THE ROYAL SOCIETY

17 April 2017

Response to *Building our Industrial Strategy* Green Paper

Summary

- The Society welcomes the emphasis on science and skills within the Green Paper. These are crucial areas in addressing the UK's productivity gap. Combined with the government spending commitments in the 2016 Autumn Statement and the creation of UK Research and Innovation, this is a strong signal that the government recognises the value of scientific research and innovation to the UK's future. The society also welcomes the Government's ongoing commitment to supporting the full spectrum of research, with resources being allocated on the basis of excellence.

- To have a successful industrial strategy, it is crucial that the UK has the investment, skills and physical, digital and regulatory infrastructure to capitalize on existing and emerging technologies. Consistent leadership, coordination, planning and implementation are required over decades, not years, providing a consistent policy and investment environment. This must support the full spectrum of research and innovation including established industries, scale-ups, start-ups and academia.

- **Investment**

    - Government must aim to stimulate the investment of 3% of GDP in research and innovation by 2025.
    - The Industrial Strategy Challenge Fund can act as an important driver but must be carefully scoped

- **Skills**

    - The UK has significant skills gaps. To remain a world leading destination for science, research and business, the UK needs to invest in its own workforce while continuing to attract the best international talent. This should include strategic initiatives to boost skills and infrastructure in areas of emerging technologies.
    - People with the right skills are essential for all parts of the research and innovation ecosystem including established industries, start-ups, scale-ups and academia
    - Education will be crucial to equip people with the skills that they will need to succeed in the workforce of the future and ensure the UK can benefit from these. Key areas that must be addressed include: having appropriate curriculum pathways to age 18, widening the access of science, technology, engineering and mathematics education to all students, and increasing the supply of excellent teachers in these subject areas.
    - Quality technical education, alongside traditional academic routes, is essential to ensure that people have the skills required for high-wage jobs and employers can get the highly skilled staff they need.
    - Lifelong learning will also be important in a changing work environment and improvements in further education will be required to support an industrial strategy in which economic growth and support for working communities dovetail effectively with changing industrial practises linked to (for example) automation.
    - Future research leaders and entrepreneurs need a broader range of skills, and working across industry and academia should be seen as normal and held in the same regard as careers spent in one or the other. They should also be drawn from the widest range of individuals. We cannot fill the skills gap entirely with home grown talent and so, as the UK prepares to leave the EU, we must ensure the world's brightest and best entrepreneurs and researchers from at home and abroad choose to work and live in the UK.

- **Physical, digital and regulatory infrastructure**

    - Infrastructure investment should aim to reduce the isolation and improve the connectivity of the entire country. High speed connectivity – both through the internet and through transport – will ensure that places that are currently left behind will quickly connect up with the highest growth areas nearby.
    - The UK is respected around the world for its proportionate approach to regulating emerging technologies. A change in the UK's relationship with the EU provides challenges and opportunities to develop a mix of regulatory approaches that will make the UK an extremely attractive place for global companies to research and develop new technologies.

- Place plays a key role in attracting companies to locate their R&D activities in the UK. A successful Strategy should present a national vision while recognising that the UK and its industries are not uniform. Regional strategies should foster local strengths in research, education, innovation and business, taking opportunities to better integrate and grow these, as well as boosting existing centres of excellence.

- Care should be taken to ensure a sector-led approach does not just favour established technologies or major incumbent firms. The industrial strategy must support the growth of emerging technologies that cut across sectoral boundaries such as machine learning and genetic technologies.

Science, research and innovation

What should be the priority areas for science, research and innovation investment?

1. To fully realise the economic and social benefits of research and innovation, the full spectrum of inquiry has to be supported. Applied investigation needs a constant stream of ideas from discovery-oriented work; indeed many benefits of 'blue skies' research are unforeseen but are of transformative use to society.

2. The current reforms to the Research Excellence Framework offer an opportunity to better incentivise the valuable breadth and depth of inquiry across the UK research ecosystem, including interdisciplinary and collaborative work, which is known to often lead to new breakthroughs and innovative commercial opportunities.

3. Linear models of research do not properly describe the multidirectional flow of ideas between different types of study or acknowledge the time lags that sometimes separate investment and substantial returns. Priorities should be governed by two key principles: (1) Resources should be allocated mainly on the basis of excellence and funding decisions should be insulated from political pressure. (2) It is possible to identify emerging areas of technology and take steps to ensure that the research ecosystem is prepared to develop and exploit these. These steps must complement, but not overrule, the governing principles outlined above.

4. It is important to recognise that innovation happens in a range of different ways. While university spin outs of products derived from research are important, a lot of innovation is incremental and based on work in existing companies or ongoing relationships between established companies and academia. Marginal improvements to existing products are very important to many companies.

5. Key to this will be individuals with the skills the UK needs to undertake world-leading research and innovation. We are facing a significant shortfall in skilled workers to fill research, engineering and technology roles. The future of the UK economy will depend on a strong supply of skilled workers from both home and abroad.

