9-2020

Research 4.0: Research in the Age of Automation

Rob Procter
Warwick University

Ben Glover
Demos

Elliot Jones
Ada Lovelace Institute

DEMOS

RESEARCH 4.0

RESEARCH IN THE AGE OF AUTOMATION

PROFESSOR ROB PROCTER
BEN GLOVER
ELLIOT JONES

SEPTEMBER 2020

Published by September 2020

15 Whitehall, London, SW1A 2DD
T: 020 3878 3955
hello@demos.co.uk
www.demos.co.uk

CONTENTS

ACKNOWLEDGEMENTS

We would first like to thank Jisc for supporting us with this project.

We would like to thank Rob Procter for agreeing to partner with us for this report and for all his invaluable advice, guidance and challenge throughout the project.

We would like to thank the academics who took the time to share their thoughts and experiences with us at a workshop held at the University of Salford and everyone who gave up their afternoon to join us for our policy roundtable.

We are also extremely grateful to all those that gave up their time to be interviewed by us. Without them this report would not have been possible.

At Demos we would like to thank all the participants of our scenario planning workshop. In particular, we would like to thank Stanley Phillipson Brown for his excellent work assisting with research duties for this report.

Ben Glover
Elliot Jones

September 2020

Rob Procter is Professor of Social Informatics in the department of Computer Science, Warwick University. He is also a Faculty Fellow at The Alan Turing Institute. Previously he has held positions at Manchester and Edinburgh universities. His research interests are strongly interdisciplinary, and focus on understanding how individual, organisational and social factors shape processes of design, development and adoption of digital innovations. Current interests include social media analytics and social data science.

Ben Glover is Deputy Research Director at Demos.

Elliot Jones is a researcher at the Ada Lovelace Institute and was a researcher at Demos.

EXECUTIVE SUMMARY

There is a growing consensus that we are at the start of a fourth industrial revolution, driven by developments in Artificial Intelligence, machine learning, robotics, the Internet of Things, 3-D printing, nanotechnology, biotechnology, 5G, new forms of energy storage and quantum computing. This wave of technical innovations is already having a significant impact on how research is conducted, with dramatic change across research methods in recent years within some disciplines, as this project's interim report set out.[1]

Whilst there are a wide range of technologies associated with the fourth industrial revolution, this report primarily seeks to understand what impact Artificial Intelligence (AI) is having on the UK's research sector and what implications it has for its future, with a particular focus on academic research. Following Hall and Pesenti in their recent government review of the UK's AI industry, we adopt the following definition:

> *"[AI is] an umbrella term to cover a set of complementary techniques that have developed from statistics, computer science and cognitive psychology. While recognising distinctions between specific technologies and terms (e.g., artificial intelligence vs. machine learning, machine learning vs. deep learning), it is useful to see these technologies as a group, when considering how to support development and use of them".*[2]

Hence, we will use 'AI' as an umbrella term throughout the report to cover a range of different technologies (e.g., machine learning, data visualisation, robotics).[3]

Building on our interim report, we find that AI is increasingly deployed in academic research in the UK in a broad range of disciplines. The combination of an explosion of new digital data sources with powerful new analytical tools represents a 'double dividend' for researchers. This is allowing researchers to investigate questions that would have been unanswerable just a decade ago.

Whilst there has been considerable take-up of AI in academic research, steps could be taken to ensure even wider adoption of these new techniques and technologies, including wider training in the necessary skills for effective utilisation of AI, faster routes to culture change and greater multi-disciplinary collaboration.

We also envisage a range of possible scenarios for the future of UK academic research as a result of widespread use of AI. Steps should be taken to steer us towards desirable futures. The research sector is not set in stone; it can and must be shaped by wider society for the good of all. We consider how to achieve this in our recommendations below.

We recognise that the Covid-19 pandemic means universities are currently facing significant pressures, with considerable demands on their resources whilst simultaneously facing threats to income. As a result, we acknowledge that most in the sector will be focused on fighting this immediate threat instead of thinking about the long-term future of research. But as we emerge from the current crisis, we urge policy makers and universities to consider our recommendations and take steps to fortify the UK's position as a place of world-leading research. Indeed, the current crisis has only reminded us of the critical importance of a highly functioning and flourishing research sector.

1. Jones, E., Kalantery, N., Glover, B.. Research 4.0 - Interim Report. Demos, 2019. Available at https://demos.co.uk/wp-content/uploads/2019/10/Jisc-OCT-2019-2.pdf [accessed 15 July 2020]
2. Hall, W., Pesenti, J. Growing the artificial intelligence industry in the UK. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/652097/Growing_the_artificial_intelligence_industry_in_the_UK.pdf [accessed 15 July 2020]
3. Hall and Pesenti. Growing the artificial intelligence industry.

KEY FINDINGS

How is AI changing academic research methods in the UK?

We conducted a series of interviews with leading UK researchers that use AI in their research. Building on our interim report, we find that AI is increasingly being deployed across UK universities and in different disciplines, from STEM subjects to social sciences, the arts to humanities.

An explosion of new digital data sources and the ability to extract more data from existing sources has vastly increased the available data for researchers across a wide range of disciplines.

Once data is prepared for analysis, powerful new analytical tools are driving further breakthroughs and discoveries. This is AI's 'double dividend' for researchers: new digital data and new ways of analysing those data, allowing researchers to ask questions that would have been impossible a decade ago.

AI as it is currently deployed in academic research was generally not viewed as freeing up time for more theorising, a hypothesis we flagged in our interim report and were interested in investigating. This was because the use of AI in research is often extremely time-intensive, due to the amount of preparation and cleaning time of data and often frequent experimental iterations involved to find the best 'solution'.

How is AI changing research processes and research administration in the UK universities?

We also explored in our interviews how AI is – or could be – used throughout the archetypal research project lifecycle (e.g., literature reviews, writing proposals, analysing data, writing papers for peer review, etc.) and in research administration (e.g., reviewing papers and research proposals, specification and management of research programmes, etc.). The evidence from our interviews suggests that there is relatively little explicit adoption of AI to support the wider research process and research ecosystem in UK academic research.

For example, it is widely recognised that the peer review process has been struggling for some years to keep pace with the numbers of papers submitted for publication. However, AI was generally viewed as poorly suited to solving this problem. Most of the issues relating to peer review were perceived to be due to cultural and social factors that could not be addressed in this way without introducing new problems that might undermine confidence in the process.

However, there was a recognition amongst some interviewees that the literature review stage of the research process could be aided by the use of AI, though this does not appear to be happening explicitly at present.

How is AI changing the wider academic research ecosystem in the UK?

Our interviews also explored how the use of AI in academic research is changing the UK's academic research ecosystem. This allowed us to better understand the financial, institutional and cultural barriers to the further adoption of AI within universities.

Interviewees were generally not concerned that the use of AI will negatively impact early career researchers' prospects by, for example, automating some of the tasks normally performed by early career researchers. This is because its application is often highly labour intensive. As a result, there are often more tasks for early career researchers as a result of using AI in academic research, not fewer.

However, there are concerns that researchers are not receiving appropriate recognition for these tasks (e.g. data cleaning, data annotation and curation, model building, etc.). Appropriate recognition could include ensuring that the creation of re-usable datasets is properly credited in journal articles that utilise their data, for example.

The capacity of digital infrastructure in UK universities also appears to vary significantly. Researchers in different departments, universities and regions often have different experiences accessing the infrastructure they need to conduct research. This suggests that any attempt to improve national digital research infrastructure must be informed by a rigorous assessment of where the problem lies, so support can be targeted where it is most needed. In particular, those working in the arts and humanities appear to face significant challenges accessing the technical infrastructure they would need in order to innovate their research methods.

Interviewees described how academic researchers often lack the necessary skills to make full use of

AI. We heard how humanities researchers often lack sufficient quantitative and/or digital skills and that appropriate utilisation of AI requires domain knowledge and technical know-how, a multi-disciplinary combination that may be hard to find. We also heard that too often those with the technical skills lack a proper awareness of the ethical risks posed by AI. This is an evolving problem; for example, risks relating to privacy breaches increase with the linking of datasets, and possibilities of introducing bias into decision-making processes increase as we rely more on AI trained on datasets that themselves contain hidden biases.

Successful utilisation of AI is also likely to demand multidisciplinary expertise and working. Whilst there are numerous strong examples of multidisciplinary academic research applying AI in the UK, interviewees described that there are often barriers to this way of working. These barriers are likely to be challenging to overcome given they often stem from deep-rooted structural factors, such as the way research funding is organised and, relatedly, the structure and nature of academic disciplines.

Interviewees widely described how AI talent is being lost from academia to the private sector and often does not return. Whilst this is partly due to a significant pay differential – owing to the widely recognised global shortage of AI skills – it may also be because returning to academia from industry can be challenging for non-financial reasons. For example, academic roles typically demand a strong journal publication record that is sometimes difficult to acquire when working in the private sector. Steps need to be taken to facilitate greater movement of skilled people between academia and the private sector.

How will AI impact the UK research's sector in the future?

We undertook a scenario planning exercise to help understand how the rise of AI will continue to shape the UK's research sector in the future. Instead of making precise predictions about the future, which is fraught with difficulty and too often highly inaccurate, we used scenario planning to produce several distinct potential visions of the future of UK research as impacted by the AI and the technical innovations associated with 'fourth industrial revolution'.

Using a three-stage process, we developed five possible futures for the UK research sector in 2040 as a result of the fourth industrial revolution. Summaries of these scenarios are provided below. More detail about the scenarios and the methodology used to devise them can be found in Chapter Two.

