IOP Institute of Physics

Comprehensive Spending Review: submission from the IOP

Contents

Introduction

The UK policy landscape

The UK is going through a period of significant change. The nation has left the EU and is looking to re-define its international relations and status, beginning its new relationship with the EU from 1st January 2021 and exploring and negotiating new relationships farther from home. In the midst of this, the COVID-19 pandemic has created a public health crisis, resulting in the largest recession on record[1]. These era-defining challenges mean the upcoming Comprehensive Spending Review is a vital conduit for shaping the UK's future and make investment in science, innovation, education and skills essential to the UK's economic recovery, long-term growth and prosperity.

The Government has recognised the importance of science and innovation to the country's future and has set itself a series of ambitious targets. Its Research and Development (R&D) Roadmap is intended to set the UK on the path to becoming a scientific superpower. In doing so, it is intended that research and innovation will help strengthen the UK's position in the world, and tackle the biggest challenges facing the UK – such as achieving net zero carbon emissions by 2050. By setting such ambitious goals, unlocking the resources needed to fulfil them, and engaging with people and communities from across the whole of the UK, there are unprecedented opportunities to achieve long-lasting economic and societal benefits for the whole country.

The importance of the spending review therefore cannot be overstated. The Government now has an opportunity to equip the UK's science and innovation community with the resources to drive a Green Recovery from the COVID-19 pandemic, boost economic growth and productivity, harness the benefits of the coming fourth industrial revolution and meet the nation's Grand Challenges. In this spending review, the Government should further its commitments to invest in science and innovation, education and skills to unleash a new wave of UK innovation.

The UK has many existing areas of strength and potential (in terms of programmes, research fields and technologies). These include the national fusion programme (including small scale fusion), renewables, battery technology, electric economy, artificial intelligence and materials science. In this submission, we refer to some of these examples but focus mainly on the conditions in the UK and internationally that need to be created and sustained to allow high quality physics research and innovation to flourish for the benefit of our country.

[1] Coronavirus and the impact on output in the UK economy, ONS.

The Institute of Physics

The Institute of Physics (IOP) is the professional body and learned society for physics in the UK and Ireland. The IOP's mission is to raise public awareness and understanding of physics, inspire people to develop their knowledge, understanding and enjoyment of physics and support the development of a diverse and inclusive physics community. As a charity, the IOP seeks to ensure that physics delivers on its exceptional potential to benefit society.

The IOP is making this submission to the Government ahead of the Comprehensive Spending Review on behalf of the Institute's membership. The IOP comprises 23,000 members from across the physics community: in industry, academia, the classroom, technician roles or in training programmes. It also works with a range of partners to support and develop policy positions and recommendations, aimed at encouraging innovation, growth and productivity in business. The policy recommendations in this submission reflect the views of the IOP's membership, as well as leading figures in the physics community.

Summary of recommendations

The Institute of Physics recommends that government:

- Maintains its commitment to investing 2.4% of GDP into R&D by 2027 and develops the detail of its roadmap for achieving this objective.

- Directly boosts public investment into R&D and increases resource for development-stage activities, to support later stage TRL technologies and facilitate commercialisation.

- Creates and resources an agile ARPA funding system which addresses the UK's biggest challenges and promotes a tech-to-market system.

- Removes barriers to collaboration by creating programmes which support cross-sector partnerships.

- Commits to resourcing international collaboration channels.

- Ring fences funding for the two possible outcomes of EU negotiations on Horizon Europe membership;

    - Secures and funds the UK's participation in the upcoming Framework Programme Horizon Europe as an associate member; or
    - Resources a domestic alternative to Horizon Europe, which matches, or exceeds, funding which would have been available if the UK were a full member of the Framework Programme.

- Commits to seeking new and innovative partnerships outside of Europe. The IOP recommends that BEIS invest in the development and implementation of strategic partnership programmes with other nations to develop physics capacity both domestically and abroad, strengthening the physics talent pipeline, and facilitating stronger research and innovation (R&I) linkages between the UK and other nations.

- Commissions a National Skills Survey to run alongside the R&D roadmap and UKRI's talent strategy. Findings should be used to inform a UK-wide skills strategy, aimed at providing the skills required for the next industrial age.

- Supports the objectives of the Government's R&D Roadmap by taking action to boost uptake of physics and science subjects in the education system in underrepresented groups.

- Invest in a world-class system of subject-specific continuing professional development (CPD) for teachers, to provide them with the necessary subject knowledge quickly and efficiently and build a more confident, engaged teaching profession.

1. Investing and revitalising the system of science and research

A thriving, well-resourced, science sector is a necessity for economically competitive modern nations, enabling the creation of knowledge and the resulting development and innovation which allows society to prosper and develop. As it is discovered, scientific knowledge is accelerated through technology readiness levels (TRL) to develop the technologies we use today, and the disruptive technologies of tomorrow.

