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The Science and Technology Facilities Council is part of UK Research and Innovation.
Introduction

UK Research and Innovation is a new organisation that brings together the UK research councils, Innovate UK and Research England into a single organisation to create the best environment for research and innovation to flourish. The vision is to ensure the UK maintains its world-leading position in research and innovation. Visit: www.ukri.org for more information.

As a publicly funded research organisation, the Science and Technology Facilities Council (STFC) has the responsibility to report the outcomes of our research and demonstrate the value that the research base can add to our economy and society. Along with the other research councils, we collect information about our research funding in UK universities using an online system called Researchfish. The system allows our university partners to log a range of outputs from their research for at least five years after the end date of their award. The outputs range from publications and collaborations, to commercialisation and public engagement.

A key part of STFC’s remit is to fund frontier research in our partner universities; encompassing astronomy, space science research, particle physics and nuclear physics. UK research supported by us in these subjects is world-class. In 2016/17 we committed over £100 million to support frontier research. This support also included funding for the on-going technology development necessary to support our experiments and facility upgrades. It also includes funding provided to universities and other research organisations nurturing students through their doctoral training. Equating to 19% of our total budget, this funding was used to support 80 universities and research organisations (ROs) across the UK in these areas.

The research undertaken by our principle investigators leads to the creation of new knowledge. The transfer of this knowledge can have scientific impacts, for example through publications and further research, but it can also impact on the economy and society through its subsequent commercialisation. The outputs from frontier research find application in industry or can be exploited in novel ways, although sometimes this transfer can take many years to happen. New technology and software are common outputs from our research and these can be applied to many areas outside STFC’s disciplines including in healthcare, the environment, security, communications and aerospace.

There are various ways in which research can be commercialised. The creation of a spin-out company allows researchers to enter a market or markets with a new product or service. There are other options open to researchers to work with established organisations, allowing them to draw on existing expertise to move their product from the laboratory to market.

In addition to more serendipitous innovations that arise from our research, STFC has several schemes to proactively encourage and cultivate innovation. These include the Innovation Partnership Scheme and the Challenge Led Applied Systems Programme. More information is available at: www.stfc.ac.uk funding/working-with-industry/.

The following examples give a flavour of the innovation that has emerged from STFC-supported research reported through Researchfish.
Science and Technology Facilities Council - Innovation

STFC-supported research can be commercially exploited through the formation of spin-out companies which generate economic impacts such as the creation of new jobs and new products or services.

24 spin-outs started by STFC-supported principal investigators have been reported since 2012 through Researchfish\(^\text{1}\), creating a number of highly skilled new jobs. These companies cover a wide range of industry sectors including:

- grid computing and software
- spectroscopy, stem cell research
- decontamination technology
- unique 3D sculpture creation
- educational app development
- scientific instrumentation manufacture.

This range of subjects highlights the diversity of applications that can result from STFC-funded research.

\(^1\) We believe that the number of spin-outs generated by our university funding has been higher than this but these have not been reported through Researchfish.
AEON Engineering

Created following support from STFC, AEON Engineering specialises in providing professionally managed engineering solutions for complex, dynamic and multi-faceted engineering problems. They are providing their unique expertise to some of the biggest science projects ever conceived.

AEON Engineering's founding members were involved in the Square Kilometre Array (SKA) project, due to be the world’s largest radio telescope, whilst working at the University of Manchester. From here, they spotted an opportunity to create a new systems engineering company.

AEON Engineering is currently leading the systems engineering for the SKA Signal and Data Transport (SaDT) Consortium, described as the backbone for the telescope. The SaDT element includes all hardware and software necessary for the transmission of data and information between the various elements of the SKA. One of the biggest challenges for SKA is the problem posed by the sheer volume of data that will be created, requiring the handling of data volumes, provision of high-performance computing and design of software that are thousands times larger than the worlds current radio observatories.

STFC plans, develops, constructs and provides access to cutting-edge science facilities used by UK researchers across a range of scientific disciplines. We seek to maximise the economic return to the UK through promoting tender opportunities for UK companies from our international projects. Over the past 10 years, UK companies have won over £220 million in contracts from our UK-supported international facilities. This demonstrates the scale of opportunities available to companies such as AEON.