Decentralised Research

- Technological developments allow for a democratisation and decentralisation of science, with independent researchers having access to the same tools as those working in universities and large companies. This allows for more fluid research, with collaborations more easily springing up between the public sector, private sector, communities and citizens, with the state enabling this through less hierarchical research funding and open access to research for all.

National Champions

- The state works in concert with homegrown, UK technology companies to push the frontiers of science, creating a nexus where the public and private sectors are co-equal partners in research. The state funds and protects these companies from outside competitors, be it from the US, China, or Europe, and, in exchange, shares in their successes and has a seat at the table in their decision-making.

Public Service Science

- A state-driven research sector, directed by government missions with the government providing vastly increased public research funding, public service cloud computing facilities and experimenting with new research models, e.g., in the mould of the Advanced Research Projects Agency in the US (ARPA). However, the country is more closed off to the rest of the world and research is focused primarily on serving the UK, not on serving other countries or the pursuit of knowledge.

Big Tech Research

- The UK's research sector is now dominated by large technology companies, most of them based in the U.S. and China. UK academic research, where it continues to exist, does so in explicit partnership with technology companies, who provide most of the funding. Whilst the UK continues to produce world-leading research, much of this is behind closed doors, hampering scientific breakthroughs.

Backwater Britain

- The UK's research sector has stagnated and is entering a period of terminal decline. A failure to invest in the right technologies, infrastructure and skills means that the UK has not been able to keep hold of its position as a world-leading country for research. The decline of the research sector affects the wider economy, given the relationship between research and innovation. The UK is viewed as a less attractive place to invest and do business; its decline is symptomatic of a wider economic malaise.

RECOMMENDATIONS

Education and Skills

To ensure that UK universities and the research sector have the skills needed to fully and safely harness the potential of AI, we propose some key ideas that could deliver change. We recommend these ideas are explored further by the sector, along with the full range of '4.0' technologies:

Recommendation 1: **Skills**. The current post-16 curriculum should be reviewed to ensure all pupils receive a grounding in basic digital, quantitative and ethical skills necessary to ensure the effective and appropriate utilisation of AI.

Recommendation 2: **Ethics**. Universities should ensure undergraduate and postgraduate courses in AI embed a 'Responsible Research and Innovation' approach in the curricula to anticipate the negative impacts of AI and designing methods to avoid or mitigate them.

To ensure that researchers working with AI receive the recognition they deserve, we recommend that:

Recommendation 3: **Early Career Researchers**. UK research funders should require research proposals to make a clear statement that the work early career researchers undertake will be appropriately recognised.

Infrastructure

To level up infrastructure provision to ensure that researchers across the UK in all institutions can access fast, secure and reliable digital infrastructure, we recommend that:

Recommendation 4: **Infrastructure**. A UK-wide audit of research computing and data infrastructure provision is conducted to consider how access might be levelled up.

Research Funding and Investment

To encourage greater uptake of AI within universities, we recommend that:

Recommendation 5: **AI Incentives**. UK Research and Innovation (UKRI) should consider incentivising institutions to utilise AI wherever it can offer benefits to the economy and society in their future spending on research and development.

Strong interdisciplinary working is critical to effectively utilising AI in research. To encourage more interdisciplinary research in UK universities we recommend that:

Recommendation 6: **Interdisciplinary/ Multidisciplinary Research**. UKRI should devote more funding to interdisciplinary and multidisciplinary research programmes, such as the Strategic Priorities Fund.

Universities and the private sector

To encourage greater movement between academia and industry, we recommend that:

Recommendation 7: **Researcher Mobility**. Universities should take steps to ensure that it is easier for researchers to move between academia and industry, for example, by putting less emphasis on publications, and recognise other outputs and measures of achievement when hiring for academic posts.

Recommendation 8: **AI Fellowships**. UKRI should create and fund a number of 'AI industry fellowships' at UK universities.

INTRODUCTION

A decade ago, Demos, supported by Jisc, published *The Edgeless University*.[4] Then, we looked at how the internet, social networks and online collaborative tools were set to transform the creation of, and access to, knowledge. Today, Demos is again looking at how technology is transforming academia, this time examining how the fourth industrial revolution and AI, in particular, are reshaping the research landscape.

DEFINITIONS

Whilst there are no universally agreed definitions of AI, it is important to be clear about which definitions we are following in this report. The Engineering and Physical Science Research Council uses this definition:

> *"Artificial Intelligence technologies aim to reproduce or surpass abilities (in computational systems) that would require 'intelligence' if humans were to perform them. These include: learning and adaptation; sensory understanding and interaction; reasoning and planning; optimisation of procedures and parameters; autonomy; creativity; and extracting knowledge and predictions from large, diverse digital data."* [5]

Following Hall and Pesenti, throughout this report we will use the term AI as "an umbrella term to cover a set of complementary techniques that have developed from statistics, computer science and cognitive psychology. While recognising distinctions between specific technologies and terms (e.g., artificial intelligence vs. machine learning, machine learning vs. deep learning), it is useful to see these technologies as a group, when considering how to support development and use of them".[6] More detail about different AI technologies that are included in our umbrella term is given below.

- Machine learning

  Machine learning "...allows computer systems to learn directly from examples, data, and experience. Through enabling computers to perform specific tasks intelligently, machine learning systems can carry out complex processes by learning from data, rather than following pre-programmed rules." [7]

  Significant developments in machine learning in recent years (see below) are one of the key drivers of the recent resurgence of interest in AI. We now often interact with machine learning on a daily basis, from voice recognition used by virtual personal assistants to the recommendations tailored to us when we shop online.

- Deep learning

  Deep learning is a family of powerful machine learning techniques based on Artificial Neural Networks (a model of computation inspired by biological neural networks). These techniques have achieved "state-of-the-art results in most machine learning tasks since their development".[8]

- Natural Language Processing

  Natural Language Processing (NLP) uses machine learning techniques to extract information from unstructured data.[9] Applications include 'chatbots' and language translation.

- Computer vision

  Computer vision uses machine learning techniques to extract information from digital images.[10] Applications include classifying images and detecting objects within an image.

4. Bradwell, P. The Edgeless University. Demos, 2010.
5. Hall, W., Pesenti, J. (2017), Growing the artificial intelligence industry in the UK. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/652097/Growing_the_artificial_intelligence_industry_in_the_UK.pdf [accessed 15 July 2020]
6. Hall and Pesenti. Growing the artificial intelligence industry.
7. The Royal Society. Machine learning: the power and promise of computers that learn by example. Available at https://royalsociety.org/-/media/policy/projects/machine-learning/publications/machine-learning-report.pdf [accessed 15 July 2020]
8. Defence Science and Technology Laboratory. The Dstl Biscuit Book. 2019 Available athttps://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/850129/The_Dstl_Biscuit_Book_WEB.pdf [accessed 15 July 2020]
9. Engineering and Physical Sciences Research Council. Natural language processing. Available at https://epsrc.ukri.org/research/ourportfolio/researchareas/natlangproc/ [accessed 15 July 2020]
10. IBM, Computer Vision. Available at https://www.ibm.com/topics/computer-vision [accessed 15 July 2020]

Whilst this report is focused on AI, we recognise the extent to which data science – the use of statistics, mathematics and computer science to extract insights and understanding from data – overlaps with AI and machine learning.[11]

Finally, throughout this report we make frequent reference to early career researchers. Whilst there is no commonly agreed definition of an early career researcher, we are following the Research Excellence Framework and others in defining this group as anyone that is in their first 4-5 years of a full-time contract undertaking research or research and teaching, e.g. a postdoc or junior lecturer.[12]

SCOPE

This report is focused primarily on how AI is changing research. It seeks to address the following primary research questions:

- How is AI changing the UK's research sector and what are the barriers to its further adoption? In particular:
  - How is AI changing academic research methods in the UK?
  - How is AI changing the archetypal academic research process and research administration in the UK?
  - How is AI changing the wider academic research ecosystem in the UK?
- How will AI impact the UK research sector in the future?
- How can policy makers, universities and businesses ensure that the rise of AI in the research sector benefits the UK research sector and wider society as much as possible?

We focus on AI for two primary reasons. First, AI stands out from other fourth industrial revolution technologies given the extent to which they are widely considered to be general purpose technologies: applied across many sectors, can enable other technologies and which are rapidly improving. Second, for reasons of scope: it would be almost impossible in a report of this length to cover in appropriate detail the full breadth of technologies associated with the fourth industrial revolution.

The scope of this report is further limited in timescale. It is concerned with how research will change in fifteen to twenty years. Beyond this timescale, there are so many critical uncertainties and potential unknowns that we cannot meaningfully envisage the future of research without slipping into speculative science fiction.[13]

Finally, our primary research was completed in 2019 before the emergence of Covid-19. As a result, the bulk of this report does not directly discuss or address the pandemic. However, given the long-term focus of this report, and the extent to which the trends identified will be at play post-Covid-19, its findings and recommendations are still highly relevant to a world responding to the pandemic. Indeed, the crisis has only highlighted the importance of the UK's research sector, for example, through several UK-based attempts to develop a vaccine, and the need to ensure it retains this position.

