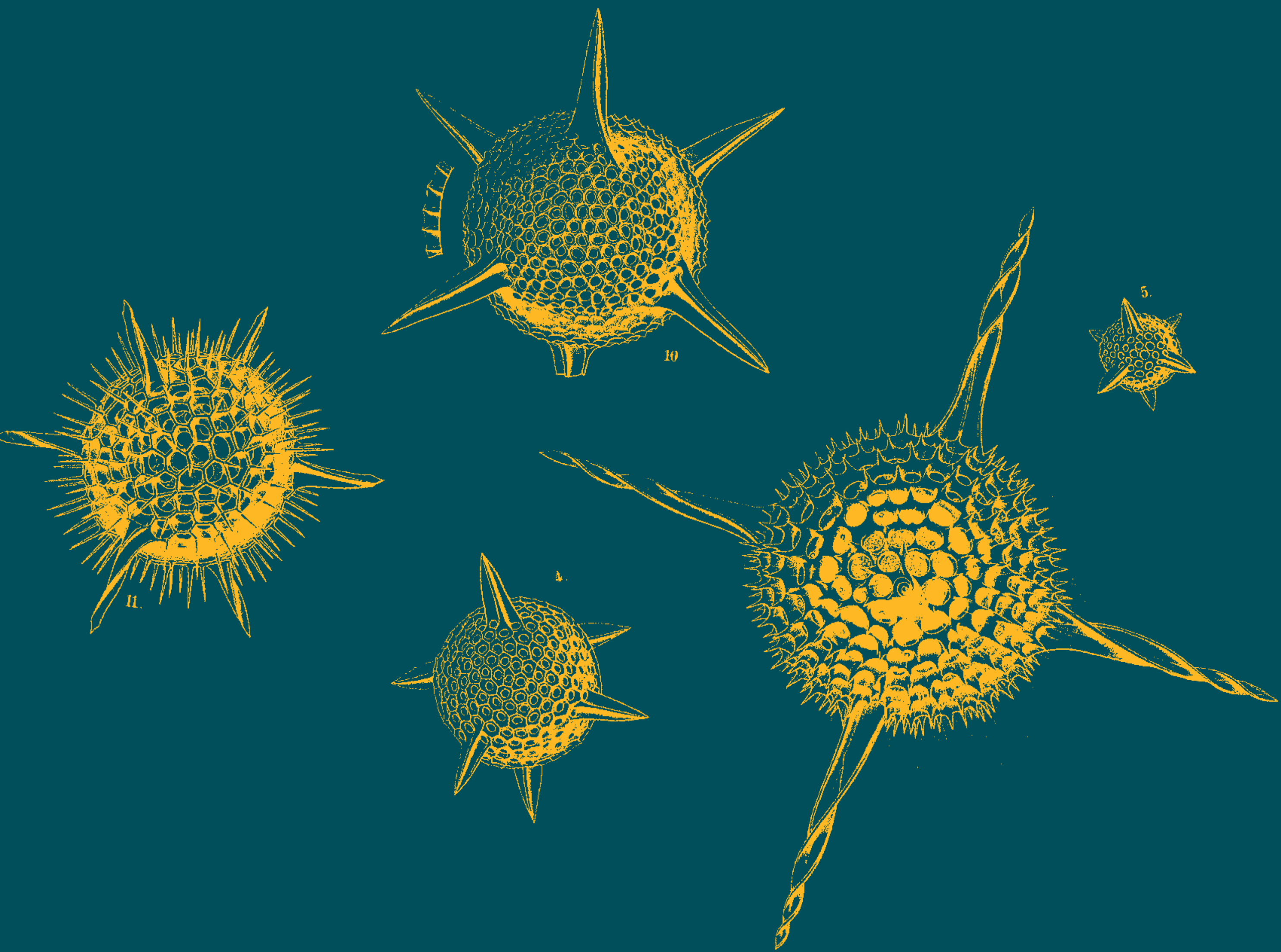
Increasing the size of the pool

A summary of the key issues from the Royal Society's 'state of the nation' report on preparing for the transfer from school and college science and mathematics education to UK STEM higher education



EXCELLENCE IN SCIENCE

THE ROYAL SOCIETY

Cover image: Species of *Hexastylus radiolaria*, a type of plankton, magnified up to 400×, from *Report on the scientific results of the voyage of H.M.S. Challenger*, by Sir C. Wyville Thomson, 1880. From the Royal Society Archive.

