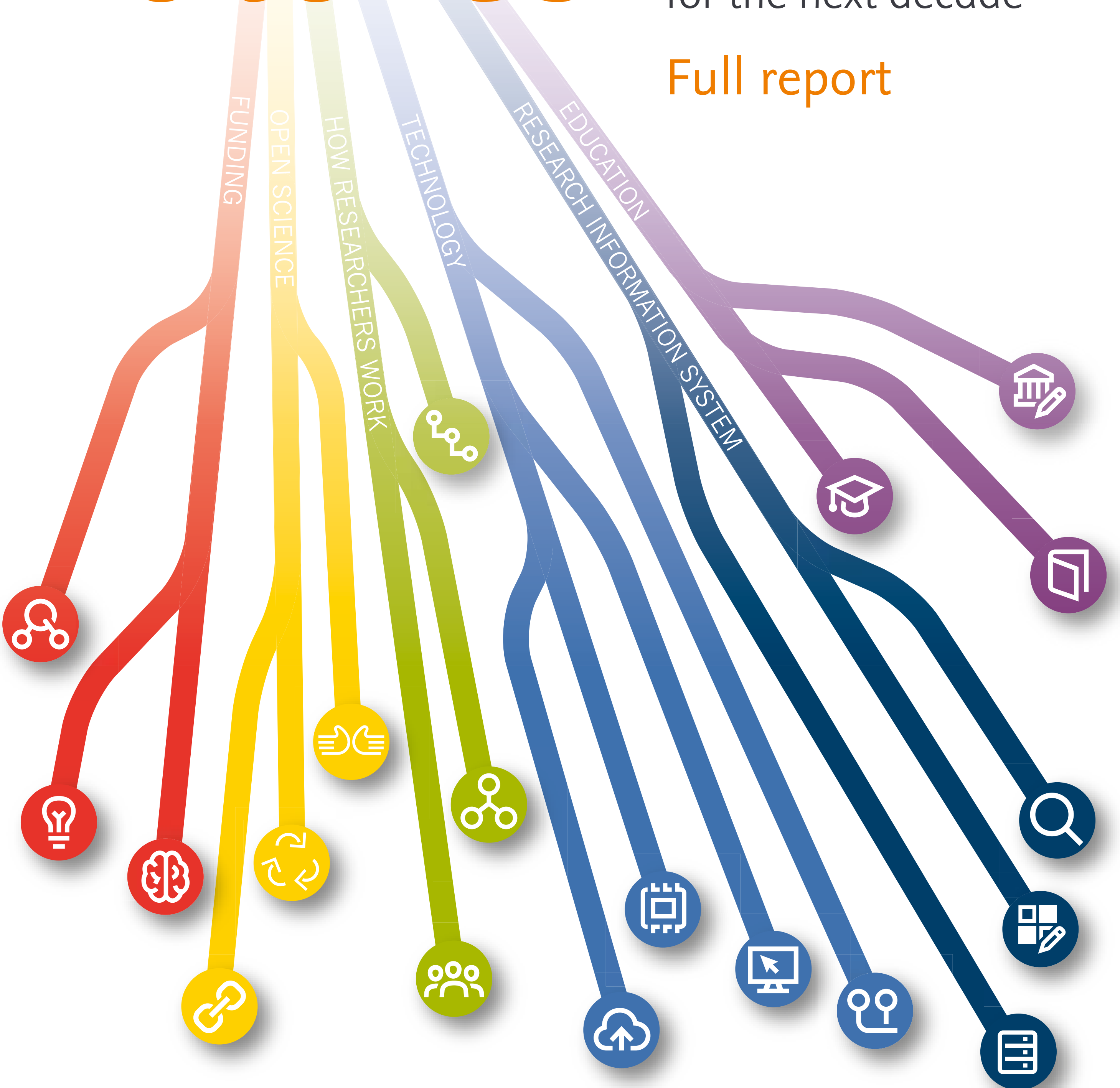
Research futures

Drivers and scenarios for the next decade

Full report



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Ipsos MORI

A study by Elsevier and Ipsos MORI
Published February 2019

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Foreword

It's not enough to think about the future – you have to build it

At Elsevier, we have constantly pushed boundaries in our efforts to support researchers. From helping exiled German scientists in the late '30s to publish their works, to pioneering the digital dissemination of journals on ScienceDirect; we've never been afraid to take bold steps.