6. The government should signal the UK's ambition to compete internationally by setting a target of 3% of GDP for combined public and private R&D spending and at least matching public investment to the OECD average of 0.67% of GDP invested into R&D by 2025. Taking this action now will send a strong message that the UK is open for business, stimulating private and charitable investment, creating jobs and enhancing the UK's ability to compete on the world stage.

7. The Royal Society's long-standing Fellowship programmes, including its flagship University Research Fellowship and Research Professorships, aim to help attract and retain the most talented researchers to the UK. These programmes contribute to the strength and breadth of the UK's research base, as well its knowledge economy. Our newly awarded University Research and Dorothy Hodgkin Fellows are able to apply for support for PhD studentships as an enhancement to their fellowship helping them to build and develop their independent research group. This approach complements the doctoral training centres which are now more prevalent in the UK concentrating doctoral training both scientifically and geographically. It is important to ensure a varied model for doctoral training whilst ensuring high quality training provision.

8. Mobility and collaboration give UK businesses, universities and research and innovation organisations access to a broader range of knowledge, people and facilities than could be obtained in the UK alone. This enables new ideas to be generated, shared and refined and has helped build the UK into the global powerhouse it is today. The Royal Society will be publishing new research on mobility and collaboration in the coming weeks.

9. Research is an increasingly international undertaking and the UK must not only ensure it remains a leading hub of research and innovation but also that we are seen globally as open to the world and keen to offer strong collaborations and partnerships. The Royal Society provides funding through its Newton International Fellowship scheme to attract the best emerging researchers from all over the world to the UK, with follow-on funding to support ongoing collaboration. The Royal Society is also one of the Designated Competent Bodies for the Tier 1 Exceptional Talent visa route open to world class leaders and emerging leaders in the sciences and the arts to come and work and eventually settle in the UK.

10. Government should continue to recognise the potential of open data and open science to enhance the excellence of the science base. They should continue to develop policies for opening up scientific data that complement policies for open government data, and support the development of the software tools and skilled personnel that are vital to the success of both.

Which challenge areas should the Industrial Challenge Fund focus on to drive maximum economic impact?

11. In the Autumn Statement, the government announced the development of a DARPA-like research body. Currently there is no existing framework for funding of this type within the UK. However, the UK can learn from existing international approaches to achieve an ambitious rate of progress. The Royal Society is currently investigating the factors that should inform the design of arrangements for independent challenge-led funding in the UK. This includes looking into how to support flexible and rapid decision making, and consideration of intellectual property. We expect to report in June.

12. A challenge-based approach can help develop applications that address real-world issues. The Government has already recognised the significance of robotics and AI in extreme environments as an area for attention by the Industrial Strategy Challenge Fund. Machine Learning should be considered a key technology in this field, and one which underpins advances in AI and robotics across the board. The Royal Society's machine learning project has been investigating the

potential of machine learning in industry sectors including manufacturing, the legal sector, pharmaceuticals, energy, cities and transport, and will be publishing its report on 25 April 2017. Another inclusion in the proposed Industrial Strategy Challenge Fund areas is bioscience and biotechnology. The Society is developing a work programme on genetic technologies which have the potential to increase productivity across a range of sectors including agriculture and healthcare. The Society's *Progress and Research in Cybersecurity* report also highlighted the value of a challenge-based approach to cybersecurity research.

What else can the UK do to create an environment that supports the commercialisation of ideas?

13. Research should have the widest possible benefit to society, and new knowledge and discoveries should be applied beyond the academic setting wherever possible. Effective translation is essential for this to take place. Along with the Royal Academy of Engineering, Academy of Medical Sciences and the Wellcome Trust, the Royal Society is developing a series of high level commitments to ensure that the UK can effectively translate its research findings into economic and societal benefits. Through the work of the four organisations, we bring together considerable experience and evidence around the successes of and barriers to the successful translation and technology transfer in the UK, and what good practice looks like.

14. Over the past 10-15 years, the UK technology transfer system has grown and professionalised, with a greater emphasis placed on universities. The UK is ranked fourth globally for university-industry collaboration (Global Innovation Index), and its universities have seen increases in the incomes generated from patents (£49m to £155m), and from industry collaborations (£698m to £1.257bn) between 2003/04 and 2014/15. This is to be welcomed, but there is more to be done and we support the intention laid out in the Green Paper to "commission research on different institutions' principles and practices on commercialisation."

15. In academia, commercialisation of research should be accepted as a normal activity and its outputs (such as patents) held in the same regard, particularly in recruitment, retention and promotion of staff, as publication records currently are. Researchers need to be given the time and opportunity to explore the translation of their research and training and development to enable them to do so successfully.

16. Funding is also important, and we have observed that access to proof-of-concept and seed funding remains a challenge for researchers trying to commercialise their work. Schemes, such as our Innovation and Translation Awards (previously Brian Mercer Awards), which offer relatively small, short-term grants focused on taking an aspect of research through proof-of-concept to near market readiness are an important part of this commercialisation ecosystem.