AEON's founders have previously worked alongside STFC, providing design solutions for two aspects of the ATLAS High-Luminosity project. ATLAS is one of four detectors at the Large Hadron Collider (LHC), the world’s largest and most powerful particle collider. The high-luminosity project aims to upgrade the performance of the LHC and its detectors in order to increase the potential for new and exciting discoveries. It will allow the observation of rare processes that are inaccessible at the LHC’s current sensitivity level.

With AEON Engineering being located in the North West of England, the hope is to maintain strong links with the University of Manchester and the SKA headquarters, located at Jodrell Bank Observatory, with the hope of securing further opportunities and boosting economic development for the region.

2 https://stfc.ukri.org/files/tender-factsheet-web-2018/ - UK industry has won £221,625,807 in industrial contracts from 2007-2017 from CERN, ILL, ESRF and ESO. This amount has been converted into pounds from Euros and Swiss Francs using the average annual exchange rates from the Bank of England for the past 10 years.

3 https://stfc.ukri.org/innovation/tender-opportunities/
Intellectual property is an important input to the innovation process, which in turn is important for a successful economy. The protection provided by intellectual property law allows the creator to exploit their product without fear of it being copied or stolen. Scientific developments can have multidisciplinary impacts, encouraging the exploitation of generated products can lead to advancements in a number of sectors. STFC-supported researchers have reported over 90 different forms of intellectual property.

Intellectual property developed includes supercomputer benchmarking software, apparatus for generating x-rays, telescope operation software, air quality monitoring tools and magnetic field measurement devices. Patents generated with support from STFC have the potential to transfer to many sectors including manufacturing, bio-medical, cultural/heritage, aerospace, digital/communication/information technologies, electronics, healthcare, environment and many more.

4 The World Intellectual Property Organisation defines intellectual property as ‘creations of the mind: inventions; literary and artistic works; and symbols, names and images used in commerce’
Crystal Clear Analysis

Improved x-ray analysis for the mining and metals industries using crystallographic phase analysis

A handheld mineral analysis instrument capable of phase analysis and quantification, with no sample preparation, has been developed with support from STFC. This has the potential to significantly reduce the time taken to provide accurate materials analysis and save on sample preparation and laboratory costs.

For the mining industry, analysis of the quarried material is essential to understanding the composition and therefore the true value of the goods. The standard technique for this analysis is called x-ray diffraction which has been extensively utilised for materials analysis across various science disciplines for decades. In x-ray diffraction, individual crystallographic phases generate unique patterns of x-rays which are diffracted from the crystallographic planes of atoms comprising the material. These patterns provide fingerprints of each material, making it possible to identify the composition of a sample.

The key feature of the handheld instrument is the technique it utilises to perform the analysis, developed by Dr Graeme Hansford from the University of Leicester. The technique is a novel form of x-ray diffraction. Adapting Dr Hansford’s technique for use in a handheld instrument requires no sample preparation and no need to send samples to a laboratory for testing. This means accurate phase analysis can be provided in minutes rather than days or weeks and laboratory costs are all but eliminated. The current prototype (pictured) has shown that a handheld instrument is possible, and Dr Hansford will now be taking the next step to produce a working handheld instrument.

Since developing the instrument, Dr Hansford has received further support from STFC for its utilisation in the steel industry, working in collaboration with Tata Steel UK. The unique technique allows for identification and quantification of the phase composition in steel production. Controlling the precise composition is important in steel manufacture in order to ensure the final steel product has the desired mechanical properties. Diversifying Dr Hansford’s instrument could significantly reduce costs and would allow for ‘point-and-shoot’ analysis.

Support for the creation of the instrument was also received from the University of Edinburgh and Dr Hansford’s home institution, the University of Leicester.

Dr Hansford’s instrument was initially developed for use in the mining sector, however it has become clear that the technique can also be applied to the metals sector including aerospace, marine, nuclear and power systems for commercial application. More recent work has seen the technique applied to analysing historical artefacts, yielding useful insights into how the artefact was produced and the organisation of ancient industries, as well as estimating the possible date of creation. Due to the fact that no sample preparation is required, the technique is completely non-destructive which is of crucial importance when studying historic artefacts.

Prototype phase analysis instrument
Credit: Dr Hansford, University of Leicester
A further way in which new knowledge arising from research has wider benefits is novel advances in research methods or techniques. We ask our supported principal investigators to tell us about research tools or methods that have arisen directly as a result of their funding. An improved technique or tool applied in a new way can have as big an impact as a completely new product that has been developed over a number of years.