As part of the contribution from science and the STEM sector, physics provides huge benefits to individuals and to society – opening doors, broadening horizons and driving innovation. It provides powerful and beautiful explanations about the workings of the world – explanations that have value and are applicable in a wide range of industries and research communities. In addition to the direct contribution made by physics, it also underpins many other aspects of research and infrastructure. Furthermore, it develops ways of thinking and reasoning that are rewarding and highly valued by employers in many sectors, from accounting to zoology to engineering, or law and medicine.

The UK boasts world-class institutions, has a reputation for excellence in science and engineering and a track record of ground-breaking discoveries. Its universities are among the best in the world, with three ranked within the top 10 globally[2], and with just 0.9 per cent of the world's population, the UK is home to 4.1 per cent of researchers. It accounts for 10.7 per cent of citations and 15.2 per cent of the world's most highly cited research papers[3]. Science research leads to breakthroughs in healthcare, drives technological advancements and boosts the economy. It is a building block for the future health and wealth of the nation.

The importance of a healthy science system is well understood by the Government, as seen in the recent R&D Roadmap[4]. This sets out the UK's vision and ambition for science, research and innovation, and must be at the forefront of investment decisions in the Spending Review.

The IOP recommends that the Government:

- **Maintains its commitment to investing 2.4% of GDP into R&D by 2027 and develops the detail of its roadmap for achieving this objective.**
- **Directly boosts public investment into R&D and increases resource for development-stage activities, to support later stage TRL technologies and facilitate commercialisation.**
- **Creates and resources an agile ARPA funding system which addresses the UK's biggest challenges and promotes a tech-to-market system.**
- **Removes barriers to collaboration by creating programmes which support cross-sector partnerships.**

[2] Times Higher Education Rankings (THE), 2020, at: https://www.timeshighereducation.com/world-university-rankings/2020/world-ranking#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/stats

[3] Smith and Reid, (2019); Changes and Choices Advice on future frameworks for international collaboration on research and innovation, at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/844488/Changes_and_Choices.pdf

[4] Department for Business, Energy and Industrial Strategy (2020); R&D Roadmap, at: https://www.gov.uk/government/publications/uk-research-and-development-roadmap/uk-research-and-development-roadmap

1.1. Investing 2.4% of GDP in R&D

The world is on the cusp of a new industrial era, powered by science, technology and engineering. Governments around the world recognise the potential of these developments to shape the social and economic futures of their countries, and are investing in education, skills, research and innovation in order to maximise their development. As a result, global competitors, such as Germany, Israel, South Korea and Japan, are investing more than 3% of their GDP in research and development.

Over the past decade, the UK's total R&D intensity – public and private – has remained consistent at approximately 1.7% of GDP, one of the lowest levels in the G7. This low level of R&D limits the UK's ability to develop and build on scientific discoveries and innovations. Delivery of the government's 2.4% target would mean an increase in R&D expenditure of almost 50%, presenting an unprecedented opportunity for the UK's science and innovation sector. One former Government Minister put this into context, by saying this is the equivalent of four additional Rolls-Royces, four new GSKs and four new Oxford Universities.

The UK Government has committed to boosting investment in R&D to 2.4% by 2027. This commitment should be re-affirmed to reflect the role of science and innovation in raising productivity and long-term economic growth. The UK STEM community has the talent, skills and knowledge to capitalise on these investments and fuel technological, social and economic change. This investment has become all-the-more significant as we turn to technology, knowledge, skills, ingenuity, and innovation to support economic recovery from the impacts of COVID-19.

It is important for the Government to commit resource to a coherent long-term and well-resourced R&D strategy to build our position as the global hub for new world-leading technologies, to draw on our strengths across multiple disciplines, to attract talent from around the world and to promote British entrepreneurship. The review must generate a clear investment roadmap with fresh thinking about the balance, distribution, sources and scale of funding, as well as how to identify prospects with genuine potential for scientific, economic or societal transformation.

The UK enjoys a position of global leadership in fundamental physics, and continues to punch above its weight when compared to other nations. As a result, the UK has a strong base from which to develop technologies such as compound semi-conductor capabilities, and other core areas of high value manufacturing. Sectors such as quantum, photonics, space, and data science (including AI) are all areas in which the UK has strong foundations from which, with the right government support, it can develop further, marketable technologies.

For example, the UK space sector continues to grow, with recent developments including new sensors and detectors; applications to observe and record space weather; and improvements in engine technology (such as those being developed by Reaction Engines) leading to new research into horizontal take-off and landing of spacecraft, which have shown greater promise than many of the vertical solutions that have previously been proposed.

The UK also has the largest gaming sector in Europe, and continues to attract and develop world-class talent from across the globe.

Medical physics has also demonstrated its strength and potential to further contribute to the life sciences. Areas such as proton beam therapy, multi-spectral medical imaging technologies and related small scale portable devices (which have also helped further develop robotic surgery), have all continued to demonstrate potential for further growth.

Similarly, new facilities such as the Electron Microscope Facility (EMF), based at Cardiff University, could provide the potential for developing a UK-wide capability for producing radioactive isotopes. These have many useful applications including medicine (for use as a radiation source to treat cancer patients) and diagnostics, as well as research on metabolic processes. Radioactive isotopes also have many industrial applications, such as measuring the thickness and strength of metal or plastic sheets, as well as being used as compact sources of electrical power.