17. There is no 'one size fits all' approach to strategies and policies of universities and their Technology Transfer Offices (TTOs), as noted in the Commons Science and Technology Committee's recent report[1]. However, they do need to be transparent and flexible and be harmonised wherever possible across the sector to deliver impact. The funding for TTOs needs to be sustainable so that they can prioritise delivering longer-term impacts over quick returns on investment and there is also a need to develop networks of experienced individuals who can advise the TTOs and mentor researchers seeking to commercialise their ideas. As the Committee highlighted, "lack of a 'one-size-fits-all' approach to successful technology transfer does not preclude the sharing of best practice". Some of the issues that have been raised in relation to TTOs include:
    a. Transparency and flexibility around the strategic aims, policies and practice of TTOs.
    b. Governance and resourcing of TTOs so that they are able to prioritise long-term impacts above short-term revenue generation,
    c. The over-valuation of intellectual property and inflated equity demands made by some Universities

[1] Commons Science and Technology Committee (2017) *Managing IP and Technology Transfer*

d. Access for university and institutions to expert networks needed to effectively support technology transfer.

18. For TTOs to take longer-term approaches to technology transfer, they need supportive funding and a recognition that they may operate as cost centres as well as income generators to the university. External sources of funding such as Higher Education Innovation Funding (HEIF) play an important role in supporting knowledge exchange, of which technology transfer is only one activity.

19. We believe that working across industry and academia should be seen as a normal activity, and held in the same regard as careers spent solely in one or the other[2]. Boosting mobility between industry and academia would yield substantial dividends for the UK. Much innovation takes place in industry, which can benefit from individuals with skills and experience from other sectors. However, the Dowling review noted that mobility between academia and industry is less common in the UK than in other countries. In a recent series of case studies, we have highlighted examples of successful researchers who have worked across both sectors while keeping excellent, innovative research at the core of their careers[3] .

20. At the Society, we have also been supporting scientists involved in outstanding collaborative projects through our Industry Fellowship scheme, which has funded the secondment of nearly 200 individuals from academia to industry and vice versa since 1998. Our evaluations of this scheme demonstrate that these Industry Fellowships lead to the growth of long term business-university collaborations, significant commercial and academic outputs, follow-on funding and investment that far exceeds the initial investment and the enhancement of the individuals' career through obtaining new knowledge, skills and a wider network. It is important that more opportunities for secondments are funded and available at all stages of peoples' careers, and that these schemes offer the types of flexibility that allows companies of different sizes to use them.

21. The Society would welcome the opportunity to work with the team commissioned to undertake research into commercialisation practices as outlined in the green paper, to share the examples we have been made aware of and highlighted through our Science, Industry and Translation work.

How can we best support the next generation of research leaders and entrepreneurs?

22. Future research leaders are expected to be not only strong in research but also develop the skills to be excellent leaders, communicators and managers, able to demonstrate the 'impact' of their research to funders and the public.

23. The Council for Science and Technology recently wrote to the Prime Minister to outline the importance of entrepreneurship education to help scientists and engineers turn new ideas into innovative business that can increase productivity, support economic growth and create jobs[4].

24. The Society provides a suite of training activities to our research fellows including our course *Innovation and the business of science,* which is run in partnership with the Imperial College Business School. This helps researchers understand what it means to be an effective leader, the relationship between science and industry and what it means to be a scientific entrepreneur.

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[2] UK National Academies (2016) *Open for Business*

[3] Pushing the revolving door, The Royal Society (2017)

[4] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/592424/Improving_entrepreneurship_education_-_cst_letter_-_more_accessible.pdf

We delivered this course to 93 researchers in 2016/17 including researchers supported by the MRC, BBSRC and Wellcome.

25. In 2015 the Society undertook an internal evaluation to track the commercial activity of our grant and fellowship holders, highlighting ten examples in our Translating innovations case studies[5]. For many of the researchers we spoke to, two elements of support were instrumental in them undertaking commercial research – the freedom and independence a Royal Society grant or fellowship gave them to explore the possible commercial applications of their research and participating in our *Innovation and business of science* course.

26. Many accelerators, competitions and programmes exist already to train, develop and build the networks of entrepreneurs, across different sectors and at a variety of career stages. There is an opportunity, through the review being undertaken by Professor Tim Dafforn, to highlight the most effective schemes and to evaluate what aspects of support are most useful for entrepreneurs.

27. Opportunities are also needed for entrepreneurial scientists and SMEs to meet potential investors. This will enable investors to make more informed decisions through better understanding of the scientific products and help scientist entrepreneurs develop the skills to navigate the finance system and grow their businesses.

28. There is also value in adopting a strategic approach to best support research leaders and entrepreneurs in emerging areas, for example machine learning. While recent acquisitions of UK start-ups show the success of the sector they may also reinforce a sense that the UK environment and investor expectations encourage the sale of technologies and tech companies before they have reached their full potential.