Foreword

This fourth and final Royal Society 'state of the nation' report considers the 'pool' of the UK's 16–19 year old students taking mainstream science and mathematics combinations suitable for entry to higher education. It makes three major points about these students.

- Firstly, the size of this 'pool' is critical to the success of any policies to produce more UK science and technology undergraduates to meet the globally competitive ambitions of a knowledge-based economy. England, Wales and Northern Ireland should aim to emulate the high levels of student participation in science and mathematics evident in Scotland. A perpetual cycle of too few of these students feeding through to becoming specialist teachers in schools and colleges needs to be broken.
- Secondly, the quality of this 'pool' needs to be further improved by ensuring that these specialist teachers are provided with subject-specific continuing professional development, that the curriculum they teach is rigorous, engaging and inspiring, and that the schooling structure within which this happens is conducive to the needs of science and mathematics as subjects.
- Thirdly, the potential progression routes for students into higher education must remain as open and transparent as possible aided by relevant and accessible careers information, advice and guidance.

'The UK has great scientific strengths, which underpin our society, culture and economy: we must build on these and continue to aspire to be the best country in the world in which to do science.'

This was a key message from the Society's major policy report of a year ago, *The scientific century: securing our future prosperity*. The Coalition Government has recognised these strengths by largely protecting the overall science budget, though issues remain about the importance of mechanisms for ensuring improved innovation. There are further concerns about the cultural value of science, which need more investigation, preferably in conjunction with the arts and humanities.

While this report does not pretend to solve these concerns or focus on the important area of vocational routes to employment, it does attempt to strengthen further the link between mainstream 5–19 science and mathematics education and higher education. It is only by working together coherently that interested parties in both arenas will collectively defend their case for a high quality education that can give everyone with potential the opportunity to progress, whatever their initial life circumstances. Ultimately, a minority of these will become the next generation of excellent UK scientists and technologists that we so badly need.

Paul Nurse
President of the Royal Society

Increasing the size of the pool

A summary of the key issues from the Royal Society's 'state of the nation' report on *Preparing for the transfer from school and college science and mathematics education to UK STEM higher education*.[1]

1 Background

The series of Royal Society 'state of the nation' reports, of which this is a summary of the final one, has covered key aspects of 5–19 science and mathematics education in the UK. These reports have looked in depth at features of primary, secondary and tertiary science and mathematics education, including participation, attainment, progression and the teaching workforce. They have provided new insight and understanding regarding the strengths, weaknesses and challenges facing each of the four Home Nations, and the UK as a whole.

The Royal Society has identified the role science plays in stimulating the UK's economic growth and more specifically the expansion of (and innovation within) the service sector, which now accounts for 80% of UK employment.[2] Increasingly urgent voices from business leaders are to be heard appealing for more employees with better science, technology, engineering and mathematics (STEM) skills.[3] With insufficient numbers of STEM graduates for the needs of both higher education and employment, a seemingly self-perpetuating cycle has been established, with too few scientists and mathematicians being produced to help inspire and educate the next generations.