Other physics-based sectors in the UK would benefit from government support – for example, UK-based firms working in fusion are developing a new design for a fusion reactor, to achieve small scale fusion as a proof of concept. Support from government could speed this process up, and hasten the realisation of the government's own objectives for new, cleaner sources of energy – one of the major challenges identified in the 2017 Industrial Strategy.

The Institute of Physics both welcomes and supports the government's pledge to increase investment in R&D. Now is the time to back these high-performing sectors, which will assist the UK to recover from the expected economic slowdown, caused by the COVID-19 pandemic, and support sustainable long-term economic growth. In supporting these sectors, a series of recommendations are provided in this document to both achieve this objective, and to ensure that government investment generates economic return as well as research insight.

1.2. The R&D funding landscape

The Government's commitment to increasing spending on R&D to 2.4% of GDP is vitally important to delivering on the objective of solidifying the UK's position as a global science and research superpower. The announced investment pledge to invest £22 billion per year of public funds into R&D by 2024 is a very important commitment, which the UK will rely upon in order to remain at the forefront of global research. Equally, the Government's pledge to bring forward £300 million in investment in scientific infrastructure will provide a much-needed boost to UK research institutions, many of which have been severely impacted as a result of the measures taken in response to COVID-19. Alongside this, current levels of investment in blue skies research should be maintained, and existing long term programmes preserved.

The R&D roadmap goes beyond the commitment to 2.4% investment in R&D; it details the need to invest smartly in innovation activities, taking into account the need for more investment in 'development' and the formation of agile innovation systems, such as the new ARPA. It invites a dialogue on the efficiency of the infrastructure within which R&D is undertaken, and the systems of funding. The IOP recommends the Government utilise the proposed changes to the R&D landscape and uses the opportunity to resource and develop the following:

- Ensure that the Government's increased investment in R&D is spread equally across TRLs to accelerate impact

The TRL scale represents the journey of scientific knowledge from discovery to commercialisation, on a scale from 1, where research and knowledge is created, to 9, where science has been harnessed and translated into products and services which are available on the market. Low TRL technologies – early stage research projects – are referred to as blue-skies projects, where science groups undertake primary research to create new knowledge. Once knowledge has been created, development of this can be undertaken to utilise and exploit the findings, often by industry. By the nature of this scale, different teams and organisations work on concepts and technologies across the

levels, often using different facilities and bringing their own expertise, as well as undertaking work with different objectives.

As a result of the differences in the nature of the work at the research and the development stages, and the different teams undertaking this work, funding systems differ between the TRLs. Currently, the UK invests little (compared with other nations) in the development aspect of R&D, with support at intermediate TRLs lacking. This limits the ability for new knowledge to be transformed into products and services which create impact, benefit society and provide a financial return on the R&D investment[5].

Some steps have already been taken to bring more coherence to the UK's research and innovation ecosystem. We support the proposal for a new funding agency, based on the US 'ARPA' model, in which funding is allocated by programme managers – a model which is largely absent from the existing UK funding system.

- Directly increase public funding into R&D

The ratio for public to private investment in R&D has for many years been 1:2. Roughly one third of total R&D investment comes from public sources and two thirds from private sources. When observing just investment by government in R&D compared to other nations, the UK's performance compares poorly – in 2015, the UK invested 0.46% of GDP in 2015, the lowest of all the G7 countries.

To meet (and surpass) the 2.4% target, the UK government must increase its investment in innovation. Increasing public R&D investment to £22 billion per year by 2024-25, as committed in the 2020 Budget and R&D Roadmap, will raise direct support for R&D to 0.8% of GDP – ahead of the USA, Japan, France and China in the OECD R&D league. The IOP recommends that this investment be used to boost resources for all of the key parts of the nation's innovation and science ecosystem, including those which are often overlooked such as the Public Sector Research Establishments (PSREs). Boosting resource for these public assets will result in multiple benefits including stronger engagement with, and support for, private organisations, equipping them with good access to publicly owned research tools, techniques, and standards. As a result of this access, private organisations will benefit from improved outcomes in their R&D activities, encouraging greater levels of private R&D activity and investment[6].

Supporting greater levels of private R&D will create direct and indirect economic benefits for the public. A more innovative business landscape in the UK and increased firm level innovation will support higher tax revenues as organisations become more competitive, as well as creating jobs around the UK and delivering new and improved products and services for citizens and consumers.

As part of this ongoing investment, there should be continued development of existing facilities and their capabilities, to ensure the UK remains a centre for world-class science. Facilities such as the Diamond Light Source, the Central Laser Facility, the ISIS Neutron and Muon Source (all based at the Harwell Research Campus), the Daresbury Laboratory, and other facilities highlighted in STFC's 2019 Delivery Plan[7] should be considered for further development.