29. It is also important to remember that any lack of diversity within science, technology, engineering and mathematics careers represents a waste of talent that the UK should be accessing to reach its full potential. Action must be taken to ensure that the next generation of research leaders and entrepreneurs reflect the diversity of the UK and that they gain the skills to excel. The Society is engaged in work to examine the causes of any gaps in participation and attainment and will identify promising approaches (e.g. pedagogies or interventions) that could boost science attainment and progression among students.

30. All Royal Society Fellowship programmes have in built flexibility to allow researchers to take career breaks or to work flexibly and there are a range of schemes to attract back, re-train and retain talented researchers after career breaks. This type of model could be usefully extended to the industry sector.

How can we best support research and innovation strengths in local areas?

31. A successful Strategy should present a national vision while recognising that the UK and its industries are not uniform. Different sectors and places may offer distinct opportunities. Regional strategies should foster local strengths in research, innovation and businesses, taking opportunities to better integrate and grow these, as well as boosting existing centres of excellence.

32. It is clear from our engagement with research-intensive industry that a number of factors influence decisions over where to locate. These include access to a skilled workforce, access to innovation through proximity to universities or research institutes, transport infrastructure and the broader business environment.

[5] Translating innovation, the Royal Society (2015)

33. For example, Charles River Discovery UK, who work in drug discovery research at sites in Harlow and Cambridge demonstrate that these factors are often interlinked. In conversations with the Society they cited access to talent as a key factor for success and highlighted that being able to attract new talent in emerging technology areas from a global talent pool depends on multiple factors including a buoyant local economy, where companies offer competitive salaries, and a convenient location. Due to the collaborative nature of the business, they also identified, good transport links as critical. The M11 corridor supports the Harlow and Cambridge sites, with Stansted being an important hub for European travel.

34. Lilly the US pharmaceutical firm and one of the biggest US investors in R&D in the UK told us that 'At Lilly, our success depends on access to the best talent, access to innovation and a favourable commercial environment, which is why our largest neuroscience research facility is located in the UK. The UK has a world class science base and to ensure the UK's future success, we need not only to operate at the interface between life science, digital and engineering, but also encourage a good ecosystem, including access to a world class financial market.'

Skills

What more can we do to improve basic skills? How can we make a success of the new transition year? Should we change the way that those resitting basic qualifications study, to focus more on basic skills excellence?

35. Ensuring that science, technology, engineering and mathematics careers are open to all is essential. A broad curriculum that includes science and mathematics to 18 will improve the skills pipeline. By 2030 all young people should be learning science and mathematical skills as part of coherent curriculum encompassing academic and technical education across a broad range of subjects. This approach will help the Government to achieve its ambition of increasing take-up of mathematics and science at university, and provide a working population more resilient to changing work requirements.

36. We note that 50% of post-16 learners do not achieve grade C in GCSE Mathematics (and English) and are expected to continue studying these subjects post-16.[6] Resitting GCSE Maths is often a negative experience and results are generally poor, especially for those with prior grades lower than D.[7]

37. Removing the barriers to accessing science, technology, engineering and mathematics education faced by disadvantaged and underrepresented groups will become increasingly important in meeting the skills needs of the UK economy.

38. Evidence suggests that educational attainment in the sciences and economic disadvantage are closely related. However, this relationship is complex and is mediated by factors such as the level of literacy, scientific reasoning and metacognitive skills, all of which can be targeted for intervention in schools to support children from low socio-economic backgrounds. Research commissioned by the Royal Society and the Education Endowment Foundation, due to be published in spring 2017, will help to elucidate some of these complexities and mediating factors by studying closely the causes of, and potential remedies to, poverty-related attainment gaps.

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[6] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/180504/DFE-00031-2011.pdf

[7] http://www.acme-uk.org/media/20266/mathsto18.pdf

39. The Institute of Physics report *Opening Doors* on gender found that girls are still receiving the message that subjects are gender specific with 45.6% feeling that girls are often steered towards art and humanities and only 25.4% feel that old –fashioned gender stereotypes are challenged by their school. The Equality Challenge Unit (ECU) report *Experiences of black and minority ethnic (BME) staff in HE in England*[8] found that BME staff were more likely to report having fewer opportunities to develop research capacity and enhance their promotion prospects and a lack of mentoring and support for career development, and difficulties in gaining promotion.

40. As well as having the skills and opportunities needed in science, technology, engineering and mathematics, encouraging more young people to consider studying these subjects, or having a related career is essential. Creative and experimental approaches that develop the natural curiosity and creativity of young people are particularly important for keeping students interested and engaged in science, and for equipping them well for the future, whether or not they pursue a career in science.

41. The Society's Partnership Grants scheme supports UK schools or colleges to partner with professionals to offer their students the opportunity to carry out projects. Early findings from an analysis of the British Science Association CREST awards (which are very similar in principle to the Society's Partnership Grants) indicated that taking part in the Silver CREST award leads to a small increase in attainment and progression in science, with an indication that this increase is greater for students from disadvantaged backgrounds, improving social mobility.