2 Major concerns

From the evidence presented in this report, and drawing on the other reports in the 'state of the nation' series, it is clear that breaking this self-perpetuating cycle requires three issues to be addressed:

1. The **size** of the 'pool' in terms of the numbers and proportion of 16–19 year olds studying mainstream science and mathematics qualifications needs to increase in England, Wales and Northern Ireland towards the level of participation seen in Scotland (see figure 1). This will require more specialist science and mathematics teachers to be recruited and retained throughout all phases of 5–19 science and mathematics education within the UK.
2. Improving the **quality** of the 'pool' of 16–19 year old students. This will require subject-specific professional development for the specialists who teach them, a streamlined system of qualifications and assessment, more dynamic science and mathematics curricula, as well as a better understanding of how schooling structures impact learning.
3. The careers information, advice and guidance available to this 'pool' of 16–19 year olds must enable them to make subject choices that will allow smooth **transfer** to STEM higher education courses, wherever they are located in the UK.

Within our 'state of the nation' reports, we have identified the following particular areas for focus:

(i) the primary and secondary curricula.

(ii) access to state-of-the-art laboratory facilities and scientific equipment.

(iii) enrichment and enhancement of the curriculum.

(iv) assessment.

(v) qualifications.

(vi) careers information, advice and guidance.

(vii) teacher recruitment and training—opportunities and programme content.

(viii) retention of teachers, including continuing professional development (CPD) and progression.

(ix) the need to reach, as never before, areas of deprivation.

The levels of participation in science and mathematics particularly outside Scotland indicate problems with the structure of post-16 qualifications provision and an underlying cultural indifference towards science across the population as a whole. Both need to be confronted if attitudes towards and progression in science and mathematics are to become measurably more positive, and if the tremendous investments in initiatives to stimulate young people's interest in these subjects are to have genuinely meaningful returns. Tackling these issues successfully will require an open admission of the extent of the problem, and an unparalleled long-term commitment from a variety of interested parties, most notably Government, employers, professional bodies and the teaching profession.

3 Policy actions

3.1 Actions to increase the size of the pool of post-16 students studying mainstream sciences and/or mathematics

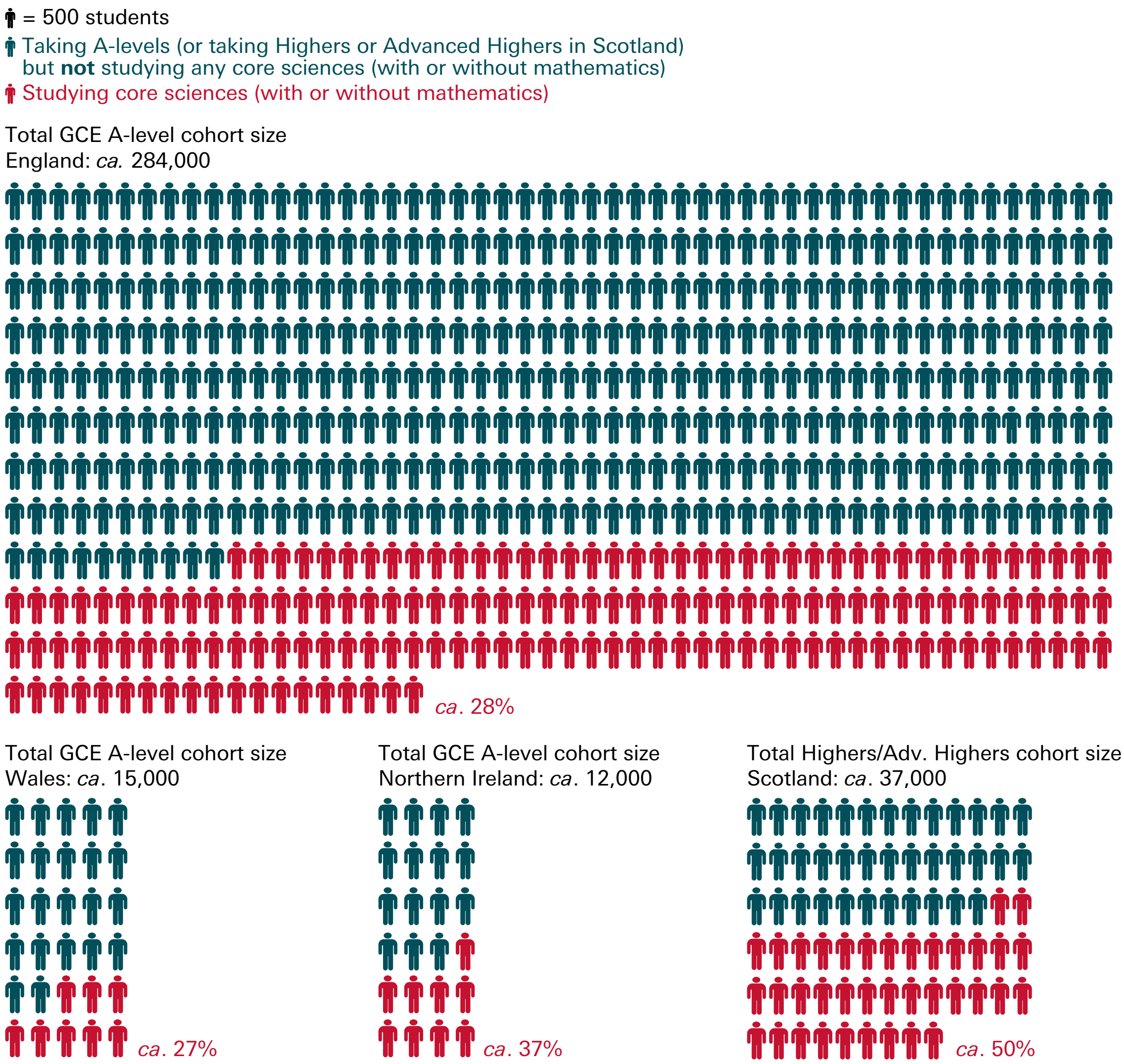
Although it appears that there are enough science and mathematics subject specialist secondary teachers in Scotland, the shortages of such teachers in England and