[5] AITRO (2020); A more development-focused strategy for paving the way to impact

[6] King, M; Renedo, E (2020) Achieving the 2.4% GDP target: the role of measurement in increasing investment in R&D and innovation. NPL Report. IEA: 3

[7] STFC 2019 Delivery Plan, at: https://stfc.ukri.org/files/delivery-plan-2019/

- The development of an agile ARPA system which addresses the UK's biggest challenges and promotes a tech-to-market system

Some of the IOP's members have identified short-term funding as a challenge for larger or more technical projects. In such cases, problems can arise when short-term funding runs out with the research still incomplete. This is particularly the case in less developed research areas, for example, quantum technology may need twenty-year funding, rather than ten, to get it to the point of commercialisation.

At the same time, the Research Councils' flat cash budgets have diminished their scope for funding genuine blue skies and high-risk research in recent years. This threatens the undertaking of cutting edge, next generation knowledge research.

Issues in irregular funding have been acknowledged by the Government. As part of the drive to increase funding in R&D to 2.4%, the Government has plans for the development of a new funding agency, based on the model of the US Advanced Research Projects Agency (ARPA) system. The IOP support the development of an ARPA system; the establishment of a new funding agency focused on 'blue skies' and 'high-risk, high-reward' research is a welcomed tool to boost public investment in R&D.

The development of a programme manager-led funding stream would benefit the community by creating issue-focused projects which have secure funding and promote the tech-to-market process. However, it is important that the review is used to commit to an ARPA model which works efficiently. Specifically, ARPA should:

- Be created from truly additional funding and not come at the expense of support for research and innovation provided by UKRI.
- Fill the gaps in the current funding landscape, without duplicating existing activity and making a clear distinction between its remit and that of UKRI and its councils, to avoid complicating the R&D funding landscape.
- Bring together both technical and commercial experts from academia, industry and Government in a non-bureaucratic, agile system to undertake high-risk and high-impact activities. Due to the vast TRL span of the projects, the project teams' expertise will be crucial to successful delivery.
- Focus on truly disruptive research and the largest issues facing society, with the aim of achieving step changes in technological capability and solving difficult challenges that require a critical mass of cross-disciplinary researchers and innovators.
- Support the Government's levelling-up agenda, ensuring that investment benefits researchers, institutes and organisations across the whole of the UK, not just those based within the Golden Triangle.

1.3. Funding collaboration

The IOP has a diverse membership drawn from many sectors of the economy. Many of our members work in research and innovation (in academic and industrial settings) and their work is often highly collaborative. Consultations on collaboration have allowed some members to report facing barriers to successful partnerships, most notably between academia and industry, and this is mirrored across sectors and disciplines in successive iterations of the UK Innovation Survey. Collaboration creates unparalleled benefits in the science community, enabling the flow of ideas and

information through knowledge exchange (KE), movement of experts, and sector spill overs to benefit other fields. These networks accelerate breakthroughs in R&D and create partnerships which can span the TRLs to optimise the use of knowledge.

There have been many independent reviews and strategies aimed at increasing business-university collaboration, and nearly all have highlighted the impact of the misalignment or absence of incentives for business-university collaboration. The 2015 Dowling Review of Business-University Research Collaborations[8] acknowledged the lack of incentives in place for academics to work with industry. On the other side of the fence, successive editions of the UK Innovation Survey[9] show that innovation active firms are more likely to have (and to value) collaborative partnerships with other businesses than they are to collaborate with universities.

There is a long history of initiatives to boost collaboration and knowledge exchange between universities and industry. The Higher Education Innovation Fund (HEIF) is very well regarded and has been shown to provide a good return on investment, with £9.30 generated for every £1 of funding according to Research England[10]. Despite this, the Fund is still a relatively modest £213 million.

IOP members have also identified firm size as a potential constraint on collaboration or accessing business and innovation support from government. A supportive economic and regulatory framework is beneficial for all firms, but arguably more so for SMEs who drive a lot of growth and innovation. Micro businesses and SMEs are often at the cutting edge of new technologies and innovations but many lack the time, resources or know how to access support. These (and other) constraints appear to impact SMEs' ability to access and benefit from the R&D tax credit. Further support is required to encourage innovation among SMEs. This support could be modelled on successful engagement projects, such as the National Measurement System's Analysis for Innovators Scheme[11].

Finally, reviews have shown that instruments of support that work in one area do not necessarily translate to others. Rather, relevance, coherence and matching support to specific, identified needs are more important considerations. Targeted or even bespoke approaches must have a place alongside blanket availability of instruments or schemes. For example, quantum technologies have benefited from a coherent programme of support orchestrated by EPSRC and Innovate UK.

2. The importance of international collaborations

The UK's physics and science communities are closely intertwined with international networks, infrastructures, facilities and investment streams and this has contributed significantly to the UK's world leading research and innovation base. To remain at the forefront of scientific discovery and innovation, a strong presence must be maintained in international networks, partnerships and programmes. Of equal importance is that the UK remains open and attractive to talented researchers and innovators.