42. There is a great need to address the shortage of specialist science, mathematics and computing teaching and to ensure greater access to subject specific ongoing professional development for teachers. Data from the latest review of teacher shortages by the Migration Advisory Committee shows a growing shortfall in the number of new entrants specialising in maths and computing. In England, the shortfall in the number of mathematics entrants required has increased from 8% in 2014-15 to 16% in 2016-17. Across the same time period, the shortfall in computing has increased from 15% to 32%. In comparison, physics faces a 19% shortfall in 2016-17 whilst the target for biology was exceeded (115%) and chemistry was at 99%.[9]

43. Creative and experimental approaches that develop the natural curiosity and creativity of young people are particularly important for keeping students interested and engaged in science, and for equipping them well for the future, whether or not they pursue a career in science.

44. A focus on maintaining high standards in Initial Teacher Education (ITE) and professional development is essential for the supply and retention of teachers. In our *Vision* report, we emphasised the need for teachers to gain mastery over digital technologies to enhance learning, and to engage with current educational research in ITE. Our Advisory Committee on Mathematics Education (ACME) has published guidance for STEM policymakers on delivering effective ITE for mathematics teachers[10]. ACME's expert group on professional development in mathematics education advocates a personalised but collaborative approach to professional development which supports teachers to develop specific knowledge and skills.

45. There is a growing need across the labour market for mathematics, computing and wider digital skills. Building on our review of computing education, *Shut Down or Restart?* The Royal Society has partnered with Microsoft and Google to investigate the challenges faced by teachers delivering computing education and computer science and share best practice. This project, due to report in this year, will provide evidence of best practice through its analysis of computing

[8] Equality Challenge Unit (2011) *Experiences of black and minority ethnic (BME) staff in HE in England*

[9] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/585998/2017_01_26_MAC_report_teachers_SOL.pdf

[10] http://www.acme-uk.org/home

teachers' experiences as well as of the experiences of pupils and we will be happy to share our findings.

46. One example could be in machine learning where schools need to ensure that key concepts are taught to those who will be users, developers, and citizens. The Government, maths and computing communities, businesses and education professionals should help ensure that relevant insights into machine learning are built into the education curriculum and associated enrichment activity in schools over the next five years. More broadly, to thrive in an environment augmented by machine learning, and in which machine learning is a key tool for daily activities and work, citizens will require data literacy skills, which enable them to use and interact with data, and an understanding of the strengths and weaknesses of technologies such as machine learning.

What skills shortages do we have or expect to have, in particular sectors or local areas, and how can we link the skills needs of industry to skills provision by educational institutions in local areas?

47. There is a consistent, ongoing demand for STEM skills across all parts of the country and most industry sectors. 32% of UK firms have difficulties recruiting staff with skills in science, technology, engineering and mathematics[11]. Research by the ScaleUp Institute found that 82% of scale-up leaders stated that access to people with the right skills was the biggest barrier preventing their growth[12].

48. Strong links between schools and industry are essential for ensuring the knowledge and skills of young people meet the broad and fast-changing requirements of employers. Our recent joint report with the CBI, *Making Education Your Business*[13], provides guidance for connecting STEM education and training to the labour market, particularly focusing on the roles businesses can play in supporting teachers.

49. Data and quantitative skills are a particular area of acute concern across science-using industry sectors. As many as 58,000 data science jobs are being created each year in the UK and demand is outstripping supply. GSK for example has reported that 25% of their vacancies in data science have remained vacant over the past 18 months. As well as growing the underlying pipeline of trained data scientists with the necessary depth of quantitative skills to meet these demands, there are other issues that need to be considered when addressing this gap, including:
    - Career signalling from industry to the education system about the types of roles data scientists fill within their organisations and the types of statistical and computing skills needed;
    - Training of data scientists with appropriate business and communication skills so that the findings of statistical analyses can be communicated in terms of the business context through which they will be applied;
    - An ability to work in interdisciplinary teams and apply creative problem-solving in new research areas of featuring a high degree of uncertainty;
    - The use of tools such as machine learning, AI and data visualisation that can aid and support data analysis.

    Universities and business need to work together, e.g. through the exchange of professionals between organisations or by the former offering training and CPD, to build appropriate curricula that address these challenges.

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[11] http://www.cbi.org.uk/index.cfm/_api/render/file/?method=inline&fileID=92095A98-3A90-4FBD-9AF891997B103F50

[12] http://www.scaleupinstitute.org.uk/scaleup-review-2016/

[13] https://royalsociety.org/topics-policy/publications/2016/making-education-your-business/

50. Machine learning is a rapidly progressing area, and one which will be in demand across a range of fields. In the short term, new mechanisms are needed to build capability in machine learning. Increasing the pool of people who have advanced machine learning skills. This could be through government support for advanced courses, for example at masters level.

51. Computing is another area of concern where the UK's competitiveness will depend on a home-grown, reliable and increasing supply of highly skilled graduates with deep knowledge in computing disciplines, and the skills to operate in multidisciplinary and fast changing environments across industry and research. A high level of digital literacy across the workforce is also important. Acute skills gaps must be filled by recruiting from overseas to maintain UK companies' ability to innovate and develop new technologies

52. We believe that it is important that science students are able to gain work experience during their degrees as this makes them highly valued by many employers, but in many subjects it is difficult to find employers willing to offer such work placements and for many smaller companies it can be particularly difficult to offer such experience. In a recent survey of 14-18 year olds in England, 28% said they wanted to do science, technology, engineering and/or mathematics related work experience but were unable to[14], Interesting work in this area is being done by organisations such as Founders4schools, Workfinder and the Greater London Authority.