METHODOLOGY

The content of this report draws on:

- A comprehensive review of the relevant academic and industry literature conducted for our interim report.[14]
- A series of semi-structured interviews with academics working at research-intensive UK universities. Though we have anonymised the contributions of interviewees to this report, we have provided below details of their seniority, discipline and region.
  - Fellow, Science and Technology Studies, London
  - Fellow, Neuroscience, London
  - Professor, Humanities, London
  - Professor, Social Sciences, South West
  - Professor, Geography, Yorkshire & Humberside
  - Professor, Chemistry, South East
  - Professor, Humanities, Scotland
  - Professor, Computer Science, North East
  - Professor, Humanities, London
  - Reader, Engineering, Wales
  - Reader, Social Sciences, Midlands

11. Defence Science and Technology Laboratory.The Dstl Biscuit Book. 2019 Available athttps://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/850129/The_Dstl_Biscuit_Book_WEB.pdf [accessed 15 July 2020]
12. De montfort University. Early Career Researchers. Available at https://www.dmu.ac.uk/research/research-support/early-career-researchers/early-career-researchers.aspx
13. Which certainly has its place in conceiving what the future holds, but is not so effective at generating action-relevant policy recommendations.
14. Jones, E., Kalantery, N., Glover, B. Research 4.0 - Interim Report. Demos, 2019. Available at https://demos.co.uk/wp-content/uploads/2019/10/Jisc-OCT-2019-2.pdf [accessed 15 July 2020]

As we hope is clear from the list above, we engaged with researchers across a range of disciplines and regions to get as full a picture as possible of the use of AI in UK academic research today. Furthermore, whilst our interviews were primarily with academic researchers, we also conducted the following interviews for a broader perspective:

  - Former Managing Director, academic publisher
  - Director, research council

- A forecasting forum with external attendees from academia and civil society.
- A scenario planning exercise involving an internal workshop with Demos colleagues.
- A workshop at the University of Salford.

We acknowledge that time constraints have limited the evidence base for this report. That said, we believe we have identified a number of key issues in relation to AI and UK research.

CHAPTER 1
THE FRONTIER OF AI-ENABLED RESEARCH

Our interim report explored how researchers are adopting a range of AI tools and techniques, including machine learning, natural language processing and computer vision. This chapter examines in further detail how AI is changing research methods, the research process and the wider research ecosystem, with a focus on UK universities. It is informed by the evidence review conducted for the interim report, a series of in-depth interviews with eleven leading UK academic researchers using AI, a forecasting forum with external attendees from civil society and academia and a workshop at the University of Salford. More details about our methodology can be found in the introduction of the report.

RESEARCH METHODS

What's happening now?

As our interim report explored in detail, researchers across the world are increasingly utilising AI tools and techniques to support their research. Similarly, throughout our interviews we heard of the extraordinary range and diversity of approaches in applying AI technologies to research in UK universities. This was visible across a wide range of fields and disciplines, from STEM subjects to social sciences, arts to humanities.

Getting more from existing data sources

We heard how AI tools and techniques are allowing research to be carried out at a scale that would have previously been impossible. Interviewees described how machine learning tools have been used by humanities researchers to 'read' hundreds of thousands of historic letters, thousands of newspaper articles. These tasks which would have taken humans decades and would therefore be completely unviable without machine reading. Computer vision can also be used to analyse old texts that a human would be unable to read no matter how much time they had.

New data sources

The increasing proliferation of Internet of Things (IoT) sensors is allowing researchers to undertake analysis in close to real time, where previously this would have required manual data collection and post-hoc analysis. For example, monitoring the condition of physical infrastructure, such as bridges, would previously have had to rely on despatching engineers to measure key parameters. Now, structures can be monitored in real time, allowing instant updates of maintenance plans.

Similarly, user generated content (UGC), such as social media posts, provides the opportunity for researchers to measure public opinion in real-time, reducing (if not eliminating) dependence on costly and time-consuming surveys.

New ways of gathering data are also increasing the accuracy of existing research methods. Research has shown that one of the main causes of drug trial failure is the inability to monitor patients effectively.[15] In order to be monitored, patients are required to keep a record of their medication intake and bodily responses themselves. This is laborious and can often result in patients dropping out of a trial. To address this, wearable sensors and video technology can be used along with machine learning to record and analyse patient data during trials. For example, one interviewee described how body-worn sensors, which patients can wear for weeks or months, can allow us to much better understand the effect of a treatment on people's lives than hospital-based testing.

15. Harrer, S., Shah, P., Antony, B., & Hu, J. Artificial intelligence for clinical trial design. Trends in pharmacological sciences, 2019, 40(8), 577-591

Issues relating to the ‘data explosion’

Whilst the data explosion brings several important benefits, including the potential for better quality research and new research domains, interviewees described how it raises a number of important methodological and ethical challenges.

First, the wide range of new data sources has increased the amount of time required for cleaning and preparing data for analysis. Interviewees felt there was some scope for automation to reduce the time this typically takes, but that this would likely be limited and a fairly high degree of human involvement would always be necessary. As a result, this was placing a heavy burden on researchers’ time and detracting from the potential for these new technologies to be labour-saving devices. However, it is important to note that the use of machine learning to automate data cleaning is an active area of current research, so this may not still be the case in the future.[16]

Second, the vast amount of data gives rise to new ethical challenges. Researchers are responsible for ensuring that individuals cannot be identified in any data they publish and that their privacy is protected. Using new sources of personal data for research raises new questions around consent: those who have created the data are unlikely to have given explicit consent for their data to be used for research purposes. Furthermore, the likelihood of the increased linking of datasets may make it impossible to guarantee anonymity to data subjects.[17] Models trained on historical data may inadvertently introduce bias if they are subsequently used in decision-making tasks, as studies of the use of AI by parole boards and in the online placement of job adverts have revealed. Researchers need to be aware of these and other undesirable impacts when considering whether the use of AI is justified ethically.

A broader issue concerns the fact that potentially valuable datasets collected by private companies, such as social media platforms, are often unavailable to researchers. This creates a very real barrier to research and we will consider how to address this later in the report.

CASE STUDY 1: ROBOT SCIENTIST ‘EVE’ [18]

In 2015 researchers at the University of Aberystwyth and the University of Cambridge developed ‘Eve’, an artificially-intelligent ‘robot scientist’ that aims to speed up the drug discovery process and to help make the discovery of new drugs more cost-effective.

Eve’s primary purpose is to automate early-stage drug design. Eve’s robotic system is able to screen over 10,000 compounds per day, but mass screening - whilst fairly simple to automate - is still a relatively slow process, as an extremely large number of compounds must be tested. In addition, it is an unintelligent process, as mass screening in this manner does not make use of what is learnt during screening.

As an improvement on this process, Eve uses machine learning and statistics to predict new structures that could score better against the tests. As Professor Ross King describes, “bringing in machine learning to make this process intelligent – rather than just a ‘brute force’ approach – could greatly speed up scientific progress and potentially reap huge rewards.” [19]

Eve showed that a compound often used in cancer drugs inhibits a key molecule in malaria parasites. Professor King describes how “despite extensive efforts, no one has been able to find a new antimalarial that targets DHFR and is able to pass clinical trials...Eve’s discovery could be even more significant than just demonstrating a new approach to drug discovery.”

16. Krishnan, S., & Wu, E. Alphaclean: Automatic generation of data cleaning pipelines. arXiv preprint arXiv:1904.11827, 2019.
17. Lane, J. et al. (Eds.) Privacy, Big Data and the Public Good. CUP, 2014.
18. University of Cambridge, Artificially-intelligent Robot Scientist ‘Eve’ could boost search for new drugs. 2015. Available at https://www.cam.ac.uk/research/news/artificially-intelligent-robot-scientist-eve-could-boost-search-for-new-drugs [accessed 15 July 2020]
19. University of Cambridge. ‘Eve’ could boost search for new drugs.

Analysis

Once the data has been extracted from the documents, AI technologies such as machine learning can help identify trends and classify drugs more effectively. This combination of vast quantities of new data and powerful new analytical tools is driving breakthroughs that would have been unimaginable a generation ago. For example, AI tools are used to discover novel materials that meet particular requirements, with their properties screened in robotic labs. The possibilities for new ground-breaking discoveries are significant.

These are just a few select examples from our interviewees of how AI tools and techniques are being used in research at UK universities. More details about the specific use of these tools in UK universities are provided in case studies throughout this chapter.

Will the use of AI free up more time for theorising?

It is useful to consider how AI might impact researchers' time. Its use to automate more manual tasks could enable researchers to devote more time to intellectually demanding and interesting activities.

However, in general, our interviewees didn't think this was happening today or likely to happen in the near future. This is because the use of AI is frequently perceived to be extremely time-intensive, due to the amount of preparation and cleaning time that data often requires before it can be analysed. One interviewee described how they spent a year cleaning 160,000 letters to prepare them for analysis. This was not automatable because a machine learning tool wouldn't have had the nuance required to properly analyse the text. And though it was possible to train early career researchers to carry out this work, it would likely have to be checked for validity quite extensively by more senior researchers, viewed as a significant drain on their time.

Furthermore, the wider research process has seen little automation, as we will explore in greater detail in the next section of this chapter. There remain many labour-intensive, manual stages to the research process, for example, attaching sensors, downloading files, etc. This is partly because, in the view of one interviewee, "there's not a Microsoft research tool for doing all of these things", leaving people to join lots of different processes together.

However, some interviewees did feel that "some of the drudgery" had been removed by automation. Simulations meant that those working in a lab could focus on more "higher level activities". They were able to run many more experiments and the costs associated with re-running experiments reduced. This meant it is possible to have more confidence in results in a shorter time frame.