[8] The Dowling Review of Business-University Research Collaborations
[9] UK Innovation Survey 2019
[10] UKRI HEIF figures
[11] Analysis 4 Innovators Scheme (A4I)

Many of the challenges that the UK faces are global; the UK must work with the world-wide science community to overcome the threats of climate change, pandemics such as COVID-19, and to fully exploit the benefits of the coming fourth Industrial Revolution. International collaboration strengthens the UK's ability to respond to challenges in areas including health, climate and energy. As Professor Sir Adrian Smith and Professor Graeme Reid have stated, "International collaboration is not an optional extra. It is fundamental to high quality research and business innovation."[12]

The physics community in the UK is enriched by talented people from all over the world, with its world leading academic institutions continuing to attract global talent. In 2017, 27% of academic staff in UK physics departments were from non-UK EU countries and 18% were from non-EU countries. More than half of physics postdoctoral researchers were from outside of the UK[13]. Openness to talent and ideas has allowed the UK to build strong international ties, valuable and productive research collaborations and world-class shared infrastructure.

The Government should investigate ways in which it could both maintain existing, and develop new, international collaboration channels. It must invest in a manner which asserts to domestic and international investors that the UK is open for business and ready to embrace the opportunities of a changing world.

A comprehensive, cross-government international science and innovation strategy is needed alongside the R&D roadmap. In the past, such strategies have been framed narrowly and have not fully acknowledged or encompassed the richness and diversity of the UK research and innovation landscape. Many of the UK's research institutions and facilities (including PSREs) have significant world standing but not all have benefitted from previous strategies. A large proportion of R&D spending in the UK comes from overseas, and without this, UK innovation would be at a disadvantage. A rounded, coherent and genuinely cross departmental international strategy could make an important contribution to increasing and maintaining the foreign direct investment in R&D, which will be vital in reaching the Government's 2.4% target.

The IOP recommends that the Government:

- **Commits to resourcing international collaboration channels.**
- **Ring fences funding for the two possible outcomes of EU negotiations on Horizon Europe membership;**
    - **Secures and funds the UK's participation in the upcoming Framework Programme Horizon Europe as an associate member; or**
    - **Resources a domestic alternative to Horizon Europe, which matches, or exceeds, funding which would have been available if the UK were a full member of the Framework Programme.**
- **Commits to seeking new and innovative partnerships outside of and beyond Europe. The IOP recommends that BEIS invest in the development and implementation of strategic partnership programmes with other nations to develop physics capacity both domestically and abroad, strengthening the physics talent pipeline, and facilitating stronger research and innovation (R&I) linkages between the UK and other nations.**

[12] Smith and Reid, (2019); Changes and Choices Advice on future frameworks for international collaboration on research and innovation, at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/844488/Changes_and_Choices.pdf

[13] IOP Data Brief 2018: Staff and students in physics departments.

2.1. Horizon Europe

As the UK begins its new relationship with the EU from 1st January 2021, funding and collaboration opportunities with EU-based peers and colleagues will be impacted. It is of vital importance for UK R&D, innovation and the economy for these research projects and partnerships to continue.

In assessing the value of existing UK-EU partnerships, figures from the previous Framework Programme, Horizon 2020, demonstrate that during Summer 2019, there were over 13,000 UK-led projects being funded - the second highest number of project participations. UK businesses had the fifth highest level of participation of EU countries (around 3,000 participants under Horizon 2020), securing just over €1 billion in funding since 2014. Moreover, as of June 2019, the UK had secured around €5.9 billion in funding from Horizon 2020, 13.5% of the total, second only to Germany. R&D funding makes up about 18% of EU awards coming to the UK and is the second largest component of EU funding into the UK after agriculture[14].

The Royal Society has estimated that the EU Framework Programmes and European Structural and Investment Funds (ESIF) provided UK organisations with around €9bn in grants across the seven-year term 2007-2013[15] (with a further €5.5 billion in funding provided under Horizon 2020, the Framework Programme which operated between 2014-2020[16]). The Royal Society report also calculates that these two sources of EU funds have provided UK organisations with income of circa €1.1bn a year, which amounts to more than 10% of total government support for UK research and innovation and around 5% of UK Gross Expenditure on R&D (GERD), including both public and private funding. These figures demonstrate the financial importance that participation in the Horizon Framework programme had on the UK's academic and innovation sectors, and how impactful the next programme, Horizon Europe, could be.

The IOP urges the Government to take steps to secure as close a relationship with the European science community as possible. To achieve this, UK researchers must continue to participate in the upcoming Framework Programme, Horizon Europe. This will enable current research to progress to impact and the UK to continue to be at the forefront of research and development of tomorrow's ideas and technology.