1 Royal Society (2011). *Preparing for the transfer from school and college science and mathematics education to UK STEM higher education*. London: Royal Society.

2 Royal Society (2009). *Hidden wealth: the contribution of science to service sector innovation*. London: Royal Society. Royal Society (2010*a*) *The scientific century: securing our future prosperity*. Report 02/10. London: Royal Society.

3 CBI (2008). *Taking stock. Education and Skills Survey 2008*. London: CBI. Also CBI (2009). *Emerging stronger: the value of education and skills in turbulent times. Education and Skills Survey 2009*. London: CBI. CBI (2010). *Ready to grow: business priorities for education and skills. Education and Skills Survey 2010.* London: CBI.

Figure 1. The proportion of the student pool in England, Wales, Northern Ireland and Scotland taking core sciences A-levels or Scottish Highers based on 2008/09 data.[a]



Sources: DCSF, Welsh Assembly Government, DENI, Scottish Government.

(a) Core sciences include biological sciences (biology and human biology), chemistry and physics.

Wales limit the extent to which these subjects are taught post-16.[4] Data from this report have shown that there is a significant number of institutions in England, Wales and Northern Ireland that do not enter any candidates in A-level physics or mathematics, and that the overall proportions have been falling. In 2009, 18%, 12% and 43% of all relevant institutions across England, Wales and Northern Ireland[5] failed to present a single physics A-level candidate.