We are currently on the cusp of a new era, one that will likely transform the research information system.

Drawing on our roots in publishing, we are creating analytical solutions to serve the needs of science and health. Whatever the future holds, by applying technological and data expertise, we will continue with our mission to help institutions and professionals advance scientific knowledge and health care.

We also recognize that it has never been more important to collaborate closely with research institutes, funders and other information providers, enabling a quicker response to genuine needs faced by those in the field.

To equip us all with the knowledge required to navigate the opportunities – and challenges – that lie ahead, we have partnered with Ipsos MORI to examine the research landscape in detail, both what is happening and what could happen in the decade to come. In this report, we share with you the insights we've gleaned from a great variety of stakeholders.

Focusing on a single potential outcome is problematic. Instead, we've thought about a number of possible, plausible futures. Our goal is that these scenarios will fuel considered, controlled decisions. Our founding motto remains apt: Non Solus – Not Alone. By working together today, we can shape a more positive tomorrow. Please do contact us with your thoughts and ideas – you can find out how in the conclusion. We look forward to hearing from you soon.

Alexander van Boetzelaer
EVP of Strategy, Elsevier

Introduction

Why we did this project

Rarely in the history of science, technology and medicine have we witnessed such rapid and profound change. Advances in technology, funding pressures, political uncertainty, population shifts, societal challenges on a global scale; these elements are all combining – in uncertain ways – to transform how research information is created and exchanged.

The ability of the research community to thrive in this new world will depend on understanding the opportunities and the challenges these changes offer and what steps need to be taken now.

To assess how today's trends might shape the research landscape in the decade ahead, Elsevier joined forces with Ipsos MORI, the global market and opinion research specialist. Together, we conducted a large-scale, future-scoping and scenario-planning study. The focus of this study was not which topics will be researched 10 years from now, but rather how that research might be conducted and its findings communicated.

What we did

We reviewed the literature and examined market drivers. Critically, we interviewed expert stakeholders to gather their views and elicited the opinions of researchers. Over the course of 2018, we talked with 56 experts from funders and futurists to publishers and technology experts, and we surveyed more than 2,000 researchers.

We started all our expert interviews with the same question – if you could discover one thing about the world of research 10 years from now, what would you want to know? This helped participants to focus on the questions and challenges already keeping them up at night, and identify issues likely to increase in importance over the coming decade.

The interviews and literature review sketched a picture of the many interrelated trends; taken together with the researcher survey, they helped us identify the factors most likely to drive change, a summarized version of which can be found in the visual overview on pages 6 to 7. We took these 19 key drivers, grouped them into themes, and turned them into the six essays you'll find on pages 31 to 135. The essays explain why each driver could potentially cause seismic change and how that change might come to pass.

However, looking at each of the key drivers in isolation, or even linking them to a theme, wasn't enough to provide the insights we were seeking. So, during 2018, we held several creative workshops and invited external experts to join us. In the workshops we used the key drivers to develop plausible future scenarios, all set a decade from now, which we ultimately reduced to three – you can find these on pages 10 to 27.

Along with the 19 key drivers and the six essays, the three scenarios form the key findings of this study.

In the conclusion, on pages 28 to 30, we look at the implications of these scenarios and the plans that Elsevier is putting in place in response to this study. We also invite you to join us. And we have created a webpage on Elsevier.com[1] where we will continue to monitor the market-available data and track progress towards the scenarios we've imagined. While no-one knows what the future holds, our hope is that this report, particularly the scenarios, will help us all understand the implications of the decisions we make today and ensure we are well placed to meet the future – whatever it brings.

1 www.elsevier.com/connect/elsevier-research-futures-report

Building a guide to the future

A visual overview of the study

Together, the drivers, essays and scenarios form the key findings of this study.