The UK should ensure that associate membership of the next Horizon Europe should be a minimum requirement for negotiations for a future UK-EU trade deal and we should seek to play a role in ESFRI and other joint programmes that support physics. Alternatively, the Government has pledged to meet any shortfall in funding in the event of the UK's non-participation in Horizon Europe. While the IOP strongly recommends the former, the Government should also prepare – and provide advance notice of its plans to fulfil – the latter. The Government should therefore ring fence funding for the two possible outcomes of EU negotiations:

[14] Smith and Reid, (2019); Changes and Choices Advice on future frameworks for international collaboration on research and innovation, at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/844488/Changes_and_Choices.pdf

[15] Royal Society (2017); The role of EU funding in UK research and innovation, at: https://royalsociety.org/~/media/policy/Publications/2017/2017-05-technopolis-role-of-EU-funding-report.PDF

[16] BEIS (June 2020); Horizon 2020 funding if there's no Brexit deal; at: https://www.gov.uk/government/publications/horizon-2020-funding-if-theres-no-brexit-deal/horizon-2020-funding-if-theres-no-brexit-deal--2

- Secure and fund the UK's participation in the upcoming Framework Programme Horizon Europe as an associate member; or
- Resource a domestic alternative to Horizon Europe, which matches, or exceeds, funding which would have been available if the UK were a full member of the Framework Programme as an EU member state.

The UK has also provided investment – and received considerable direct and indirect benefits from participation – in projects such as CERN, the European Space Agency, the European Centre for Medium-Range Weather Forecasts (ECMWF) and Copernicus observation programme, and the European Extremely Large Telescope (ELT). Many of these projects are part of the European Strategy Forum on Research Infrastructures (ESFRI) List of infrastructure investment and commercial opportunities. In contrast, the UK Space Agency has been forced to abandon plans to develop a back-up to GPS satellite navigation, and there have been arguments in some policy quarters in favour of re-joining the EU's Galileo system, much of which was informed, developed and funded by the UK. To avoid similar costly withdrawals and the loss of valuable intellectual property and commercial opportunities, the UK should continue to invest and participate in such international and pan-European projects where possible.

2.2. Development of new international collaboration channels

Beyond the UK's relationship with the European Union following Brexit, international collaborations and partnerships are likely to play an even greater part in finding solutions to the biggest challenges faced by society, such as those identified in the Government's Industrial Strategy. As the UK leaves the EU, it has the opportunity to partner with countries around the world in new and exciting ways, and benefit from creating new opportunities and networks.

An example of the kind of new collaboration which could be developed has been proposed by the IOP to the Department for Business, Energy and Industrial Strategy (BEIS). The IOP has invited BEIS to invest in the development and implementation of a strategic partnership programme to develop physics capacity in sub-Saharan Africa (SSA), strengthen the region's physics talent pipeline, and facilitate stronger research and innovation (R&I) linkages across SSA and with the UK. The Africa-UK Physics Partnership Programme can be an ambitious partnership between the UK and SSA centred on global challenges-oriented physics R&I, aligned with the Global Challenges Research Fund, Ayrton Fund and other BEIS investments, and implemented with the support of established UK and African partners.

The goal for the programme is that the African physics community is integrated into global R&I and contributes meaningfully to sustainable improvements in energy, health, and climate and weather management, and access to large-scale research facilities (LSRFs) and advancement of artificial intelligence (AI) and big data can form part of the solutions.

An IOP mapping study found that across SSA physics is significantly underrepresented among research projects in the mentioned areas, and that a range of factors prevent African physics from realising its potential, including a lack of critical mass of knowledge, expertise and a talent pipeline; limited access to research infrastructure; lack of engagement by the UK physics community; limited visibility of African physics R&I; and various factors affecting researcher mobility.

The partnership aims to enable impact by:

1. Catalysing impact- and innovation-focussed physics collaborations and networks.

2. Ramping up access to research facilities to drive physics impact across SSA.
3. Transforming support systems for inclusive innovation and commercialisation.
4. Championing women in physics across Africa, as well as inclusion and diversity more broadly.
5. Building a vibrant and diverse African physics pipeline for the 21st century.
6. Unlocking enabling policies and funding for Africa-based physics.

The IOP proposes an initial BEIS investment of £50 million over five years to support equitable physics partnerships and capacity development activity with Ethiopia, Ghana, Kenya, Malawi, Nigeria, Rwanda, South Africa, Tanzania and Uganda. Co-funding is being sought from partner governments, industry and philanthropic organisations to add to this investment ensuring sustainable and long-term impact.

The programme has potential to drive significant change for African physics and will have a broad range of secondary benefits for the UK's R&I commitments and wider sectoral and government ambitions. It will align with the UK's new strategic partnership with Africa, reinforcing that the UK is open to ambitious partnerships and ensuring that the UK is recognised as a catalyst for pioneering physics-led R&I that tackles some of the greatest global challenges. It will deliver impact in shared challenge areas that are in the UK's national interest, open up opportunities to the UK physics community, and grow the UK's physics talent pool. The programme will also maximise synergies with, and value-for-money of, existing UK ODA and R&I investments.

3. Education and skills

The government's industrial strategy places emphasis on the high demand for skilled workers in the sciences, technology, engineering and mathematics. Physics-based skills are required in many of these growth areas, and thousands more workers will need to be trained every year to keep the UK economy competitive. The Government is also seeking to boost economic growth and 'level up' opportunity in all parts of the UK.

Progress towards these goals can be propelled by increasing the flow of well-educated students moving from our schools into employment or continued education with valuable skills and knowledge; equally, progress will be hindered if we do not take steps now to increase the availability of knowledge, skills and talent in the workforce and education system. The UK has a strong and effective education system, and the Government recognises that 'great education is fundamental to the success of children, their families and our communities, as well as the success of our country.'