In addition, it is worth highlighting that many interviewees argued that the ideal model for the use and deployment of AI is one in which machines and people work closely together. This is because, as one interviewee described, AI is at its most powerful when it interacts with and complements people, instead of entirely replacing them. Tasks or problems that require creative thinking and are not well defined from the outset will benefit from people and machines working closely and iteratively together; the idea that the researcher can set the parameters for a machine to then 'go off and do its thing' is wrong.

CASE STUDY 2:
LIVING WITH MACHINES[20]

Living with machines is a research project seeking to take a fresh look at the history of the Industrial Revolution using data-driven approaches. Housed at the Alan Turing Institute and the British Library, it brings together data scientists, historians, computational linguists and curators from a number of different universities.

This multi-disciplinary team aims to devise new methods in AI that can be applied to historical resources. This will allow digitised collections to be analysed at scale for the first time. These will initially be drawn from millions of pages of newspaper collections from the British Library's National Newspaper Archive and from other digitised collections, such as the census and government collected data. The new research methods developed will allow researchers to track change in society and culture during the Industrial Revolution.

The Alan Turing Institute describes how the project will be driven by a "strong collaborative research philosophy that will be methodical, self-reflexive and designed to evolve". This means that the development of methods, tools and infrastructure for the project will be driven by the central datasets used and the research questions. In turn, the findings from these methods will allow for research questions to be further honed and nuanced. As well as being iterative the project will also be collaborative, with engagement with a wider audience throughout the project.

'Living with machines' is a five-year research project funded through UKRI's Strategic Priorities Fund. [21]

RESEARCH PROCESS

In this section we consider how AI is changing the research process, with a focus on UK universities. We consider the research process to be everything that researchers do that is not primary research activity, from sourcing funding to reviewing literature.

Literature Review

What's happening now?

Reviewing the existing academic evidence is an essential stage of the research process. AI has the potential to significantly speed up and improve this process. Researchers at MIT have demonstrated that natural language processing techniques can be usefully applied to the summarisation of scientific papers, producing short plain-English summaries that highlight key information.[22] However, it is important to flag that this technology is still at an early stage of development and is not yet mature.

This can be used by researchers to more easily and more quickly parse the contents of a large number of papers, reducing the amount of time required to identify valuable sources for the literature review itself. The use and further development of tools such as this could significantly speed up the literature or evidence review stage of research, which at present can be highly time and resource intensive. Other platforms are utilising machine learning to uncover similar, relevant papers across fields and enhance searching capabilities in specific domains.

20. The Alan turing Institute. Living with Machines. Available at https://www.turing.ac.uk/research/research-projects/living-machines [accessed 15 July 2020]
21. The Alan turing Institute. Living with Machines
22. Dangovski, R., Shen, M., Byrd, D., Jing, L., Nakov, P., & Soljacic, M. Improving Neural Abstractive Summarization Using Transfer Learning and Factuality-Based Evaluation: Towards Automating Science Journalism.. 2019

CASE STUDY 3: THE EXISTENTIAL RISK RESEARCH ASSESSMENT

The University of Cambridge's Centre for the Study of Existential Risk has developed the 'Existential Risk Research Assessment' to improve the evidence review stage of the research process.[23] It utilises expert human judgement to classify the relevance of papers to existential risk and then uses that dataset to train a machine learning model that can identify other potentially relevant papers from existing databases of research papers. This automatically generates a continually updating bibliography of publications relating to existential risk. This allows researchers to access "a vast amount of collective work and knowledge, rather than having to 'reinvent the wheel' by doing their own search" in a field not traditionally categorised by publishers. [24]

CASE STUDY 4: arXlive

Nesta have launched an open-source platform, 'arXlive', for live monitoring of research papers on the research repository, ArXiv, in order to facilitate innovation policy research. This tool helps researchers follow the latest research in computer science when "traditional means of monitoring industrial and academic activity are relatively slow" and research in machine learning and related techniques are moving quickly. [25]

23. Shackelford, G., Kemp, L., Rhodes, C., Sundaram, L., ÓhÉigeartaigh, S., Beard, S., Belfield, H., et al. Accumulating evidence using crowdsourcing and machine learning: A living bibliography about existential risk and global catastrophic risk. Futures, 116, 2020. https://doi.org/10.1016/j.futures.2019.102508
24. Shackelford et al. Accumilating evidence using crowdsourcing and machine learning.
25. https://arxlive.org/ (accessed 15 July 2020)

Discussion

Our interviewees acknowledged the potential for AI to improve and speed up the literature review stage. In particular, it was felt that digital tools could point researchers towards the most relevant information and help summarise high-level evidence for the reader. In this way it would act as an advanced filtering mechanism, in conjunction with, or embedded within, a search engine. There was broad recognition that some of the tasks undertaken by a human are quite repetitive, time consuming and could be usefully automated:

> *"The way you do a literature review as a human is to scan the index and the introduction or the abstract to see whether there's something relevant to your research there and being able to automate that to at least filter out stuff that you're not going to have to bother reading would be very useful indeed."*

However, there was disagreement over whether it would be possible to 'outsource' this stage of the research process to machines altogether. Some interviewees were concerned that a summary of an article alone would give the researcher an insufficient level of understanding. Instead, it was suggested that AI tools should be used to highlight what not to read, as opposed to providing complete summaries of relevant papers:

> *"I think an automatically generated summary of a research article, for most people, I think is not enough. It's a cue to go and look further rather than, 'Okay, I know what's in that I don't need to read it.'"*

Alongside making research processes more efficient, there was a view amongst some interviewees that AI tools could help tackle research biases, in particular, gender bias. There was a recognition that tools could be used to analyse the references in research papers, for example, allowing the proportion of citations to female authors to be identified. This could then help researchers to better understand the biases of their source material and to identify fewer biased sources.

> *"I think maybe you could evaluate manuscripts to see that they were referencing, you know, [...] all the appropriate female authors working in an area. So, in other words, that we could use it to counter any bias in citation."*

Grant Writing and Grant Awarding

What is happening now?

The use of AI could significantly reduce the amount of time that researchers spend applying for research grants and funding. At present these tasks can be time-consuming with significant administrative burdens, taking researchers away from conducting research.

It could also make the evaluation of applications for funding easier and simpler, boosting the efficiency of standard processes for research funders. For example, software has been developed to automatically filter out applications that fail to complete certain essential criteria or are unfinished. This can leave more time for tasks that are harder to automate, such as the qualitative review of bids.[26]

Discussion

There was a strong recognition amongst interviewees that the current process of applying for funding is extremely time consuming and reduces the time that researchers are able to spend researching. There was some recognition that AI may be able to address this.

However, some interviewees believed technology could only ever play a limited role in this process; for example, automatically filling in simple pieces of information on application forms (e.g., administrative information, biographies etc.). This was because human creativity was viewed by some as essential when writing a research proposal. However, other interviewees felt an AI tool could produce a first draft from which a researcher could then work.

There were also concerns regarding the use of AI in the review of funding applications. This primarily related to whether the use of automated reviewing processes would potentially screen out novel or innovative applications, which might be seen as anomalies by an algorithmic approach to reviewing applications. It was felt that a human would be better than a machine at distinguishing a genuinely innovative, novel application from a poor application.

However, it is also important to flag that if the increased use of AI tools leads to more applications, and the amount of funding doesn't

26. Keriann Strickland. 6 Easy Ways to Automate Your Grants Review Process. 2018. Retrieved 23 September 2019, from Submittable Blog | Submission Management Software website: https://blog.submittable.com/easy-ways-toautomate-your-grants-review-process/

increase to match the increased number of applications, we could see a situation in which there are simply more rejections. Furthermore, if reviewing remains the responsibility of humans, the bottleneck that already exists in the system – reviewers of bids having too many bids to review – could just be intensified.

Peer Review

What's happening now?

Peer review within academic research can be incredibly time consuming. Again, it is worth considering whether AI could make this process more efficient.

AI tools could automatically review data standards and other methodologically laborious elements of the review process, freeing up time for other more qualitative tasks that humans might be better suited to. For example, Elsevier uses the AI system StatReviewer which checks that statistics and methods in manuscripts are sound.[27] Technology could also save time by ensuring the expertise of researchers is best matched with particular papers: another time-consuming task for those involved in the peer review process.

Discussion

Some interviewees were sceptical of whether the peer review process could ever be conducted entirely or almost entirely by machines. This was because it was argued that the technology is yet to evolve to respond in relation to the lens of nuance, context, complexity and underpinning scholarship through which research outputs appear. One respondent argued that because "the paper is written for human consumption it needs to be read by a human".

Furthermore, some interviewees argued that AI would be unable to help with the most pressing issues affecting peer review. For example, interviewees reported that it was common for reviewers to take six months to review a paper and – unless you automated this process entirely, which was not deemed possible or desirable – technology would not help with this problem.

It seems unlikely that AI would ever entirely replace people in the peer review process, for reasons outlined above. What's more, just as academics today would be unlikely to accept the judgement of a single reviewer, we would not expect them to accept the judgement of a single software tool. It is therefore best to consider AI as providing assistance to the existing human reviewers, rather than replacing them altogether.

Indeed, interviewees recognised that there are a number of specific parts of the peer review process that could be improved by AI, even if the most pressing issues with peer review are social problems without technological fixes. For example, we heard that papers are often submitted for peer review with grammatical or spelling errors, mismatching citation formats, references missing from the bibliography, or mathematically impossible data, e.g. percentages totalling over 100%. An automated layer to the peer review process could filter these papers out before a human peer reviewer receives them, allowing the authors to correct mistakes and speed up the process. As one respondent explained:

> *"I spent a lot of time rejecting just really terribly written papers from professional academics. And I was shocked at the standards, at the sloppiness of it. And sometimes, you know, if there was a sieve that could just say that was written really badly with very bad grammar I would have happily put that through an automated sieve. It was, quite frankly, a real waste."*

Finally, some interviewees recognised that systems could be used to try to address biases in research. For example, publishers could build tools that analyse the references of a paper to assess the gender balance of its sources, with papers that fail to offer a sufficiently gender-balanced list of references rejected.