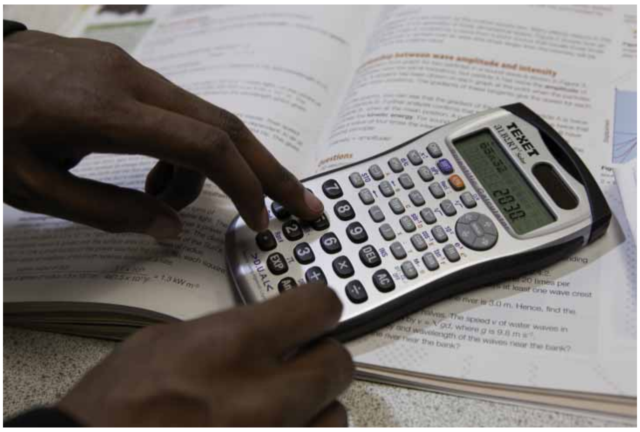
There are other explanations for the proportional falls, but clearly institutions will only be able to offer A-levels in specific subjects if they have sufficient appropriately qualified teaching staff.

In England, the Department for Education has admitted that the targets set by the previous Government for numbers of specialists teaching physics and mathematics will not be met.[6] The Department created a variety of initiatives to boost teacher recruitment, and some have proved more successful than others. But they need to be seen for what they are: measures that, at the national level, have achieved little in terms of solving the fundamental problem of attracting sufficient numbers of science (especially chemistry and physics) and mathematics graduates into teaching. Given that each year UK

4 Royal Society (2007). *The UK's science and mathematics teaching workforce. A 'state of the nation' report*. London: Royal Society. As we demonstrated in this, our first 'state of the nation' report, there are no clear data on the size of the science and mathematics teaching workforce in Northern Ireland. While data in the main report that accompanies this summary suggest that grammar schools have sufficient numbers of these teachers, it is not clear if the shortfall in other secondary schools is due to there being insufficient numbers of such teachers or unrelated difficulties in recruiting specialists to teach in these schools.

5 The dearth of physics in other secondary schools in Northern Ireland contrasts with the strength of this subject in its grammar schools, and suggests that much more could be achieved if the appropriate teaching resources existed.

6 National Audit Office (2010). *Educating the next generation of scientists*. London: The Stationery Office.



universities produce fewer than 10,000 home-domiciled graduates in science and mathematics,[7] and the generally fierce competition for these among employers, it is clear that the solution ultimately lies in generating many more such graduates if the need for specialist teachers is ever to be satisfied. Unfortunately, the crisis in recruitment and retention of science and mathematics teachers has been apparent for more than 25 years,[8] and it will take many more years to achieve a turnaround. As our 'state of the nation' reports have shown, there is a need for action on an unprecedented scale if there is to be any real hope of changing this situation.

Recommendation 1

The UK Government and Devolved Administrations must do all they can to maximise the number of mathematics, chemistry and physics specialist teachers available for employment in secondary schools and colleges.[9] This demands working closely with employers, the STEM community and educational institutions to address weaknesses in the UK's educational systems.

Although A-level is still the most popular qualification for entry to university, the emergence of competitors has inevitably created a patchwork of provision, with institutions having to make tough decisions about which qualifications and subjects to offer for study post-16. Progression routes from some of these qualifications are unclear, which leads to confusion, and this increased 'choice' is actually creating inequity in the system, with students potentially being unable to access the course(s) they desire or are best suited for. Moreover, having such a wide range of qualifications on offer makes it incredibly difficult to measure and monitor the effectiveness and performance of the post-16 qualifications system reliably, particularly when the awarding organisations do not make information on participation and attainment freely available.[10]

Recommendation 2

The increasing diversity of A-level and equivalent qualifications provision (particularly in England) needs to be reviewed, and its impact on the numbers of students taking science and mathematics post-16 evaluated by governments. Awarding organisations should make available detailed data on the participation, attainment and progression of students taking their specifications in science and mathematics.