DISCOVERY PHASE

Step 1
LITERATURE REVIEW

Comprehensive review of the published literature.

▶ Visit Mendeley[2] to explore the references used in this report

Step 2
EXPERT INTERVIEWS

Interviews with 56 technology, research and publishing experts around the globe.

▶ See who we interviewed in the Acknowledgements on page 139

Step 3
RESEARCHER SURVEY

A survey of 2,055 researchers worldwide, asking them what they think the future holds.

▶ The full survey results are available on Mendeley Data[3]

▶ Read more about the methodology on pages 136 to 138.

ANALYSIS PHASE

19 key drivers were identified, each of which is expected to shape developments in the decade to come. These drivers (abbreviated versions of which are listed below), have been grouped into six themes.

▶ Find the comprehensive versions of the drivers and their associated essays on pages 31 to 135.

THEME ONE: Funding the future

1. The funding mix is changing; public funders will have less influence over research priorities
2. China is stepping up the funding and production of research
3. The research agenda is changing; there is an increased focus on making research accessible

THEME TWO: Pathways to open science

4. Research grants will increasingly have open science conditions attached
5. Researchers are expected to spearhead adoption of open science, but not without experiencing conflicts of interests
6. Metrics will continue to expand, enabled by new technology

THEME THREE: How researchers work: change ahead

7. New technologies are expected to transform the researcher workflow over the coming 10 years
8. Behaviors and skillsets will change as a new generation of researchers arrives on the scene
9. Collaboration will drive research forward

THEME FOUR: Technology: revolution or evolution?

10. Big data is fast becoming the lifeblood of nearly all research
11. Artificial intelligence (AI) and machine-learning tools are changing the shape of science
12. Blockchain has the potential to facilitate open science, but the technology is still in its infancy and may not fulfil its promise
13. Augmented reality (AR) and virtual reality (VR) will become key learning tools for a number of institutes

THEME FIVE: Building the future research information system

14. The role of the journal is transforming to meet modern needs
15. The article structure is evolving and new forms will become the norm
16. The measurement system will become even more critical

THEME SIX: The academy and beyond

17. Courses will diversify from a lecture-focused model
18. Higher education institutions are changing structure
19. EdTech will become a serious higher education contender

2 www.mendeley.com/community/research-futures
3 https://data.mendeley.com/datasets/w6mj4tmkxp/1

SCENARIO BUILDING PHASE

Step 4
WORKSHOPS

Three one-day workshops were held with internal and external experts. Attendees considered how the 19 key drivers might influence research.

The result: Three credible scenarios, each imagining what the future might look like a decade from now.