53. While we can increase the numbers of home grown high skilled workers, science and innovation are increasingly global undertakings. 28% of academic staff in the UK are from outside the UK and a third of UK start-ups were founded by non-UK nationals. As the UK prepares to leave the EU, we must encourage the world's brightest and best entrepreneurs and researchers from at home and abroad to choose the UK. It will be important to ensure that any new immigration arrangements continue to enable us to recruit those with strategically valuable skills, and facilitate short-term visits for conferences or collaborations. Strategically valuable skilled individuals include not just successful leaders in research fields, but the early-stage researchers, technologists and technicians with specialist expertise that support them as well as those with entrepreneurial and management skills.

How can we enable and encourage people to retrain and upskill throughout their working lives, particularly in places where industries are changing or declining? Are there particular sectors where this could be appropriate?

54. Ongoing educational opportunities to support lifelong learning and career development will become increasingly important to enable people to learn new skills as the jobs UK employers need their staff to undertake change over time.

55. As part of its programme of work on data, which includes an upcoming report on machine learning and work with the British Academy on data governance, the Royal Society is currently considering a project on the future of work.

56. It's never too late to become a scientist and we work hard to dispel the myth that there is only one way to be a scientist. The Royal Society's video series 'I wasn't always a scientist'[15] reveals the stories of scientists who didn't take traditional routes into their scientific careers.

[14] https://wellcome.ac.uk/what-we-do/our-work/young-peoples-views-science-education

[15] https://royalsociety.org/topics-policy/diversity-in-science/i-wasnt-always-a-scientist/

57. These elements will be important in contributing to the social mobility that will allow the greatest number of people to enjoy the maximum benefits of a growing economy driven by science and innovation.

Infrastructure

How can local infrastructure needs be incorporated within national UK infrastructure policy most effectively?

58. It is important to ensure that scientific infrastructure is well served by traditional infrastructure such as rail. For example, Cambridge – one of the world's leading research and innovation hubs - is too isolated from Harwell – one of our top research campuses.

59. There are opportunities for research funders, institutions, cities and businesses to work together to cluster facilities and expertise and embed strategically important research networks across the UK. However, if UK funding becomes increasingly regionalised, the risk of duplication and unhelpful competition grows. Aligning the planning and resourcing of science and regions could help turn regions into hubs of excellence with distinctive opportunities for growth.

60. A successful Strategy should present a national vision while recognising that the UK and its industries are not uniform. Different sectors and places may offer distinct opportunities. Regional strategies should foster local strengths in research, innovation and businesses, taking opportunities to better integrate and grow these, as well as boosting existing centres of excellence.

61. The UK public landscape for research, higher education and innovation is currently undergoing major reforms at a national level. Under the right leadership and strategic direction, the proposed creation of UK Research and Innovation (UKRI) offers opportunities to make more efficient and strategic investment in national research programmes and capabilities. This could help address disconnects between capital investment and funding for operational costs (the "batteries not included" problem), which has led some publicly funded research facilities not being used to full capacity due to shortfalls in the budget available to cover running costs.

62. Increasing access to data which is in a machine-friendly form could catalyse further innovations based on machine learning, and help bring about its benefits. Such data can be made more accessible to machine learning systems by ensuring it is curated in a machine-readable way, based on the increased use of open standards. For instance, in an environment where data is used to support the functioning of cities – through transport, energy and services – a data infrastructure is needed. Such new infrastructure would define the data that needed to be collected, provide mechanisms to make this data open and usable, and ensure that it is produced in a way that is interoperable between systems. For companies operating in such an environment, data would be both an asset and a revenue stream, and used or shared.

Business growth and investment

What are the most important factors which constrain quoted companies and fund managers from making longer term investment decisions, and how can we best address these factors?

63. To fully realise the economic and social benefits of research and innovation, the Government needs to provide a consistent policy and investment environment over time. The commercialisation of research requires patient and sustained investment. With UK investors commonly expecting returns within two to five years, there is a financial returns timeframe mismatch between these expectations and what most products of research can deliver. Long-

term timeframes are required to realise the full potentials of new scientific discoveries, whether that is bringing a new drug to market or developing technologies to meet challenges such as energy or climate change. The science and finance communities would benefit from greater exposure to each other. It is important that new policies and programmes are robustly evaluated using long-term economic and social benefit metrics.

What are the barriers faced by those businesses that have the potential to scale-up and achieve greater growth, and how can we address these barriers? Where are the outstanding examples of business networks for fast growing firms which we could learn from or spread?