Scottish students generally take five Highers while their counterparts elsewhere in the UK typically take three A-levels. Data suggest that it is already established practice in Scotland to take post-16 combinations involving two core sciences and mathematics, while the proportions of such students in England, Wales and Northern Ireland are also increasing. Higher education institutions tend to want STEM undergraduates to have taken more than one science subject (excluding mathematics) and many students would welcome being able to take a wider range and number of subjects at A-level and equivalent. A Baccalaureate-type approach to post-16 education is being taken forward in Wales and Scotland and in England a GCSE-based English 'Baccalaureate', an attainmnent measure designed to help drive up the numbers of young people achieving good GCSE grades in five subjects (including science and mathematics) is being introduced.[11] An A-level-based Baccalaureate is needed, too, based on attainment within a coherent framework of educational programmes. The argument for this is consistent with the Advisory Committee on Mathematics Education's (ACME) recent proposals for reforming A-level and equivalent mathematics in England from 2016.[12]

Recommendation 3

In undertaking reforms to A-level and equivalent qualifications in England, the Department for Education should consider modifying their structure to enable students to study a wider range and increased number of subjects than is usually the case now.

7 *Op. cit.*, note 4, p. 98. London: Royal Society.
8 *Ibid.*, p. 13.
9 *Ibid*., p. 17. As this 'state of the nation' report first documents, there are no universally accepted definitions for a 'specialist' science or mathematics teacher across the four Home Nations, and no reliable up-to-date counts exist.

10 Royal Society (2008). *Science and mathematics education,14–19. A 'state of the nation' report on the participation and attainment of 14–19 year olds in science and mathematics in the UK, 1996–2007*, pp. 120–121 London: Royal Society.
11 Michael Gove to Westminster Academy, 6 September 2010, updated 9 September 2010. (See http://www.education.gov.uk/inthenews/speeches/a0064281/michael-gove-to-westminster-academy, accessed 17 November 2010.)
12 See http://www.acme-uk.org/downloaddoc.asp?id=228, accessed 17 November 2010.

It is evident from dialogue with the Scottish Government that Scottish Intermediates have enhanced progression to Highers leading to greater levels of participation at Higher level than would have been the case had they not been available.

Recommendation 4

Scottish Intermediates have proven effective in helping maximise the number of students progressing to Scottish Highers. The Scottish Government should ensure that in reforming its qualification system to suit the new 'Curriculum for Excellence', Intermediates are replaced by a similar and equally successful option.

3.2 Actions to improve the quality of the pool of post-16 students studying mainstream sciences and/or mathematics

Teachers will have a more positive influence on students if they are confident and interested in the subject they are teaching. This requires that they have access to high quality teacher training and career-long subject-specific CPD. The momentum towards 'professionalising' teaching has been increasing over recent years, particularly with the launch of the national network of Science Learning Centres and the National Centre for Excellence in the Teaching of Mathematics. It is vital that continued investment is provided to these organisations.

Recommendation 5

Science and mathematics teachers should undertake subject-specific continuing professional development (CPD) as a part of their overall CPD entitlement. Funding should be maintained for the National Science Learning Centre, the National Centre for Excellence in the Teaching of Mathematics and the Scottish Schools Equipment Research Centre, to allow these bodies to continue to support effective subject-specific CPD for science and mathematics teachers.

England is a divided nation, retaining a mixture of state-funded education systems where students either progress directly from primary to secondary schools, or from primary to a middle school before progressing to upper secondary school. In addition, a growing number of 5–19 'through' schools has been emerging, seemingly encouraged by the lead given by the previous Government in order to counter the dips in performance that many students suffer upon transferring to secondary education.

A study involving 55 maintained schools varying in their gender make-up, specialism and selection policies, identified a variety of factors that contributed to high uptake of science post-16 concerning leadership, pedagogy and the curriculum.[13] However, it remains unclear which of these schooling systems works best for educating children and which, more specifically, is most appropriately geared to optimising attainment and progression in science and mathematics.

Recommendation 6

The Department for Education should investigate the diversity of schooling structures in England, to establish which of these is generally best suited to educating students, and optimising performance and progression in science and mathematics.