Scenario one: Brave open world

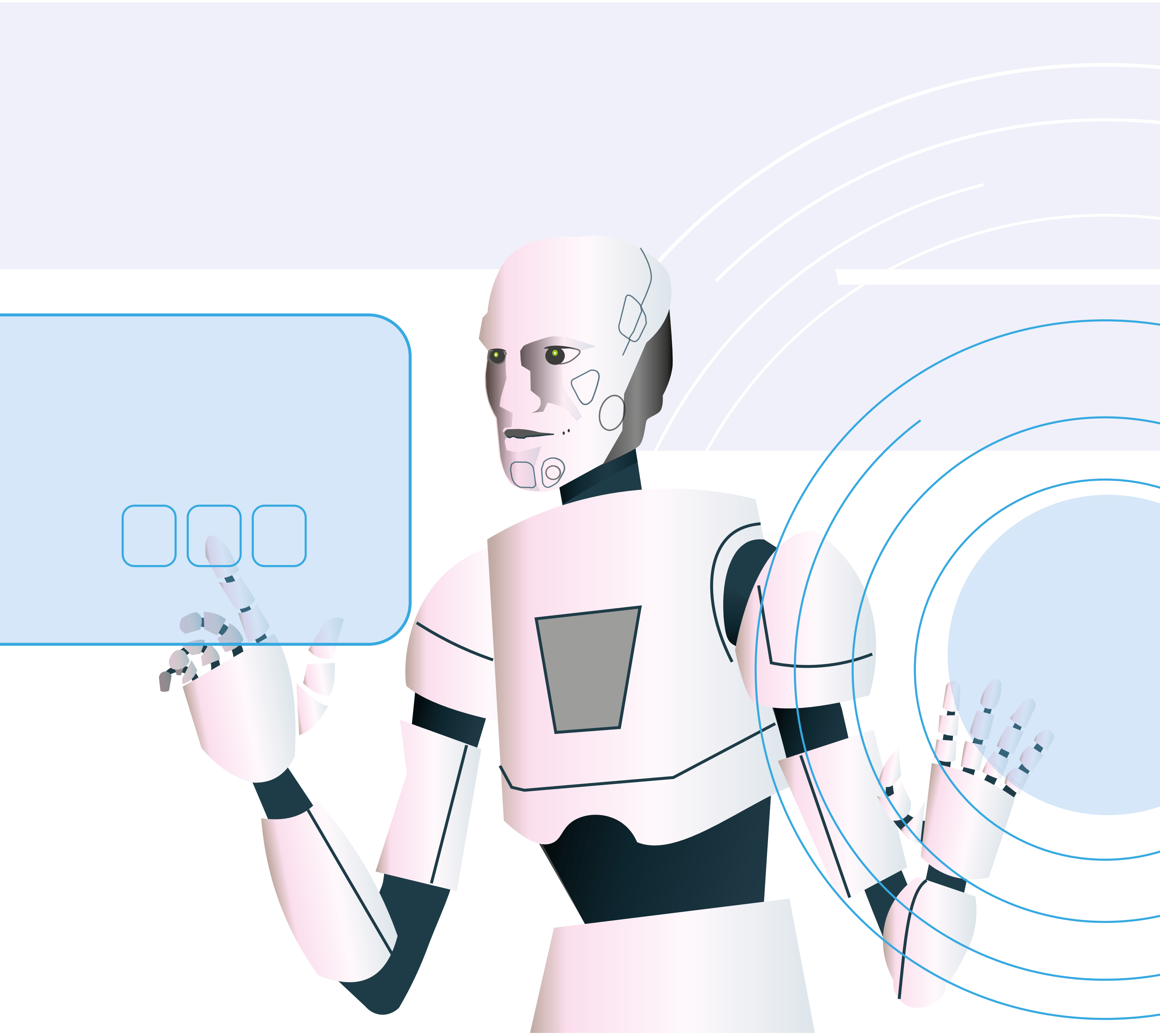
State and philanthropic funders align in their goals, approaches and principles, resulting in open science taking off, aided by artificial intelligence-enabled technologies.

Scenario two: Tech titans

Technology companies support the research ecosystem and become knowledge creators and curators in a world where industry funds more and more research.

Scenario three: Eastern ascendance

China's growing economic power and focus on research and development (R&D) influences the previously Western-dominated research landscape, resulting in a fragmented world.



Visualizing the future through scenarios

Together, Elsevier and Ipsos MORI used the trends, survey results and expert input to develop three scenarios which explore what the research ecosystem might look like a decade from now: These scenarios are **Brave open world**, **Tech titans** and **Eastern ascendance**.

There are a few important points to bear in mind as you read them:

- Scenarios are plausible futures, i.e. they have the potential to unfold but they are not definitive predictions.
- No single scenario has to be "correct"; aspects of just one could come true or they might combine in any variety of ways.
- They are built on current trends, or drivers, derived from literature, expert opinion and survey work.
- They were created in workshop settings, during which choices were made about the weight assigned to the individual drivers in each scenario.
- Each of the scenarios is comprised of four key elements:
  - Brief summary
  - Detailed description
  - An imagined personal story, designed to bring the scenario to life
  - Signposts that could help us understand whether this future is emerging

Scenario one: Brave open world

Globally, state funders and philanthropic organizations have joined forces and pushed through the creation of platforms where the research they fund must be published open access (OA). But the form of that OA varies by region; Europe is mostly gold, while North America and Asia Pacific is generally green.