64. As previously mentioned, the desire for short-term gain leads to short-term business decisions that negatively impact on businesses' ability to grow. Our Fellows have raised concerns to us that too many businesses focus on selling out rather than scaling up. This can reduce their spending on R&D and may be why the UK lacks large companies to rival those in the United States. There is a greater need for investment based on a solid understanding and belief in the business and innovation rather than short-term gains.

65. 51% of UK start-up employees come from outside the UK[16]. Access to a skilled workforce is a common barrier for companies looking to scale up quickly. This not only includes the ability to recruit skilled scientific researchers, but also technical staff [17]and entrepreneurs and business leaders who are experienced in growing companies. Where the availability of talent within the UK is insufficient, immigration and visa schemes must allow companies to recruit internationally and this must be considered as part of the Brexit negotiations.

66. In order to sustain the growth of a company, a key need exists for a pool of experienced chief executives and business leaders who can provide advice and mentoring or even be hired by fledgling start-ups to enable them to grow into SMEs. Much of the weakness with the translation of good ideas into significant businesses is not with the academics – who one should not expect to be skilled at building and running a company – but with the supply of really good chief executives.

67. Companies looking to scale-up have also identified the need for graduates to have gathered work experience before they graduate and enter the workplace.

68. Over the past three years, the Society has supported Silicon Valley Comes to the UK, which matches fast growing UK companies with Silicon Valley entrepreneurs to provide advice and mentoring. The types of bespoke mentoring and advice schemes such as SVC2UK and the London Stock Exchange's ELITE programme, are valued by the CEOs of scaling businesses and can play an important role in connecting the leaders of science-based companies with experts in finance, investment and business growth. However, many science-based companies undertake long-term R&D before bringing new products to market and may not be classed as fast-growing under the metrics used to judge entry to these types of programmes. Therefore, there is a risk that these companies will miss out on the support needed to scale, damaging their potential to bring about long-term social and economic benefits to the UK.

69. For machine learning start-up companies, perhaps the most critical issue is human capital and talent. New companies will not have the reputational pull of the large tech companies, nor will they be able to offer potential recruits comparable packages. When combined with the lack of

[16] European Start Up Monitor (2015)

[17] http://www.gatsby.org.uk/uploads/education/reports/pdf/report-of-the-independent-panel-on-technical-education.pdf

security in an early-stage company, recruiting employees in this key area can be especially difficult.

Procurement

Are there further steps that the Government can take to support innovation through public procurement?

What further steps can be taken to use public procurement to drive the industrial strategy in areas where government is the main client, such as healthcare and defence? Do we have the right institutions and policies in place in these sectors to exploit government's purchasing power to drive economic growth?

70. For every £1 spent by the government on R&D, private sector R&D output rises by 20p per year in perpetuity, by raising the level of the UK knowledge base[18].

71. Public procurement can play an important role in supporting innovation. One area the Society has looked at is cybersecurity where Government has introduced measures like the Centre for Defence Enterprise and the Small Business Research Initiative (SBRI), which has recently been used to fund some cybersecurity procurement activities. The SBRI is a useful innovation, providing valuable opportunities for early-stage and small to medium enterprises (SMEs). For the best results, government procurement, including through the SBRI, should encourage and allow bidders to take advantage of the full range of excellence and expertise available across SMEs, academia and industry.

Affordable energy

How can the Government, business and researchers work together to develop the competitive opportunities from innovation in energy and our existing industrial strengths?

72. The UK faces a challenge in deciding how it can transition to a low emission future whilst pursuing an active industrial strategy that creates growth and jobs. The Royal Society has embarked on a programme of work on energy and our emerging output provides thoughts on interesting competitive opportunities

- *Electrochemistry and energy storage.* Electrochemical energy storage will play an increasing role in ensuring a reliable supply of low carbon energy. This will be seen particularly in the transport sector. Vehicle manufacture is an early adopter. This will mostly rely on currently established technologies, such as lithium batteries. Battery manufacturing will become one of the most important areas of vehicle manufacture. There is some evidence that motor manufacturers may co-locate with battery production. In the longer term there will be new energy storage technologies for not only vehicles but also a greater role in grid storage (initially daily storage, but with a goal of inter-seasonal storage). The UK has global strength in R&D for energy storage across a number of British universities. This is an entirely foreseeable area for UK competitive advantage.

- *The potential for economic use of carbon dioxide.* Carbon dioxide can be used to manufacture new fuels that would reduce the need to extract and use virgin fossil fuels in sectors such as aviation, and to manufacture a range of organic chemicals, notably polymers, with enhanced physical and mechanical properties. Catalysis is the key here, as well as

[18] Jonathan Haskel, Alan Hughes, Elif Bascavusoglu-Moreau (2014) The Economic Significance of the UK Science Base A Report for the Campaign for Science and Engineering

access to low carbon energy and green hydrogen. The UK is one of the three strongest countries in the world in the field of catalysis, breakthroughs in this area have the potential to provide UK competitive advantage. By integrating research and innovation in these three areas of low-carbon energy, catalysis and green hydrogen would draw in industry and academia to develop the catalysts and processes that will form the basis of manufacturing technologies. These will benefit multiple UK industry sectors, drive competitiveness and inward investment in UK supply chains, and deliver technology and process solutions to sell into global markets. Demonstrators will also be needed to test technologies and explore whether carbon dioxide use can become commercially viable at large scale and we believe that the private sector would be ready to act in this capacity. There are demonstrator candidates in Wales and Teeside that could produce significant clusters, and companies from majors to fast-growing SMEs would benefit. The impact of these advances will impact the broader sustainable manufacturing agenda but using carbon dioxide will be a key component.

