proposed by policymakers and these have the potential to impact the lives of hundreds of thousands of young people. For example, a key conclusion from the House of Commons Science and Technology Committee's recent inquiry into Inclusion and Diversity in STEM is as follows:

> Access, or lack of it, to the separate study of biology, chemistry and physics at GCSE – known as the 'triple science' option – is a decisive factor for many pupils in determining whether they study STEM subjects at university and enter the STEM workforce. (House of Commons, 2023, p. 28)

In their recommendations the Committee asks the Government to inform them how it intends to ensure more pupils have access to triple science programmes. Notwithstanding the challenges of delivering an expanded science curriculum in the middle years of secondary school, this recommendation for more compulsory science up to age 16 is not borne out by the data presented in this paper. While making science a compulsory part of the national curriculum has meant that more young people are studying science up to age 16, this has not translated into increased recruitment at higher levels. For example, while the reforms that introduced the AS-level did mean that more students studied science in the 1st year of 6th form, they had only a modest impact on the number of students who continued to A-level.

The supply of undergraduates studying shortage STEM subjects (notably in the physical, engineering and computing sciences) appears to be remarkably stable, even in absolute terms, in the context of an expanding undergraduate population. Indeed, the data on applications and admissions to university suggest that participation in undergraduate degrees in ‘shortage’ STEM subjects has remained stable simply because demand had not risen. Given that UK universities compete for students, and are financially rewarded for recruiting additional entrants, the simplest explanation for this lack of expansion is a limit in the number of students wishing to study these subjects. This is notable not simply in terms of the apparent failure of initiatives intended to target these areas but also because of the long-standing and widely publicised labour shortages in business and industry.

One possible explanation is that while the numbers of students remaining in post-compulsory education have increased, these ‘new’ recruits are those who were never likely to study many of the STEM shortage subjects anyway (Osborne and Collins, 2001; Smith and Gorard, 2011). Students who would be likely to study physics or chemistry, which require relatively high entry grades and a commitment to the subject at age 16, would always have entered Higher Education and would have been largely unaffected by recent widening participation agendas or other initiatives to increase recruitment. It also appears that some of those who remain in the STEM pipeline throughout their education are unlikely to remain in the field after university perhaps because they no longer enjoy the subject or the opportunities for employment are not there (National Academies of Science and Mathematics, 2020). Or it is simply the case that they have more choice and that there are, in their view, better employment options for them beyond the STEM field.

6. CONCLUSION

This paper has considered patterns of participation in STEM-related education in the UK set against a policy context characterised by decades of reform at all levels. It has examined the stages which take students from national tests at age 16, through A-level and undergraduate study, and into the labour market. As well as considering how aggregate levels of engagement vary at each educational stage, the research reported here has used the best available evidence to monitor participation over an extended period – in some cases over seventy years.

There are three main conclusions to emerge from this study, the first is that encouraging more STEM to be taught in schools – for example by increasing the uptake of triple science, adding computer coding to the curriculum, or advocating for maths education up to age 18 – is unlikely to result in substantially increased throughput of well-qualified graduates into highly skilled STEM jobs. As many policymakers, both domestic and international, have done before them, the current UK government's proposals to develop the nation's scientific skills base largely lie in increasing the *supply* of young people into the STEM professions and the long-standing assertion that recruitment shortages in STEM areas are largely an education problem tends to be accepted unproblematically. However, it is apparent from the data presented in this paper that decades of policies along with well-funded and well-targeted initiatives have had little (if any) impact on uptake to studying the core science subjects, and even requiring that all young people study more science up to the age of 16 has had limited effect on recruitment at the next educational levels.

The second conclusion relates to the labour market and the role of employers. Although most of the policy focus has been on increasing the supply of workers, STEM graduates are no more likely to enter graduate positions than those with degrees in other subjects and are just as likely to be unemployed: there is no evidence for a labour market advantage for those with higher-level STEM qualifications. Any mismatch between the supply and demand for STEM workers cannot, therefore, be attributed to the number of students graduating with STEM degrees. One explanation for this could be that STEM graduates find STEM careers unattractive and that the sector does not offer sufficient money, job stability, good working conditions as well as other opportunities to entice bright students away from employers outside the STEM field (see also House of Commons, 2023). Yet another explanation may relate to the recruitment and training practices of employers. The UK's liberal market economy generally operates on the assumption that people will gain a qualification and then try and find a job, rather than a system where the supply of skills and the needs of employers are coordinated. This lends itself to a relatively flexible job market in which the course that one studies does not necessarily lead directly to a specific career (Dromey and McNeil, 2017). However, the disadvantage of this is that the supply of skills does not always match employer needs (Command Paper 117, 2019; HM Treasury, 2021). This market-based model also operates under the assumption that with the right incentives from Government, employers 'will invest in training for the benefit of all' an approach which according to Dromey and McNeil has 'neither delivered the quantity nor the quality of training that we need, and … has failed the people and the places that need it most' (Dromey and McNeil, 2017, p. 4). The resulting system is one where investment in continuing vocational training is half the EU average, and where the ineffective use of the skills of the workforce means that the UK has the highest levels of overqualification in the EU (CEDEFOP, 2016; CIPD, 2017; Pearce *et al*., 2013).