Rapid advances in artificial intelligence (AI) and technology mean these platforms are flourishing – they are interoperable, and content is easy to access and showcase.

As a result, there are fewer subscription-based journals. A number of broad science, gold OA megajournals with low article publishing charges exist to publish content not captured by open platforms. Major society journals remain active, many operating a gold OA model, but struggle for manuscript submissions, so revenue is low. Preprints thrive in this world and are linked to the final article versions, which are still recognized as the authoritative version. Researchers benefit from access to data in a variety of ways, for example, via bite-sized publications and dynamic notebook-style articles.

The advances in AI and technology have also provided new methods of generating and communicating results. While research quality is still an important measure of performance, journal publication plays a diminishing role in determining a researcher's career progress. Increasingly, research is assessed against agreed societal impact standards.

Overall, global research and development (R&D) investment is holding stable. There have been regional shifts – intensity (R&D investment as a proportion of gross domestic product (GDP)) has reduced slightly in North America. And although increases in R&D intensity in China have plateaued, overall R&D investment continues to rise, as China's GDP grows steadily.

Funders in China, the West and the developing nations have come together to establish shared goals for both basic research and some major applied challenges (for example, climate change, energy and food), which are now the key focuses of national funding agencies and philanthropic organizations. Funding for exploratory blue-sky research has reduced; the emphasis is on rapid development of practical solutions.

Funders have also collaborated to create guiding principles for open science and scholarly publication, as well as metrics of assessment (such as societal impact, data dissemination, peer review and the success of collaborative processes).

Thanks to this joined-up approach, global and interdisciplinary collaboration has increased, aided by virtual reality and augmented reality tools. Researchers are now rewarded more for collaboration and the usefulness of their research, and less for novelty or being first to publish. The EU has focused on strengthening its internal approach to research and initiatives like the European Open Science Cloud, an environment for hosting and processing research data to support EU science, have gained good traction. This has prompted China to adopt a similar approach, with other emerging research nations in Asia following in their footsteps. Researchers demonstrating interdisciplinary skills are the most successful. Collaboration via social platforms is common and post-publication evaluation and comment is the norm.

Funders are driving interdisciplinary, cross-institution, global collaborations and reward the sharing of data as it enables research to be more open. To support this, high-technology content management, collaboration and dissemination products are vital. Tech companies are partnering with information solution providers, major research institutions and state funders to provide them. These solutions tend to be globally interoperable and can be personalized to meet most needs. Importantly, they promote accuracy in data, contributing to improvements in reproducibility, which are further aided by the availability of data sets in large-scale data repositories. Funders and publishers have also partnered to create a global web of open citations – most article references are now freely available.

The research article is still valued as a channel for communicating the stories behind discoveries, but has become atomized with the growth in popularity of electronic lab notebooks and other tools that facilitate fragmentation of the research and publication process. This means the article has evolved into a notebook-style paper containing (as applicable) experimental methods, data and observations, source code, and claims and insights.

There are funder requirements around engaging with the public; each grant proposal must be accompanied by a public engagement plan and researchers are mandated to communicate their research findings – and their benefits to society – in an easy-to-understand way. This has helped to increase public trust in science, supported by increased access to raw elements of research (e.g. raw environmental and ecological monitoring data).

The interoperable open repositories include both preprints and peer-reviewed manuscript versions. Open access (OA) publication in journals is the norm: a number offer green OA; however, adoption is uneven across geographies and disciplines. With pressure to release information as widely, and as close to real time as possible, green OA embargo periods are approaching – and in numerous cases have reached – zero months. Many journals have transitioned to gold, others have folded; consequently, there has been a resurgence in authors choosing to publish in gold OA, broad-discipline megajournals after a lull in the early part of the decade. However, the appetite for OA involving article publishing charges (APCs) is not universal, primarily due to funding priority challenges, and this has helped to force down the cost of APCs. Prestigious journals play a role, but their influence has waned. Across a range of subject areas, researchers increasingly post preprints of their work to communicate research outcomes. As a result, new research metrics supplement the existing indicators, which typically measure citation activity.