73. Possible future projects include low carbon production of hydrogen; new means to capture and harvest energy, including solar and bioenergy; the potential of using bioenergy with carbon capture and storage; and the role of data science to help meet carbonisation goals. The output of each project will be a high level policy briefing that explains the current evidence to help answer these problems. The Royal Society may also carry out a final project that identifies any overlaps in these areas of transformational science and technology; for example, ways to strengthen the UK's research and innovation system. Tackling the various problems facing the UK's energy system may require developing solutions on different timescales: short, medium and long term. Energy innovation is multi-decade, and so the urgency of climate change needs low carbon technologies to be developed and deployed quickly. However, this should not be to the detriment of longer term, blue skies research.

Sectoral policies

How can the Government and industry help sectors come together to identify the opportunities for a 'sector deal' to address – especially where industries are fragmented or not well defined? How can the Government and industry collaborate to enable growth in new sectors of the future that emerge around new technologies and new business models?

74. In establishing new sectors, the Government should collaborate more broadly than just with industry, in particular with academia and the education system, ensuring that it engages early with all aspects of the value chain from cutting edge research to the end-user. Through our Transforming our future conference series we have highlighted the current state of potential emerging industry sectors in the UK, including machine learning, robotics, satellite applications and synthetic biology. The higher education sector plays an important role in this emergence, as it is often from here that new companies developing the commercial applications of these technologies first appear. However, the growth of a new sector is dependent on established industry taking up new technologies being developed in academic research but this can be inhibited if there is a lack of clear understanding between industry's problems and the potential solutions provided by the new technology. Greater alignment between both sectors is therefore required. Furthermore, by ensuring the HE sector is involved at an early stage of sector development, it can work with government and industry proactively, rather than reactively, develop courses needed to train the skilled workforce that will be required.

75. It is important to recognise that some sectors of industrial strength largely operate through many dispersed smaller companies without the same profile as sectors with one or two bigger companies. Their contributions to the economy are significant although they do not always have the same profile. These sectors must also be supported.

76. The UK is well-placed to capitalise on its strengths to continue to provide an attractive environment that will encourage growing companies to locate themselves here. The UK is respected around the world for its proportionate approach to regulating emerging technologies, such as the application of embryology research to reproductive technologies, in a way that balances emerging scientific understanding and competing values. This has enabled new techniques to be researched and made available to patients in the UK with public confidence.

77. A change in the UK's relationship with the EU provides challenges and opportunities to develop a mix of regulatory approaches that will make the UK an extremely attractive place for global companies to research and develop new technologies.

78. The Royal Society's work on machine learning has shown that there is significant benefit to be gained by using these technologies in a range of industrial sectors, as noted earlier. For example, manufacturing could see a step change in efficiency through use of machine learning to optimise supply chains and production processes. It can be used to improve parts of the manufacturing process, such as visually checking for faults. It can form the basis for innovation in product development, such as the use of machine learning to finesse beer recipes to create brews that incorporate the feedback of thousands of customers. One barrier to its uptake is the ability to share data across the sector to develop more accurate algorithms. Solutions to the challenge of sharing data while maintaining commercial confidentiality could be technological, or could be met through robust commercial agreements to enable companies sharing data to extract financial value from data trade. Finding these solutions is a governance challenge that is significant to the UK's competitiveness in this area.

Driving growth across the whole country

Do you agree the principles set out above are the right ones? If not what is missing?

79. We have addressed the principles in other areas but also wanted to comment on the issue of *local connectivity with strategic infrastructure investment.* For the benefits of economic growth to be widely dispersed geographically rather than concentrated in a few dense clusters, infrastructure investment should aim to reduce the isolation and improve the connectivity of the entire country. High speed connectivity – both through the internet and through transport – will ensure that places that are currently left behind will quickly connect up with the highest growth areas nearby.

What are the most important new approaches to raising skill levels in areas where they are lower? Where could investments in connectivity or innovation do most to help encourage growth across the country?

80. In order to thrive in the global economy the UK will need to be smarter. Quality technical education, alongside traditional academic routes, is essential to ensure that people have the skills required for high-wage jobs and employers can get the highly skilled staff they need. To ensure that the skills pipeline is working, we also need to look at our schools. The Government should also ensure that by 2030 all young people are learning science and maths skills as part of broader education to age 18.

81. We have referred earlier to the need to widen access to science, technology, engineering and maths education and our work with the Education Endowment Fund and to the importance of having strong links between schools and industry and the work with have done with the CBI on *Making Education Your Business.*

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