STFC-supported researchers have informed us of over 60 different research tools or methods they have developed, the majority of which have been improvements to research infrastructure. These include development of grid computing tools, new techniques for detecting solar radiation and the structure of asteroids, openly available code for calculating the chemical evolution of galaxies, and improved radioactivity measurements, amongst a host of other developments.
From Hadrons to Healthcare

Technology developed for use on the world’s largest science experiment is being utilised in the fight against cancer

A multidisciplinary consortium has created one of the most complex medical imaging devices ever conceived, allowing real-time monitoring of the radiation dosage being given to cancer patients using proton therapy. The work will also improve treatment verification and planning, based on images from proton computed tomography (pCT), greatly reducing errors in tumour targeting.

There are over 300,000 new cases of cancer diagnosed in the UK every year. Of those around 4 out of 10 people will have radiotherapy as part of their treatment. Annual NHS costs for cancer services are £5 billion, but the cost to society as a whole, including costs for loss of productivity, is £18.3 billion. Recent advances in cancer treatment have seen the use of proton particles as an alternative to x-rays. To improve the treatment of cancer, the UK government have committed to building two new dedicated proton beam therapy centres at The Christie Hospital in Manchester and University College London Hospital NHS Foundation Trust.

Proton therapy enables a lower radiation dose to a patient receiving radiotherapy (compared to x-rays) and allows more accurate targeting of the tumour. Like x-rays, protons can penetrate tissue to reach deep tumours. However, compared to x-rays, protons cause less damage to healthy tissue in front of the tumour, and no damage at all to healthy tissue lying behind, greatly reducing the side effects of radiation therapy.

Using technology originally developed for the High Luminosity-Large Hadron Collider (HL-LHC), members of the Proton Radiotherapy Verification and Dosimetry Applications (PRaVDA) consortium helped overcome obstacles associated with proton beam therapy. Proton therapy is more sensitive than conventional x-ray treatment to uncertainties in both treatment planning and delivery.

The Large Hadron Collider (LHC) is the world’s largest and most powerful particle accelerator, it lets scientists reproduce the conditions that existed within a billionth of a second after the Big Bang. HL-LHC is the planned upgrade to the LHC that will allow the accelerator to provide more accurate measurements of new particles and enable observation of rare processes, making it possible to detect rare events not previously witnessed.
PRaVDA consisted of a team of leading instrumentation engineers and scientists, medical, high-energy and nuclear physicists and oncologists from across the UK and South Africa. Institutions involved from the UK include the Universities of Birmingham, Lincoln, Liverpool, Warwick and Surrey, University Hospital Coventry and Warwickshire NHS Trust and the University Hospital Birmingham NHS Foundation Trust. The consortium worked with UK industry in the manufacturing of hardware for the device; this includes Micron Semiconductor (UK) Ltd, Image Sensor Design and Innovation (ISDI) and Express Circuits Group Ltd. This demonstrates the skills and knowledge UK industry has to be able to provide unique components for pioneering instruments.

The instrument originally developed by PRaVDA is a tracking detector which allows the user to predict the path of a particle very accurately as it passes through space. The instrument will also measure the loss of energy and scattering of protons as they pass through a patient. This means a 3D image of the tumour can be created using the same beam that is also used to treat the tumour.

Clinicians will be able to better predict the energy level and location of the dose, allowing treatment to be altered to ensure the tumour is being hit, rather than the surrounding healthy tissue. This is particularly important in vulnerable parts of the body such as the brain, eye and spinal cord.

The instrument is seen as ideal to treat cancer in children, reducing the risk of secondary cancers that can appear many years later in a patient’s life. This has particular social and economic benefits as the patient’s long-term health is improved and reduces the chance of more cancer treatment being needed.

Alongside support from STFC, PRaVDA received funding from the Wellcome Trust to develop the instrument based on technology for the upgrade programme at the LHC. STFC is continuing to support this area of technology development with an award of just under £1 million for the Global Challenge Network+ in Advanced Radiotherapy.