As has been suggested elsewhere, an important factor impacting on students' attitudes towards and choice of subjects to study post-16 is their previous experience with these subjects, in terms of the content of GCSEs or equivalent qualifications studied. This experience will be informed largely by the effectiveness of the teaching. It must be remembered that a curriculum is only as good as the teachers who deliver it and, as we have noted here and in our previous 'state of the nation' reports, there is a shortage of science and mathematics specialist primary and secondary teachers across much of the UK.

Recommendation 7

Science and mathematics curricula need to be inspiring and engaging for both boys and girls, whilst retaining rigorous development of subject-specific knowledge and skills. Governments should work closely with experts from learned societies, the higher education sector and other key stakeholders to develop and maintain appropriate subject curricula.

13 DCSF (2009). *Progression to post-16 science. An inquiry into the factors which are influential in achieving high levels of take-up of science subjects post-16*. London: DCSF. (See http://www.stemforum.org.uk/assets/pdf/SNS%20Sci%20post%2016%20wholebook.pdf, accessed 16 November 2010.)

3.3 Actions to smooth progression from 16–19 to higher education

In order to understand the full extent to which the size of the student cohort limits the overall supply of STEM skills to higher education and beyond, the destinations of school and college leavers would need to be analysed. Students holding science and mathematics qualifications have a range of options before them, only one of which might be to study a STEM subject at degree level. Plausible explanations as to why students might not choose to continue studying science and mathematics at university mirror those at the post-16 boundary: lack of enjoyment of the subject, perceived difficulty, insufficient prior attainment, or a lack of knowledge about the types of STEM careers that can lead from a STEM degree could all contribute to constraints on the transfer rate.

A further issue could be the formation of STEM 'deserts' in higher education, which already exist in the physical sciences. Indeed, an A-level student who lives in Norwich and wants to study physics at university will have to travel to London to do so, or a similar distance. As higher education funding is cut and tuition fees rise, these 'deserts' may become much more expansive and could even extend to the biological sciences. Given the many factors outlined above, which affect the flow of students into STEM higher education, there is a clear need for further investigation into the transfer from school and college to higher education.

Recommendation 8

The unique pupil number (UPN), or equivalent, should follow school and college students into and through higher education to make it easier to track student progression. Linking these records to details of the STEM initiatives that young people may have experienced could provide an efficient mechanism for measuring their longer-term impact.

Students' decisions about what to study in school or college, or what career path to pursue are influenced by a range of factors. In addition to their attitude towards

subjects (which is likely to be affected by their prior attainment in them), some of the most powerful influences will be from teachers and students' peers, siblings and parents. Further, it is impossible to ignore the fact that boys tend to favour physics and mathematics and that girls tend to prefer the biological sciences. These biases have been known to exist for years,[14] and as this report shows, they are well established across the whole of the UK. However, it is unhelpful simply to insist that these imbalances be 'addressed', or indeed to throw money at the problem. Instead, more needs to be done to try to understand what is responsible for these biases, with a view to ensuring that follow-up action is informed by reliable evidence.

Recommendation 9

Further investigation is needed into understanding motivations for post-16 students' continuing with sciences and/or mathematics at university. This could include pursuing the following approaches, with a view to taking appropriate action:

(i) Role models: identifying whether the lack of female physics teachers affects girls' perceptions of physics.[15]

(ii) Educational neuroscience: this emerging field of research is enhancing understanding of neurological processes involved in learning as well as factors that influence motivation to learn.[16] There is scope here for collaboration between neuroscientists, cognitive psychologists and educational researchers aimed at developing a shared and more complete understanding of the factors underlying subject preferences among girls and boys.