This apparent reluctance of employers to invest in high-quality work-based training should perhaps offer a moment of reflection to those who view the STEM skills deficit as primarily a consequence of the failings of the education system. The notion that people 'leave the formal education system fully formed is an antiquated one' (RAE, 2019, p. 51) yet it is one that persists (e.g., CIPD, 2017). This perspective, coupled with recruitment practices that draw from a narrow field of expertise, and where there are limited opportunities for returners or those seeking a career change (RAE, 2019), suggest that a focus on the role of employers in investing in work-based training is long overdue.

Our final point relates to the quality of the data that underpin STEM shortage claims – simply put, we need better data. A recent report from the National Audit Office drew the following conclusions about the quality of the evidence that informs policymaking around skills: the Government does not 'currently gather robust intelligence' on STEM skills issues; current estimates of the STEM skills problem 'vary widely' and do not apply to the whole of the workforce; there is no 'stable and consistent' set of definitions for STEM either in education or the workplace; and what evidence there is points to a 'skills mismatch rather than a simple shortage' (National Audit Office, 2018, pp. 6–7, see also House of Lords, 2012 for a similar conclusion). To anyone not closely involved in researching STEM skills shortages, these findings may seem surprising – particularly as these issues are not new and especially given that decades and decades of policies which have cost billions of pounds and influenced the lives of many millions of people are largely based on what was described even as far back as the 1950s as 'an exaggeration of the empirical evidence' (Arrow and Capron, 1959, p. 292).

In summary, our research points to the ethical, practical and financial challenges of relying on solutions to the STEM skills deficit which require more young people to study science in formal education for longer periods of time – skill shortages, where they exist, need to be supported by high-quality evidence about demand across different areas and different industries (e.g., EMSI, 2022). A refocusing on demand rather than supply would also enable schools to concentrate on what are arguably the primary goals of science education: 'to educate students both about the major explanations of the material world that science offers and about the way that science works' (Osborne and Dillon, 2008, p. 8, also Sjöström and Eilks, 2018), rather than the current emphasis on preparing a minority of students to be the next generation of STEM professionals.

In 2019 almost 920,000 students in England and Wales studied for a GCSE either in double science or in one or more of the three separate sciences. In that same year just over 160,000 students were entered for an A-level in biology, chemistry and/or physics and just over 80,000 students enrolled in undergraduate degree courses in the biological, physical or engineering sciences (with 5750 studying biology, 3765 chemistry and 3565 physics). In 2017, the last year for which comparable data are available, just over 20,000 recent biological, physical and (mostly) engineering science graduates entered highly skilled STEM jobs. While it may be the case that 'more young people are studying STEM than ever before' (Education Hub, 2021) this does not translate into entry to the STEM labour market. We know that if STEM graduates do not enter highly skilled STEM jobs soon after graduation, they are unlikely to do so later in their careers (RAE, 2019; Smith and White, 2020). Indeed, when roughly 2% of the cohort are entering the graduate STEM workforce, it seems that encouraging more science to be taught in schools, with the explicit aim of training more highly skilled workers, is a rather poor return on investment. The STEM pipeline, it seems, may not just be 'leaky', it may be blocked.

7. Disclosure Statement

No potential conflict of interest was reported by the author(s).

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10. APPENDIX

UCAS main subject group categories for STEM subjects: • Medicine and Dentistry • Subjects allied to Medicine: including Nursing and Pharmacy • Biological Sciences: including Biology, Microbiology, Biochemistry Psychology, Sports Science • Veterinary Sciences, Agriculture and related • Physical Sciences: including chemistry, physics, physical geography and environmental and forensic science • Mathematical and Computational Sciences • Engineering and Technologies Sciences • Architecture, Building and Planning

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