Revolutionary developments in artificial intelligence (AI) mean hypotheses can now be data-driven – although take-up varies across the sciences – and the speed and volume of research has accelerated. AI also supports peer review by checking manuscripts are logical, consistent and comply with editorial standards. Easy-interface, off-the-shelf products have made coding relatively simple. Researchers are broadly comfortable with accessing large data sets and interrogating them (using programming skills) and working alongside data scientists; however, there are still skills gaps.

On the education front, universities have resisted pressure to commercialize, but have diversified; they now offer more online courses and lifelong learning. More cross-disciplinary degrees are available and modules on data science and writing for the public are common. Although competition between universities remains, there is more collaboration (e.g. on shared research priorities).

A glimpse into the life of a researcher in 2029

To help us build a clearer picture of this world, we have imagined a discussion between Dr. Gretel Hoffman, a team leader at Hanselberg University in Germany, and Danielle Myers, a user interface designer for Kwiksol, which has an EU contract to develop open source collaboration tools for researchers.

Danielle: Good morning Dr. Hoffman. Thanks for finding time to speak with me today.

Dr. Hoffman: Hi Danielle, no problem.

Danielle: I have been commissioned by the EU to understand a little more about your working day so that we can identify any possible synergies with the open source solutions under development by Kwiksol. Perhaps you could start by telling me about your current project?

Dr. Hoffman: Well, I'm working on a pancreatic cancer vaccine program that is really international. Funders have pooled resources so I'm working with colleagues in Portugal, the US, China, Chile and Denmark. In fact, there are 15 universities involved now, and then we've got a couple of companies – a technology firm in India, and we are talking with a pharmaceutical company here in Germany.

Danielle: So, that's quite a few locations to juggle. Are you getting the kind of support you need from the meeting and collaboration tools you use now?

Dr. Hoffman: Generally, they work fine. We can easily share feedback and content online. And, when it comes to experiments, we've been trialling a couple of virtual reality tools. I should mention, the team is not only diverse in terms of geography, the disciplines and skills vary too, from bench science to coding. Sharing the information within the team in a way that everyone can understand is a challenge for us.

Danielle: We hear that a lot and I know it's one of the items on our 2029 roadmap. We should have an update on that shortly. So, can you tell me a little more about the team's day-to-day tasks?

Dr. Hoffman: We are focused on publishing our latest findings right now, so are busy writing code, software and methodology papers and we have a lot of data to prep. As a condition of our funding, we have to publish everything pretty much straight away on our funders' open platform. It takes time to prepare content for open publication – I currently spend most of my day agreeing naming conventions or standardizing data. That's where we really need some help.

Danielle: So, what I'm hearing is that your pain points are clustered around communication within the team and pre-publication prep work?

Dr. Hoffman: That's right, but any tool would need to cater for the data taxonomies particular to our field.

Danielle: Yes, we've already been looking at field-specific taxonomies as part of our discovery phase, but if you could share a list with me, I'll double check we've captured them all.

Dr. Hoffman: Another funding requirement is that we explain our findings in a way that makes them accessible to everyone. Writing for a non-scientific audience isn't easy and soaks up a lot of my time.

Danielle: So, you need a tool that will help you convert your findings into a digestible format. I have some natural language processing colleagues that are exploring this – I'll flag your issue with them. Thank you for your time today, your feedback will be critical to the development of our tools. And we'd really like you to join our user group testing teams, when the time comes?

Dr. Hoffman: Absolutely. Anything that will help! Thanks, Danielle.

Signposts

Events that might indicate this world is emerging.

2019

One third of research articles are published gold open access in Europe, following mandates from a consortium of European funders.

Three quarters of research articles are published green open access in the US, China and India, following mandates from funding consortia in those countries.

State and philanthropic organizations unite to develop programs and fund research to contain a flu pandemic.