Another factor that should be of crucial importance in helping students make their choices is the information, advice and guidance (IAG) they receive from within their school or college, the quality and impartiality of which has been strongly criticised. One issue highlighted by higher education admissions tutors is that in their recent experience, students applying for science subjects have not realised that, for the specific course chosen at the specific university, an A-level in mathematics is also required.[17] The encouraging news from this study is that the message about the importance of mathematics for studying STEM at higher education appears to be being heard, though the reason for this is unclear. Overall though,

14 Murphy, P & Whitelegg, E (2006). *Girls in the physics classroom*. A review of the research on the participation of girls in physics. London: Institute of Physics.
15 *Op. cit.*, note 4, pp. 43–48.
16 Royal Society (2011). *Brain waves module 2. Neuroscience: implications for education and lifelong learning*. London: Royal Society. (In the press.)
17 SCORE (2010). *Admissions tutors: round table April 2010. Summary of a discussion event organised by SCORE, April 2010.* London: Science Community Representing Education. (See http://score-education.org/downloads/progression/admissions_tutor.pdf, accessed 6 December 2010.)

the complexity of the provision, matched with the lack of clarity about which subjects are preferred but not required for particular degree programmes, can make the UCAS process very hard to negotiate, especially if a student has little idea of which subject they want to study before they start applying.

Recommendation 10

In England, the Department for Business, Innovation and Skills needs to ensure that the new careers service to be launched in September 2011 is adequately equipped to provide high quality and easily accessible information, advice and guidance (IAG) on STEM careers to school and college students. This should include links to STEM careers-related websites, eg *Future Morph* and *Maths Careers.*

4 Implications for evidence-based policy

By analysing the mainstream science and mathematics subject combinations students have taken, the Royal Society has probed the enormous quantity of information that lies buried within the annual releases of subject entry data. This exercise has not been at all straightforward, and has meant facing complexities similar to those encountered in compiling the previous 'state of the nation' reports. Nonetheless, the richness of the data uncovered is impressive, and there are many aspects that merit both further exploration and explanation by others.

Recommendation 11

The UK Government and the Devolved Administrations should make better use of the data they are collecting on 5–19 science and mathematics education in England, Wales, Northern Ireland and Scotland. They should conduct regular monitoring of the combinations of subjects and qualifications students are taking, gaining understanding of progression from their prior participation and attainment, in order to determine with greater confidence actions to improve the performance of the education systems they are responsible for.

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The Royal Society
6–9 Carlton House Terrace
London SW1Y 5AG
Tel +44 (0)20 7451 2554
Fax +44 (0)20 7930 2170
Email education@royalsociety.org
Web royalsociety.org

The Royal Society

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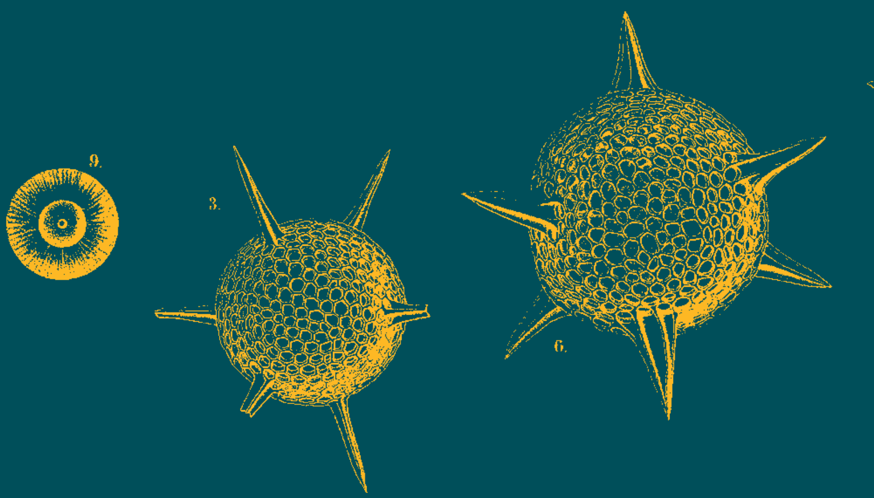
For further information

The Royal Society
6–9 Carlton House Terrace
London SW1Y 5AG

T +44 (0)20 7451 2554
F +44 (0)20 7930 2170
E education@royalsociety.org
W royalsociety.org



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