However, there are significant challenges in young people's access to world-class physics education and training. To create a system which improves education, builds skills and retains talent to the level required by the UK, new investment is required.

Through educating students to their potential, no matter where they are in the UK, the nation will benefit from a rich workforce, well equipped to tackle the issues of today, innovate, and enjoy greater productivity and economic growth across the nation.

The IOP recommends that the Government:

- **Commissions a National Skills Survey to run alongside the R&D roadmap and UKRI's talent strategy. Findings should be used to inform a UK-wide skills strategy, aimed at providing the skills required for the next industrial age.**

- **Supports the objectives of the Government's R&D Roadmap by taking action to boost uptake of physics and science subjects in the education system in underrepresented groups.**

- **Invest in a world-class system of subject-specific continuing professional development (CPD) for teachers, to provide them with the necessary subject knowledge quickly and efficiently and build a more confident, engaged teaching profession.**

3.1. Reducing the skills shortage

The IOP's Physics and the Economy[17] reports reveal that there are more than 2 million people working in physics-based industries across 80 or so economic sectors in the UK, contributing around 10% of GDP. However, employers across the UK and Ireland have reported difficulties with recruiting people with the right skills, including critical skills in science and engineering.

The scale of this skills shortage has been illustrated by the Social Market Foundation, which found that despite recent increases, there remains a shortfall of around 40,000 STEM graduates in the UK each year. Our own work showed that 89% of STEM businesses struggled to recruit people with the right skills in the year 2017-18. This equates to a skills shortage of 173,000 workers, an average of 10 unfilled roles per business. In turn, this costs £1.5 billion a year as companies are forced to inflate salaries, recruit from overseas or simply leave posts vacant.

Other recently published reports have highlighted a skills shortage in the UK, with employers reporting that 106,000 vacancies at professional level are considered hard to fill. 79,000 of these vacancies were due specifically to a low number of applicants with the required skills, with many in technical roles, such as the physical sciences, engineering, teaching (including science), and IT. It was also noted that SMEs experienced greater and wider shortages of graduates than larger employers.

Aside from the acute financial and opportunity costs of these shortages and gaps, there is a further fundamental drawback. Without sufficient numbers of skilled STEM workers, the UK will be unable to realise the benefits of additional financial investment in R&D.

The IOP recommends that the Government commissions a National Skills Survey to run alongside the R&D roadmap and UKRI's talent strategy, and its findings should inform a UK-wide skills strategy which addresses both domestic training and retention, as well as the attraction of international talent in light of changing rules on immigration and partnership funding as the UK leaves the EU.

- Improving diversity

Physics has a diversity issue, often driven by deep-seated stereotypes, and faces acute shortages of skills. For example, figures provided by the Higher Education Statistics Agency (HESA) show that in 2017/18, women made up just 24% of tertiary level students studying physics. In the same year, just 17% of UK-domiciled physics students were non-white[18].

We must ensure our profession better reflects the diversity of our society and offers all young people, no matter their background or where they live, those opportunities afforded by world-class physics education and training.

[17] IOP (2018); Physics and the Economy; at: https://www.iop.org/about/business-innovation-and-growth/physics-and-economy#gref

[18] IOP (2020), Students in UK physics departments, at: https://www.iop.org/sites/default/files/2020-07/Student-characteristics-2017-18.pdf

Barriers to entry into our field (and other STEM subjects) must be confronted and broken down, and educational, training and working environments must be welcoming and inclusive. A diverse and inclusive physics community – supported by a clear articulation of the varied educational routes, training and career opportunities afforded by physics - will also help us to close the skills gap and meet the growing demand for physicists in the workplace.

The Government should work with organisations across the science sector, such as the IOP, to engage with different groups to showcase the many and varied career options that are available. In addition, new resources should be developed to highlight the various educational routes, training and career opportunities available in the R&D sector. The objective should not only be to highlight the number and variety of rewarding career choices within the R&D sector, but to ensure more people – including those from underrepresented groups – see such careers as genuinely open and available to them.

Engaging with such underrepresented groups must be addressed early on and in a sustained manner to encourage them to consider careers in STEM. For example, girls are currently less likely to progress to A-level physics than boys, even when the subject is one of their best results at GCSE. In both 2019 and 2018, girls made up just 22% of pupils studying physics for A-level. In the same years, girls made up 26% (2019) and 25% (2018) of pupils studying physics for AS level[19]. There is strong evidence that the way that pupils are navigated through their choices is influenced by gender, especially in mixed schools. Schools should provide effective careers guidance that starts at an early stage, focuses on the next educational phase, emphasises the benefit of choosing certain subject combinations to allow progression to a wide variety of opportunities, and actively challenges gender stereotypes and unconscious biases.

In addition to encouraging more pupils to study STEM subjects, it is also important to consider the environment in which those who move into the R&D sector work and operate. For example, there is currently a disparity in the success rates of female, disabled and ethnic minority applicants in securing funding for research (particularly that provided by UKRI) compared to their white, male, non-disabled counterparts.