The scanner is now being developed by the OPTIma (Optimising Proton Therapy through Imaging) project, funded by a £3.3 million grant from the Engineering and Physical Sciences Research Council (EPSRC). It will be part of the research room at the Christie Hospital in Manchester, and will be the first time that a proton imaging system is installed in an operational proton therapy centre.
We asked our supported principal investigators to provide details of any software or technical products that have been developed for the first time or to a significant new stage, including improvements to, or modifications of, existing products.

STFC-supported researchers reported over 200 different software and technical product developments. These include detectors, grid applications, web tools, materials and instrumental engineering developments and physical models and kits.

Over 30% of the software and technical products reported to STFC were classified as open source and are available for others to adapt, potentially into new sectors and disciplines.
Improving human-machine learning across the Zooniverse

Improving the classification of large scientific datasets

One of the biggest challenges currently facing science is not the ability to generate and capture scientific data but the ability to be able to analyse all of the data that is available. Data from experiments, facilities, telescopes etc. can easily reach terabyte size (1 terabyte is equal to 3.6 million 300 kilobyte images). Science acquires data far more rapidly than the rate at which it can process, analyse and exploit it.

Researchers from the hugely successful Zooniverse project are improving the way in which large scientific datasets are analysed whilst simultaneously engaging with a vast public audience as one of the champions of people-powered research.

The Zooniverse is an online platform that enables everyone to take part in real cutting edge research in many fields across the sciences, humanities, and other disciplines. Several projects are available on the Zooniverse platform, allowing any willing volunteers, no matter what their background or expertise, access to real scientific datasets. Participants are asked simple questions regarding the data which contributes to the classification and analysis of large scientific datasets. This would take an average research team many years to be able to do by themselves. Currently, Zooniverse has received over 371 million classifications from over 1,500,000 registered volunteers.

The Zooniverse team recently received support from STFC to create a demonstration project that further improves classifications on the system by advancing how these are made by both human contributors and by machine learning. The first step will be to develop the underlying Zooniverse software so more difficult cases are shown to expert contributors, the team estimate that this will improve classification efficiency by a factor of ten. The second step will be to include machine and human classifiers together in the same project. As volunteers work their way through a dataset, so machines can learn from them. This allows an increasing proportion of the dataset to be automatically processed, reducing the burden on the volunteers. These developments will allow a cycle of human and machine classifications to rapidly search...
through large and diverse datasets, and critically will allow the team to search for categories of interest that develop during the classification process. Pushing the boundaries of citizen science by improving the human and machine classification software could prove to be a landmark in the way large scientific datasets are analysed in the future.

For this project, the team will be collaborating with the Francis Crick Institute, the biomedical research facility in London. The Francis Crick Institute will be providing data and expertise on machine learning. Zooniverse have existing partnerships with Cancer Research UK, who used the platform to build science-filled games, and with the Natural History Museum. This demonstrates the uses to which the software can be put.

The platform can also be used for more than just research. A recent partnership with an NGO, Rescue Global, and the Earth observation company Planet Labs allowed rescuers to quickly generate new maps of settlements in Nepal following the tragic earthquake there. In 2017, Zooniverse volunteers helped Rescue Global coordinate the response to hurricanes Irma and Maria, examined satellite images taken of multiple islands before and after the hurricanes, marking damage, flooding, blocked roads and evidence of temporary settlements. In total, over 5,000 volunteers provided approximately 650,000 classifications of the islands of Antigua, Barbuda, Dominica, Guadeloupe, Puerto Rico, Turks and Caicos, and the US and British Virgin Islands. This effort, which was completed in just over 3 weeks, represents 8 months' worth of continuous (24 hours a day, 7 days a week) human effort, or 2 years and 10 months of full-time employment for 1 person. This new development, which aims at efficient, rapid classification will be key in enabling the team to expand their disaster relief work for future crises.

Zooniverse has been a regular feature of the Stargazing Live programmes for the BBC and ABC in Australia. Viewers are invited to provide classifications on one of the Zooniverse's many projects. The results of the classifications are then analysed and exciting discoveries announced during the following nights. During a 3 day series in 2017, volunteers helped discover a new 5-planet system.
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Establishments at Boulby Underground Science Facility, Cleveland; Chilbolton Observatory, Hampshire; Daresbury Laboratory, Cheshire; Polaris House (STFC headquarters), Swindon; Rutherford Appleton Laboratory, Oxfordshire; UK Astronomy Technology Centre, Edinburgh.