RESEARCH ECOSYSTEM

This section considers how AI is changing the institutional nature and structure of universities. It tries to identify institutional barriers that are likely preventing further uptake of AI in academic research.

Research Career Pathways

The use of AI in academic research could affect career pathways in academia. If there is scope for simpler research tasks to be automated, and if those tasks were traditionally undertaken by early

27. Heaven, D. AI peer reviewers unleashed to ease publishing grind. Nature, 2018 563, 609–610. https://doi.org/10.1038/d41586-018-07245-9

career researchers, there could be less demand for them. In turn, this could make it more difficult for people to begin a career in academia.

However, our interviewees did not believe this was happening today or was likely to happen in the near future. This was largely due to the use of AI in research often being extremely labour-intensive; interviewees described the huge amount of researcher time that is often required for cleaning and preparing data for analysis, for example.

Interviewees expressed more significant concerns about whether the work of early career researchers using AI is being appropriately recognised. For example, there were specific concerns that more junior researchers are often involved in the cleaning and preparation of data, but that these tasks may not receive sufficient recognition (e.g., being credited as an author and/or being properly acknowledged in academic papers).

We heard how some academic projects are seeking to avoid this problem by setting out clear statements of principles or 'lab charters'. These statements clearly describe how work undertaken on the project will be recognised, helping to ensure all receive appropriate recognition. For example, the Colored Conventions Project at the University of Delaware sets out a series of principles to guide its investigation, including honouring the work of scholars through "equitable compensation, acknowledgement, and attribution".[28]

There was also a recognition among some interviewees that the rise of new technologies represents a significant opportunity for early career researchers who are open to trying new methods and are flexible. This was largely driven by the view that more experienced researchers may be unwilling to learn new methods, but that demand for these new approaches would only increase. Thus, increased use of AI in academic research could represent a real opportunity for early-career researchers to get ahead of the curve. However, it is important to flag that there could be a counteracting force to this. It might be the case that senior academics are more willing to experiment with new ideas because they are better established and have less to lose; previous studies have found that older and more senior researchers were more likely to adopt 'Web 2.0' services in their work.[29]

University Infrastructure and Skills

Recent developments in AI have arisen in part due to ubiquitous connectivity and development of data-sharing infrastructure: increases in the availability of computational power via the use of Graphical Processing Units (GPUs) and cloud-based services; increasing access to large-scale data through the creation of massive, labelled data sets, and cloud-based data storage; and the increasingly widespread and free availability of powerful machine learning algorithms.[30] If researchers are unable to access this critical infrastructure it will hamper their ability to make the most of new tools and technologies.

Some interviewees described experiencing insufficient access to digital research infrastructure. For example, sometimes requests for access to high-performance computing were rejected as they were not deemed reasonable requests. Interviewees also raised concerns that because new tools often require access to large amounts of computing power and high bandwidth, less well-resourced institutions both in the UK and internationally may be unable to conduct cutting-edge research. This could have implications for the rate of scientific discovery and create greater inequalities in the research sector.

However, it is important to flag that poor access to the right digital research infrastructure was not a concern shared by all respondents. Several interviewees described how their institutions are well-equipped and are governed by a very pro-investment in technology mindset; we heard from one interviewee that "everyone's willing to invest in new technology".

Some interviewees also described how it is relatively easy to acquire funding for purchasing additional digital resources or infrastructure needed. For example, we heard from some interviewees how research councils have been ready and willing to fund significant amounts of cloud computing time. However, researchers in the arts and humanities appeared to have greater difficulty accessing the infrastructure they needed. This suggests that the response to this deficiency may need to be targeted at certain fields or subjects.

28. https://coloredconventions.org/about/principles/ [accessed 15 July 2020]
29. Procter, R., Williams, R., Stewart, J., Poschen, M., Snee, H., Voss, A., & Asgari-Targhi, M. (2010). Adoption and use of Web 2.0 in scholarly communications. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 368(1926), 4039-4056.
30. Jones, E., Kalantery, N., Glover, B. (2019), Research 4.0 - Interim Report, Demos. Available at: https://demos.co.uk/wp-content/uploads/2019/10/Jisc-OCT-2019-2.pdf (accessed 15 July 2020)

To summarise, access to digital research infrastructure in UK universities appears to vary significantly, with researchers in different universities and departments having significantly different experiences. This suggests that any attempt to improve digital research infrastructure must first be informed by a rigorous assessment of existing provision, so support can be targeted at where it is most needed.

A lack of skills was recognised by almost all interviewees as a major barrier to the take up of fourth industrial revolution technologies in universities. There was a widespread recognition that researchers often did not have the right skills to make even limited use of these tools, often due to a lack of appropriate training.

To generalise, the skills gap appears to be a greater issue in the arts and humanities, with interviewees from these disciplines often highlighting this gap as a major barrier to progress and the utilisation of new technologies. We heard how undergraduates in these disciplines often stopped receiving any STEM education at the age of sixteen, meaning undergraduates are often without the skills needed for fairly basic quantitative analysis. The lack of quantitative training at universities within arts and humanities programmes only makes this problem worse, with undergraduates or graduates rarely offered the ability to upskill in these fields; courses may offer a quantitative or digital methods module but this alone was perceived to be insufficient and would likely only be optional.

Furthermore, interviewees described how there is relatively little mid-career training available to those academics who have missed out on developing these skills earlier in their career. These issues represent a very significant barrier to the adoption of AI technologies and techniques. We will consider how to address this in the final chapter of the report.

It is important to note however, that there are not just skills deficiencies in the arts and humanities. Interviewees highlighted that in STEM subjects there is still a need for domain understanding (i.e., related to particular fields) and technical 'knowhow'. This is because AI technologies are complex and knowing how to apply these usefully to a particular question requires a good level of domain understanding and knowledge. But interviewees described how finding people with this combination of skills is challenging, with candidates often having one without the other. We also heard concerns that, with respect to AI, researchers were learning too narrow a set of skills, with a particular focus on deep learning, whilst neglecting other techniques.

University Culture

The culture of universities will influence the rate at which AI is adopted in academic research. Some interviewees described how university culture is very encouraging of innovation and the adoption of new technology, whilst others had less positive experiences.

Specifically, we found evidence of cultural opposition to AI in certain disciplines, particularly in the humanities. We also heard how it can be difficult to get digital research published in mainstream humanities journals, particularly in subjects such as Classics, English or History. This is likely having a significant impact on what types of research are carried out in universities, given researchers are strongly incentivised to publish in high impact journals through the Research Excellence Framework (REF). If these journals are less receptive to research using digital methods, this may stifle the uptake of digital methods in the humanities.

Interviewees often highlighted how successful utilisation of AI in research is likely to require interdisciplinary working. To make full use of these tools, research teams must combine extensive subject expertise with a strong technical understanding of the tools themselves. Furthermore, to ensure that any moral or ethical risks are properly mitigated, research teams may need to involve ethicists, for example.

Whilst there are a range of strong examples of interdisciplinary research projects using AI in the UK today, interviewees described that there are barriers to this way of working within UK universities. Strong academic incentives exist for researchers as individuals to specialise and be single-disciplinary in their own research. As one interviewee described, "you just specialise, specialise and specialise in the current system...[this] creates a narrowness of thought." Furthermore, some interviewees described how there is relatively little mixing across different disciplines, with departments being described as "too closed".[31] Finally, there may also be some bias against multi-author publications in some humanities subjects, further discouraging multi-disciplinary working.

31. The Alan Turing Institute. Living with machines. Availalbe at https://www.turing.ac.uk/research/research-projects/living-machines [accessed 15 July 2020]

Similar barriers have been identified elsewhere, including by Technopolis and the Science Policy Research Unit (SPRU) at the University of Sussex.[32] In a review of interdisciplinary research in the UK, they find that discipline-oriented cultures in universities "can act as barriers against wider engagement between disciplines".[33] In particular, they highlight how "friction and misunderstanding" between teams can be created by different approaches to evidence and rigour between disciplines as well as different methodological requirements.[34] Since then, there have been a number of UK initiatives designed to encourage interdisciplinary research.[35,36] In the next chapter we consider what further steps can be taken to overcome some of these barriers.

Universities and the Private Sector

In their recent government review of UK AI, Hall and Pesenti describe how rising industry demand for sophisticated AI skills has resulted in rising salaries, leading academics to move into businesses. The report argues this is affecting "the resilience and capacity of the academic network to continue blue sky research and to train talent." [37]

Similarly, many interviewees expressed significant concern over the extent to which researchers with strong AI skills are leaving academia for the private sector. We heard how, across a range of subjects, large numbers of graduate students that would have previously been destined for an academic career are now opting for the private sector, often at one of a small number of 'big tech' companies. This was particularly common in STEM subjects such as computer science, though our interviewees suggest it is increasingly common in the quantitative social sciences too. Whilst this trend has not been seen equally across all disciplines, one interviewee described how it was only a matter of time, particularly given technology companies' increasing focus on ethics and privacy; topics on which humanities students are likely to be well-placed to advise.