- The importance of specialist physics teachers

A major step in improving outcomes for secondary school pupils, including those from underrepresented groups, can be achieved by ensuring that every secondary school pupil in the UK has access to a specialist physics teacher, rather than teachers who have been trained in biology or chemistry, to cover these lessons. Science teachers who are specialists in their subjects can support, advise and encourage pupils who are considering careers in a teacher's respective STEM field. This also provides a professional role model for pupils to aspire to, as well as someone who can help them explore potential career options. Encouraging more pupils to study science subjects at school will both help to address the current disparities in uptake of subjects such as physics and increase the numbers applying and studying these subjects at university and forms of other higher and further education. With trained graduates, technicians and apprentices entering the workplace, this will increase the number of people available to take up R&D roles.

[19] Joint Council for Qualifications; GCE A-Level and GCE AS Level Results 2019; at https://www.jcq.org.uk/wp-content/uploads/2019/08/A-Level-and-AS-Results-Summer-2019.pdf

3.2. A national programme of CPD for teachers

Subjects are at the heart of students' learning in a knowledge-rich curriculum. For students to have the best experience of subjects – to excel while at school and to aspire to further success in the future – teachers themselves need to have excellent knowledge of their subject and how to teach it.

The Government should invest in a world-class system of subject-specific continuing professional development (CPD) for teachers, to provide them with the necessary subject knowledge quickly and efficiently and build a more confident, engaged teaching profession. Participation in subject-specific CPD can positively impact a number of factors which have been shown to influence teacher retention, helping to reduce wasted investment in teacher recruitment and initial training, and improve student attainment. There have been some highly successful and impactful programmes of subject-specific CPD in England. However, these programmes are limited to some targeted subjects, they form a patchwork with little linkage between them, and they rely on year-to-year funding cycles. In addition, there are currently no common standards or methods of assuring the quality of subject-specific CPD, meaning that quality is variable and unknown and it is hard for schools to make informed choices.

A world-class system of subject-specific CPD, guided by subject experts, would build upon and strengthen existing programmes to help improve the quality of teaching in our schools, contributing to improved student outcomes, reduced disparities in our education system and improvements in the knowledge and skills that young people carry into the workforce. By ensuring every student can realise their full potential, we can accelerate progress towards the Government's vision of increased productivity and economic growth in all parts of the UK.

A world-class system of subject-specific CPD is one that:

A. Is accessible and available to all teachers of all subjects, so as to increase participation and improve teaching quality across the UK. By having ready access to CPD that is both high quality and meets their needs, teachers will view it as a more valuable and ongoing feature of their professional life
B. Is of universally high quality, providing teachers with access to CPD of a consistent standard no matter where they teach or how they access it, and improving outcomes across all schools
C. Preserves choice for schools, enabling them to address their specific needs through a variety of CPD programmes, while having assurance of quality
D. Caters for the diverse needs of teachers at different points in their careers or with different backgrounds, enabling teachers to target their specific professional learning needs and ultimately derive the greatest impact on teaching quality
E. Tracks and records the outcomes of professional learning so that teachers can identify opportunities to improve their practice and grow as professionals, and can demonstrate their subject knowledge for teaching at a topic level. This would enable schools to deploy teachers according to their demonstrable strengths and more easily identify and address any skills gaps, improving quality of teaching for students
F. Improves continuously based on regular and rigorous evaluation and evidence of impacts on student outcomes.

A system of subject-specific CPD which possesses all the above characteristics is likely to comprise a number of different, interconnected elements. As an example, the following elements could be combined to build a world-class system:

a. A national standard for subject-specific CPD to provide assurance of quality
b. Multiple providers to ensure teachers and schools have access to a variety of quality-assured providers
c. In-school CPD champions so schools and teachers can meet their identified needs
d. A subject component to the national standard for teaching, specifying the subject knowledge required for teaching in each subject, to help teachers identify their needs and to facilitate recording
e. Micro-accreditation to enable teachers and schools to track and record the outcomes of professional development
f. Evaluation to drive continuous improvement

There would be an expectation and entitlement that subject-specific CPD would make up at least half of the organised CPD that teachers take part in and, in a given year, a school should allocate an average of 2.5 days per teacher to subject specific CPD.

Strong foundations already exist on which a world-class system of subject-specific CPD could be built. They include the teachers' standards and standard for teachers' professional development, and recent innovations in the Early Career Framework and National Professional Qualifications, as well as existing high-quality programmes of subject-specific CPD.

Based on the costs of existing programmes, as well as the estimated cost of supporting an individual teacher, we estimate the cost of a world-class system of subject-specific CPD to be around £1000 per year per teacher. This equates to a total cost of around £175 million per year for all secondary school teachers, or around £12 million per year for each major secondary school subject.

Subject-specific professional learning should be an essential part of all teachers' professional growth. In the first instance, we would recommend establishing some regional pilots of a systematic, school-wide approach, initially in secondary schools. Based on evaluations of these pilots, we would then recommend scaling up to a national system which covers both primary and secondary schools.