There is nothing inherently undesirable or wrong about AI researchers moving to industry from academia. However, the extent to which researchers move to industry and rarely if ever come back is a real challenge for universities. As a result, this means that the pipeline of talent within universities is threatened and universities could be missing out on cutting-edge AI skills developed in the private sector. Interviewees believed a number of factors lay behind this 'one way street'. As has been widely discussed, pay in the private sector is often significantly higher than a university, in part because of the extent to which a global shortage of AI skills has pushed up salaries for relevant fields.

But interviewees were adamant that it wasn't just about pay. They described how researchers sometimes prefer to be in the private sector, given firms may be better equipped and have a more innovative working culture. There was also a strong recognition amongst interviewees that moving between sectors is far too difficult to do, in large part because academic career progression depends upon achieving a high number of publications, which may be unachievable in the private sector. We will consider how to address this in the final chapter.

32. Davé, A., Hopkins, M., Hutton, J., Krčál, A., Kolarz, P., Martin, B., ... & Stirling, A. . Landscape review of interdisciplinary research in the UK.
33. Hopkins et al. Landscape review.
34. Hopkins et al. Landscape review.
35. IDAP, REF 2021 Interdisciplinary Research Advisory Panel (2019), Review of the criteria-setting phase. Available athttps://www.ref.ac.uk/media/1112/idap-criteria-phase-review-report.pdf [accessed 15 July 2020]
37. The Royal Society. APEX Awards. Availabe at https://royalsociety.org/grants-schemes-awards/grants/apex-awards/ [accessed 15 July 2020]

CHAPTER 2
SCENARIOS FOR THE FUTURE OF RESEARCH

This chapter sets out five credible scenarios for the research in the UK in 2040, as impacted by the fourth industrial revolution and, in particular, the rise of AI.

MOTIVATION

Making predictions about the future is fraught with difficulty. The vast number of factors that are involved in shaping the future makes accurate prediction often impossible. The point of scenario planning is therefore not to predict what the future will look like, but to help us live with the uncertainty of the future. This technique utilises the fact that many of the trends that will drive the future are already visible around us today. By identifying the trends and drivers that we know are important, we can tell valuable stories about the future and try to meet its uncertainty.[38]

One important value of scenario planning is that it can allow a diverse range of perspectives to be aired, avoiding the risk of 'group think'. It is also helpful for decision makers to develop policies that will work in all conceivable futures; the aim is not to understand what the future will look like but rather how we can prepare for all possible futures.

METHOD

To develop our scenarios we used a four stage process, adapted from longstanding Demos work on scenario planning.[39]

Stage One - Identifying relevant factors

We first identified the trends we thought may shape the future of research in the UK using a PESTLE (Political, Economic, Social, Technological, Legal, Environmental) analysis. We then combined these trends into groups, as shown in the table below.

	EXAMPLE UNCERTAINTIES
Research 4.0 capability	• What happens to Moore's Law? • Can researchers continue to access new datasets driving new discoveries? • Do breakthroughs in AI continue or do we enter a third 'AI winter'?
Infrastructure capability	• Are investments made to 'level up' national digital infrastructure? • Can researchers access the cloud computing, storage and processing power they need?
Education, Skills & Immigration	• How well do our schools prepare students and researchers for the utilisation of Research 4.0 tools and techniques? • Can our universities attract the best Research 4.0 experts from around the world?
Academic Culture	• Does academic culture hinder or help the adoption of new tools and techniques?
Public Attitudes	• How does the public respond to the widespread uptake of fourth industrial revolution tools and techniques? • Do we see a 'tech lash'? • Does the public grow increasingly concerned about the collection of confidential data and the purposes it might be used for?
Governence and Anti-Trust	• How does the government respond to the growing economic, political and social power of large technology companies?

38. Edwards, C. Futures thinking (and how to do it...) Demos, 2008. Available at https://www.demos.co.uk/files/File/PSI_planning_for_the_future_paper.pdf [accessed 16 July 2020]
39. Edwards. Futures thinking.

Stage Two - Exploring driving forces

In a workshop with Demos colleagues we then explored how these different factors might play out. For each factor we tried to identify both the current situation in relation to that factor and how it might play out in the future. This allowed us to reach agreement on what we considered to be key driving forces. Participants identified public attitudes, governance and anti-trust, and education, skills and immigration as the likely key drivers.

Stage Three - Developing and agreeing scenarios

We then created a number of scenarios, setting out how the drivers identified in the table above could play out and interact. We set out to develop stories that are plausible and internally consistent.

SCENARIOS

Decentralised Research

Summary

Decentralised Research describes a world in which technological developments allow for a democratisation and decentralisation of science, with independent researchers having access to the same tools as universities and large companies. This allows for more fluid research, with collaborations easily springing up between the public sector, private sector, communities and citizens. The state plays an enabling role through less hierarchical research funding and opening up access to research for all.

Detail

The future is open. That, if anything, is the slogan of the UK's research sector in 2040. Research still often takes place in the hallowed halls of ancient universities and billion-pound labs of high-end biotech and AI firms. But breakthroughs are just as common in British bedrooms.

Personalised AI-enabled assistants, cheap sensors of all kinds and vast, publicly available datasets describing all kinds of natural and social phenomena, from traffic to the depths of outer space, have spurred a new generation of citizen researchers and garden-shed inventors. Much of this has happened without much state direction, although public research funders were quick to open up grants and support to community researchers.

We have our own data vaults that securely store all the data we collect and analyse about ourselves. Citizens can and commonly do share that data with private companies or public universities to support their research, but only with the consent of citizens, who ultimately retain control. This does slow research discoveries in some sectors, but forces companies and universities to make the public case for the benefits of their research first.

This is not the only way the power of large technology companies has waned. The 'techlash' of the late 2010s extended into the 2020s, as the public became increasingly aware of and resistant to the idea of 'surveillance capitalism'. This in part led to firmer competition regulation and actions to restrain the business model of these companies. It has also driven people to switch to companies and firms that offered technology that more aligned with their values, or even develop their own grassroots, community driven platforms, utilising open-source protocols. These twin factors of tighter controls and creative destruction led to a private sector ecosystem with more and more interoperable players, and the same was true in the private sector research ecosystem.

The UK is not necessarily the top destination for international star talent but the pervasiveness and ease of undertaking research by ordinary systems means it has a strong backbone of competent researchers well suited to collaborative working and crossing disciplines. This scenario has helped shake up academic culture too. The conservatism of the university system has somewhat given way to a culture where titles mean less than results and individuals are rewarded for contributing to the collective, not just individual success.

A feedback loop has resulted with the opening up of access to journals and papers that were once behind paywalls. Traditional academic publishers have been disintermediated by repositories and open-source review platforms, which allow for more dynamic peer review through ratings and open reviews and which reward the sharing of data, replications and new methodologies as much as counter-intuitive findings.

National Champions

Summary

National Champions describes a world where the state works in concert with homegrown British technology companies to push the frontiers of science, creating a nexus where the public and private are co-equal partners in research. The British state funds and protects these companies from international competitors and in exchange, shares in their successes and has a seat at the table in their decision-making.

Detail

The UK's research sector in 2040 is a symbiosis of public and private. A few home-grown British technology companies, from hardware manufacturers to AI developers, have been chosen by the British state to compete in the race against the rest of the world.

Having left the European Union and decided to strike out alone, the UK decided that it needs to work even more closely with its private-sector if it was going to compete in a world increasingly dominated by large trading blocs. It did this by going back to a model of 'national champions', exemplified by Gaullist France and followed by the UK post-war, especially in the steel and manufacturing industries, but most commonly associated with China today.

One notable example of creating a modern 'national champion', was the UK working with City investment firms to buy-out Deepmind from Google at a not inconsiderable cost. This left Deepmind partly privately controlled and partly state-owned.

The UK did not cut itself off from the world, if anything it did everything it could to spread the reach of National Champions into the rest of the world. Beyond commercial ventures, this meant assisting them in buying out foreign labs, funding international research collaborations into basic research their champions could exploit and offering very favourable immigration terms to superstar researchers and their teams to steal them away from other countries.

The model led to increasing concentration of investment in the already successful research institutions in London and the South-East, with many universities being explicitly paired with a private company based on existing specialisation and success, e.g. the biotechnology national champion being developed and partnered with Cambridge University. These institutions received all the support they could need and cooperation was promoted even more deeply between an elite group of universities to match the elite group of national champions, who shared information and resources between them.

This only perpetuated and exacerbated existing hierarchies and inequalities within academia, even within those universities. This model also led to poor support for areas of research perceived to be unprofitable and reductions in outreach and public communications budgets, which were seen as superfluous to increased competitiveness. It also discouraged more well-rounded and cross-disciplinary academics in favour of commercially minded research managers and narrow subject specialists who were prepared by their institutions for industry post-masters or PhD.

Public Service Science

Summary

Public Service Science sees a world with a state-driven research sector, directed by government missions with the government providing vastly increased public research funding, public service cloud computing facilities and experimenting with new research models, e.g. in the mold of ARPA. However, the country is more closed off to the rest of the world and research is focused primarily on serving the British nation, not others or the pursuit of knowledge.

Detail

The UK's research sector in 2040 is driven by a powerful central state. It pumps money into universities and national laboratories, pushing R&D spending up to nearly 3% of GDP; it owns all the underlying infrastructure, including vast British-based cloud computing arrays fitted out with the latest processing units, and commands the direction of research towards a series of national missions, which by the 2040s mainly focus on combating climate change.

In the early 2020s, the UK government faced a population increasingly unhappy with perceived misuse of technology, growing regional inequalities, a sense of declining place in the world and lack of unity on every axis. The already weakened economy was hit by a national crisis. The government was forced to take the reins and take on the role of a war-time central planner.

This was a tumultuous time and all sectors, including research, had to be turned to deal with the crisis, channelling resources away from blue-sky thinking and towards immediate results. Eventually the crisis was overcome and the UK emerged with a newly invigorated and confident central state. Public trust in politicians and civil servants was restored after decades of erosion and an enlarged public sector, not seen since the end of the Second World War, emerged. Certain breakthroughs in applied biomedical, energy and computing research were seen as pivotal in ending the crisis.

Following the quasi-nationalisation of many industries, many private research and computational facilities could have slipped away. However, growing concerns that more crises could be around the corner and a shared sense of national trauma, along with a statist shift amongst the population meant the UK instead stayed on a permanent war footing, with private research capabilities either being nationalised or remaining strongly state-directed.

All these factors led to an acceleration of previous plans to bring research spending to 2.4% of GDP, raising it to 3% in subsequent years. The state offers academics free access to vast amounts of public sector computing power, on the condition they can justify the value of their research to the state and its security and prosperity.

The crisis had also seen the proliferation of internet-enabled sensors to provide real-time data to the government to manage the crisis. Alongside this, privacy and civil liberties had been rolled back and measures seen at the time as a necessary and temporary response to the crisis, had become entrenched. This meant the state could provide its researchers with diverse natural and social datasets to enable research and normalisation of experimentation on citizens and their data, not necessarily with their consent.

Having felt abandoned during its time of need, the UK turned increasingly inward, imposing more restrictive immigration policies and reduced collaboration with the rest of the world, focusing instead on the need for national solidarity and self-sufficiency. The UK attracts much less international talent, is far more secretive with the research discoveries that it makes and has poorer knowledge exchange with the global academic community. A focus on self-reliance and reduction of trading links means more British-built hardware, which is up to the task but by no means cutting edge across the board.

The crisis hit the South-East, London and other wealthy urban areas most harshly. The whole-country solidarity that came out the crisis has meant a great rebalancing towards previously more deprived areas of the country and an expansion of regional specialisations, each held in similar esteem, as a result of needing a more diverse home-grown economy and research sector.

The UK is not a world leader in basic research but excels in applied research focused on overcoming national challenges, as its centralised control and strong grip allows it to effectively channel resources. It has also greatly enhanced its applied research funding environment, developing a series of ARPA-like funding bodies after the success of its original £800m experiment, each with a mission to solve energy security, health security, cyber security etc.

Big Tech Research

Summary

The UK's research sector is now dominated by large technology companies, most of them based outside the UK. UK academic research, where it continues to exist, does so in formal partnership with technology companies, who provide most of the funding. Whilst the UK continues to produce world-leading research, much of this is behind closed doors, hampering scientific breakthroughs.

Detail

Once led by its centuries' old universities, the UK's research sector in 2040 is dominated by a small number of large technology companies. These institutions have overtaken universities as the primary source of cutting-edge research.

Indeed, many companies have entered into deep and integrated relationships with longstanding academic institutions. Courses are now offered between companies and universities, taught by faculty members drawn from the companies and academia. In most of these arrangements the companies are the dominant partner, providing the bulk of their funding and making up the majority of senior decision makers. Those that graduate from 'traditional' universities and wish to conduct further research will almost certainly opt to move to one of a small number of 'big tech' companies.

Many of these arrangements arise as a result of universities facing increasing budget constraints and looking for alternative sources of funding, including through arrangements with technology companies. More broadly, the lack of government investment in crucial national research infrastructure creates the space for private funding of infrastructure spending by large technology companies with surplus profits. This further embeds these companies in the UK's research ecosystem.

The proliferation of Internet of Things devices throughout our daily lives is complete: sensors line our roads, smart devices are littered around our homes. This allows those companies with access to this data to be able to make remarkable scientific breakthroughs, aided by information on all manner of issues previously unimaginable. This further cements the shift in research dominance from universities to technology companies.

In the 2020s the UK government chose not to pursue tough antitrust measures against these technology companies as they amassed monopoly positions. This decision was largely driven by a perception that the UK needed to be open to business and that these companies were the future of world-leading research. At first this meant that technology companies were able to continue to attract the best researchers; later these companies were then able to become serious research institutions in their own right and rival the traditional universities.

Whilst the UK produces much excellent research, much of it remains behind closed doors. This scenario enables significant innovation within the companies that can access this research and data, leading to further market concentration in the economy beyond just the research sector. However, it severely impacts the ability of those universities not partnered with technology companies to continue to produce high quality research and they suffer as a result. Serious concerns are raised that research is not being driven by the public good but by the profit needs of technology companies. Some say that a failure to make breakthroughs on certain challenges, such as cancer treatment, suggests something has gone awry.

Backwater Britain

Summary

Backwater Britain describes a world where the UK's research sector has stagnated and is entering a period of long-term decline. A failure to invest in the right technologies, infrastructure and skills means that the UK has been unable to keep hold of its position as a world-leading country for research. The decline of the research sector affects the wider economy, given the relationship between research and innovation. The UK is viewed as a less attractive place to invest and do business; its decline is symptomatic of a wider economic malaise.

Detail

As the UK enters the 2040s, its research sector has been heading downward for over a decade. British universities have plummeted down the world rankings, with only a handful remaining in the top 100. The UK's last Nobel Prize winner remains the physician Peter Ratcliffe more than two decades ago. A once-flourishing commercial research sector has largely moved overseas; only those institutions with longstanding historical ties to the UK remain.

Research spending as a proportion of GDP falls below 1%, far below the government's 2.4% target. Graduates interested in further research after their degree tend to move overseas, where world class research is now much more likely to be delivered. The sector's failure drives a vicious downward spiral, with politicians unwilling to make the case for additional funding for a failing sector. Indeed, several universities are required to be bailed out by the government; others that policy makers are unwilling to save collapse altogether.

Despite commitments in the early 2020s, the government fails to deliver significant increases in research funding, knocked off course by an unforeseen global recession in the mid-2020s. This means that universities fail to receive the resources needed to carry out increasingly costly research. The quality of the UK's infrastructure fails to improve, hampering the ability of universities to carry out world-leading research. Within universities, researchers continued to be unable to access the computing power or cloud storage that they needed, particularly outside STEM subjects.

A new immigration regime focusing on home grown talent fails to deliver. This failure results in significant skills shortages for universities - unable to bring in both superstar researchers from overseas and the support staff required to support an excellent Research 4.0 agenda. Our education system also fails to adapt to the need for the researchers of tomorrow to be equipped with the full breadth of skills required for a Research 4.0 career.

A conservative academic culture also hampers progress, continuing to resist the development of Research 4.0 techniques in non-STEM fields. This means that the UK misses out on the development of new fields, including significant advances in the Digital Humanities. It also means that universities fail to adapt their programmes of work to the demands of a Research 4.0 agenda and too few mid-career researchers opt to learn methods outside their traditional domains of study.

The decline of the research sector affects the wider economy, given the relationship between research and innovation. The UK is viewed as a less attractive place to invest and do business; its decline is symptomatic of a wider economic malaise.

CHAPTER 3
A POLICY AGENDA FOR RESEARCH 4.0

Researchers in all disciplines at UK universities are increasingly utilising AI. This is allowing researchers to investigate questions that would have simply been unanswerable a decade ago. Whilst the use of AI is increasingly widespread in academic research, steps could be taken to encourage its further take-up. This includes wider adoption of the necessary skills, faster routes to culture change and greater multi-disciplinary collaboration.

We presented a number of scenarios for the future of research in the UK. The range of outcomes make it imperative that policy makers prepare for all possible futures, designing policies that will work in all conceivable futures. Furthermore, whilst the reader will have differing views on the merits and demerits of these scenarios, Demos is determined to ensure that the scenario we consider the unambiguously least desirable – 'Backwater Britain' – is avoided. Again, there is a role for policy makers to consider what steps can be taken for the research sector to avoid this fate.

This chapter thus sets out a number of policy recommendations that aim to ensure that:

- The UK remains a world leader in research and utilises the potential of AI to help it maintain this position.
- The rise of AI in academic research works for the good of wider society, including mitigating any ethical risks associated with these technologies.

Below we set out a series of recommendations across the following themes:

- Education and Skills
- Infrastructure
- Research Funding
- Universities and the Private Sector

EDUCATION AND SKILLS

Recommendation 1: Skills. The current post-16 curriculum should be reviewed to ensure all pupils receive a grounding in basic digital, quantitative and ethical skills necessary to ensure the effective and appropriate utilisation of AI.

In Chapter One we described how students and researchers at UK universities sometimes lack the necessary skills to fully utilise AI technologies. This could be holding back the ability of British universities to continue to produce world-leading research.

In particular, we heard that humanities and, to a lesser degree, social science undergraduate and graduate students often lack the necessary digital and quantitative skills to utilise AI technologies and methods. This is often due to the narrowness of post-16 education in the UK, with many humanities students receiving no mathematical or scientific education past the age of 16.

Addressing this gap will require reforms to the existing post-16 curriculum, as has been acknowledged elsewhere. The Government's AI Sector Deal, for example, set out to address the shortage of STEM skills, committing £406 million to maths, digital and technical education in schools and the launch of T-Levels.[40]

But it is not just about strengthening digital and quantitative skills. The House of Lords Select Committee on Artificial Intelligence and the Royal Society have both recommended that

40. HM Government. AI Sector Deal. 2019. Available athttps://www.gov.uk/government/publications/artificial-intelligence-sector-deal/ai-sector-deal [accessed 16 July 2020]

schools should cover the wider social and ethical implications of AI when teaching computing and/or machine learning.[41] It is vital that pupils understand the ethical risks of new technologies and this must be central to attempts to build a post-16 curriculum fit for the age of automation.

Recommendation 2: Ethics. Universities should ensure undergraduate and postgraduate courses in AI embed a 'Responsible Research and Innovation' approach in the curricula to anticipate the negative impacts of AI and designing methods to avoid or mitigate them.

In Chapter One we described concerns that researchers are sometimes unaware of the ethical risks associated with their research. This deficit could be jeopardising the integrity of research being carried out at UK universities and must be urgently addressed. Currently, research projects must provide evidence that they will conform with rules on the collection and storage of personal data. However, there is a need for researchers to also consider the wider ethical implications of AI techniques. Universities have a role in meeting this need through the provision of appropriate training. With this in mind, the Engineering and Physical Sciences Research Council (EPSRC) has recently established the ORBIT project as a vehicle for providing services to universities and industry to promote 'Responsible Research and Innovation' (RRI).[42]

Recommendation 3: Early Career Researchers. UK research funders should require research proposals to make a clear statement that the work early career researchers undertake will be appropriately recognised.

In Chapter One we described how increased use of AI in academic research means that there is a range of new tasks associated with the preparation of data and that these are often undertaken by early career researchers. It is important that this work is appropriately recognised.

Whilst there is no commonly agreed definition of an early career researcher, we are following the Research Excellence Framework and others in defining this group as anyone that is in their first 4-5 years of a full-time contract undertaking research or research and teaching, e.g. a postdoc or junior lecturer.[43]

As a first step this demands ensuring those involved in data preparation roles are properly credited in academic publications. We heard how some academic projects prepare clear statements of principles or 'lab charters' at their outset, clearly describing how all those working on the project receive appropriate recognition.

Research councils have a vital role to play here in driving best practice. Requirements should be introduced for all funding applications to include a clear statement setting out how the work of early career researchers will be recognised. Given the pressure on academic researchers to attract funding, this is likely to be a powerful lever.

INFRASTRUCTURE

Recommendation 4: Infrastructure. A UK-wide audit of research computing and data infrastructure provision is conducted to consider how access might be levelled up.

In Chapter One we described how the quality of digital research infrastructure in UK universities appears to vary significantly, with researchers in different places, universities and even departments having often very different experiences. Furthermore, those in the arts and humanities appear to have greater difficulty accessing the infrastructure they need. This difficulty is likely hampering the further adoption of new tools in these disciplines, which could be holding back innovation and breakthroughs.

The use of AI methods and tools in research is increasing the demand for compute, data and connectivity services: more complex AI algorithms and growing volumes of data require more compute power, greater data storage capacity and fast networks capable of moving large datasets rapidly. It has also created an increased demand for alternative ways of delivering these services. For example, having access to scalable compute services is often important in the model building phase of AI projects; personal data requires a secure storage infrastructure. Some universities may be able to satisfy these requirements, others will find it more challenging; but even the best equipped may find it difficult to meet the needs of collaborative projects where researchers are distributed across different institutions.

41. The Royal Society.Machine learning: the power and promise of computers that learn by example. 2017. Available at https://royalsociety.org/-/media/policy/projects/machine-learning/publications/machine-learning-report.pdf [accessed 15 July 2020]
42. https://www.orbit-rri.org/ [accessed 16 July 2020]
43. De montfort University. Early Career Researchers. Available at https://www.dmu.ac.uk/research/research-support/early-career-researchers/early-career-researchers.aspx

UKRI needs to ensure that researchers across the UK can access fast, secure and reliable digital infrastructure. A review should address the role of national digital research infrastructure for 'levelling up' access to compute and data storage, paying particular attention to the need to provide support throughout the regions of the UK for high-speed connectivity, scalability, security and, collaboration between the public and private sector. To minimise barriers to the latter, it is essential that collaborating organisations be able to share compute and data resources seamlessly, which in turn, requires a common framework for Authentication, Authorisation and Accounting Infrastructure (AAAI) and high-speed connectivity throughout the regions of the UK. Despite efforts over the past fifteen years,[44] however, progress towards AAAI has been slow and a solution has now become critical.[45]

RESEARCH FUNDING

Recommendation 5: AI Incentives. UKRI should consider that future spending on research and development incentivises institutions to utilise AI wherever it can offer benefits to the economy and society.

As has been widely documented, the UK spends less on research and development than other comparable countries. Total public and private spend on research and development in the UK currently stands at roughly 1.7% of GDP, compared to an OECD average of 2.4%. The under-spend is likely to be limiting the potential of our research sector. We therefore strongly support the government's commitment to increase levels of research and development spending to 2.4% as a step en route to 3%.

There is a need to ensure that any increased spending is targeted where it will have the most impact. As we explained in Chapter One there is great potential for AI to transform whole research areas. We therefore think it is right that some of this increased spending is targeted at research which makes full use of these technologies.

Recommendation 6: Interdisciplinary/ Multidisciplinary Research. UKRI should devote more funding to interdisciplinary and multidisciplinary research programmes, such as the Strategic Priorities Fund.

We have seen throughout the report how successful utilisation of AI in research requires strong interdisciplinary working. Research teams must combine extensive subject expertise with a strong technical understanding of methods and tools. Furthermore, there is a need to involve those outside the sciences; to ensure that any moral or ethical risks are properly mitigated, research teams may wish to involve philosophers, for example.

However, there are a number of barriers to interdisciplinary research in universities. As detailed by a 2016 review of interdisciplinary research in the UK, the often monodisciplinary focus of funding opportunities reduces the likelihood of interdisciplinary research being funded.[46] UKRI's Strategic Priorities Fund, designed to spearhead multi and interdisciplinary research and innovation, goes some way to addressing this problem; this and other similar funds must continue to be expanded.

UNIVERSITIES AND THE PRIVATE SECTOR

Recommendation 7: Researcher Mobility. Universities should take steps to ensure that it is easier for researchers to move between academia and industry, for example, by putting less emphasis on publications, and recognising other outputs and measures of achievement when hiring for academic posts.

In their recent government review of the UK's AI industry, Hall and Pesenti describe how rising industry demand for highly AI skills has resulted in rising salaries, leading academics to move into businesses. They describe how this is placing "a strain on the resilience and capacity of the academic network to continue blue sky research and to train talent."[47]

Interviewees in Chapter One expressed concern about talented researchers increasingly leaving academia to work in commercial sector technology companies. There were worries that this represents a major risk to the future of research at UK universities, with the pipeline of talent at risk of drying up. This problem has been noted widely elsewhere. In a recent review of data science, the Royal Society describe how "Big internet companies are adding to pressure on universities, which are already struggling to retain professors and other employees."[48]

44. E.g., The European Commission. Advancing Technologies and Federating Communities: A Study on Authentication and Authorisation Platforms For Scientific Resources in Europe. Terena, 2012 Available at https://www.terena.org/publications/files/2012-AAA-Study-report-final.pdf
45. UKRI. The UK's research and innovation infrastructure: opportunities to grow our capability. Available at https://www.ukri.org/files/infrastructure/the-uks-research-and-innovation-infrastructure-opportunities-to-grow-our-capacity-final-low-res/
46. Technopolis and University of Sussex. Landscape Review of Interdisciplinary Research in the UK. 2016. Available at http://sro.sussex.ac.uk/id/eprint/65332/1/2016HEFCE_Landscape%20review%20of%20UK%20interdisciplinary%20research.pdf
47. Hall, W., Pesenti, J. (2017), Growing the artificial intelligence industry in the UK. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/652097/Growing_the_artificial_intelligence_industry_in_the_UK.pdf [accessed 15 July 2020]
48. Royal Society. Dynamics of data science skills: How can all sectors benefit from data science talent? 2019. Available at https://royalsociety.org/-/media/policy/projects/dynamics-of-data-science/dynamics-of-data-science-skills-report.pdf

Whilst it is unrealistic for universities to compete on pay with commercial sector companies, other steps can be taken to ensure that the talent pipeline in universities does not dry up. The steps include making it easier for researchers to move between academia and the private sector throughout their careers. This is at present often difficult to do in practice, in large part because academic career progression requires attaining a high number of publications, something that may be unachievable in the private sector. University hiring culture should change to better recognise industry experience alongside academic experience.

Recommendation 8: AI Fellowships. UKRI should create and fund a number of 'AI industry fellowships' at UK universities.

Alongside encouraging culture change in universities, steps can be taken to encourage greater movement of minds between universities and the private sector. For example, the Royal Society recently recommended the creation and funding of joint positions across industry and academia.[49]

Building on this direction of travel, more short-term academic posts could be created at universities for industry researchers. These could allow those based in industry to spend a period of time researching and teaching in academia. This would encourage sharing of best practice between academia and industry, allowing for a valuable cross-fertilisation of ideas. It could also give industry researchers the opportunity to gain the academic experience and publications to later return to academic research on a more permanent basis.

49. Royal Society. Dynamics of data science skills: How can all sectors benefit from data science talent? 2019. Available at https://royalsociety.org/-/media/policy/projects/dynamics-of-data-science/dynamics-of-data-science-skills-report.pdf

DEMOS

PUBLISHED BY DEMOS SEPTEMBER 2020

15 WHITEHALL, LONDON, SW1A 2DD
T: 020 3878 3955
HELLO@DEMOS.CO.UK
WWW.DEMOS.CO.UK