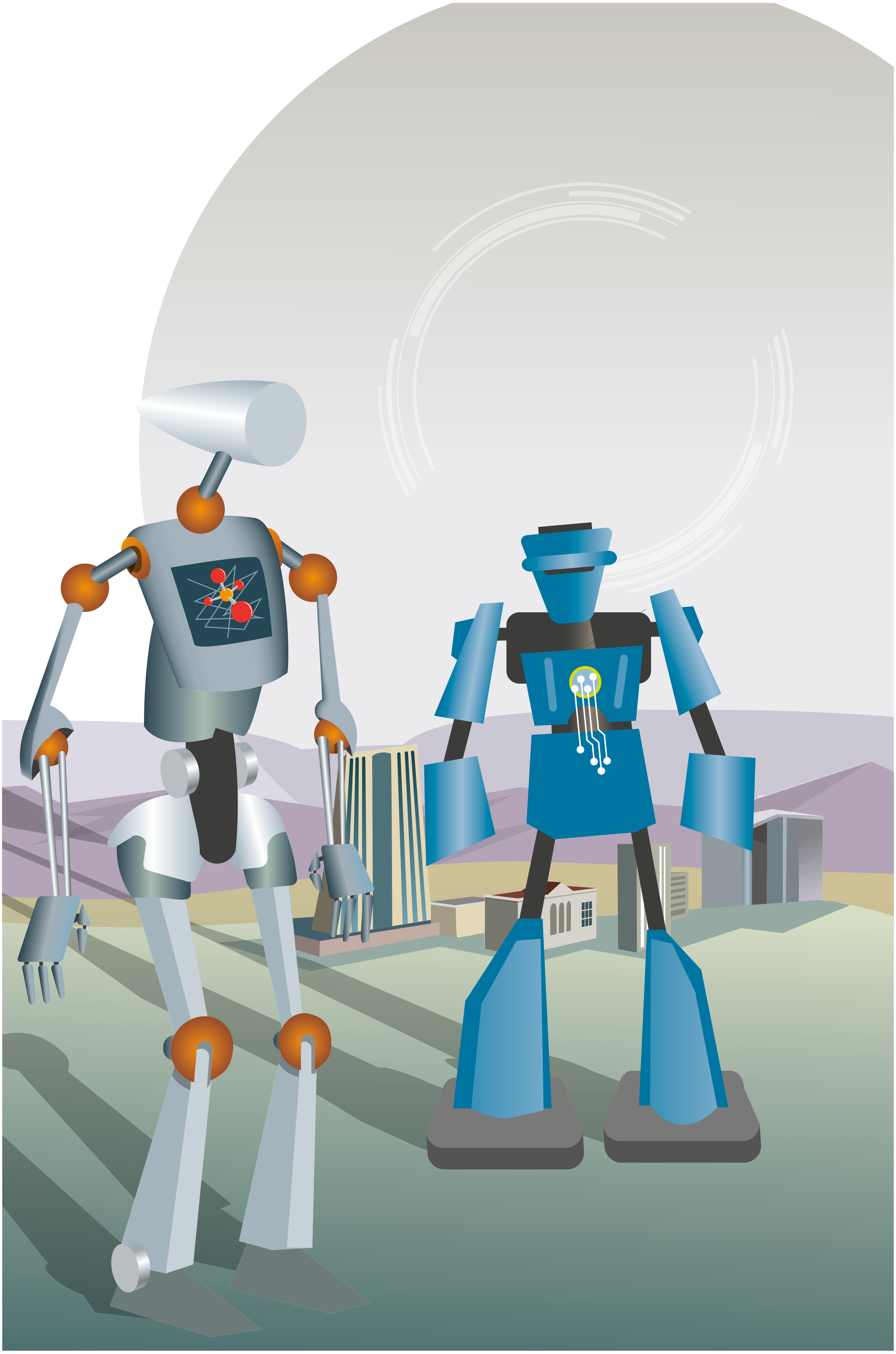
Various repositories consolidate into one platform, improving access to the expanding volume of articles, data, code, methods and preprints.

Tech companies, in partnership with universities and funders, release new online workflow tools, enabling easy formatting and sharing of data.

Research is only published if it's linked to the raw data (which must meet international requirements) and the associated code, where applicable.

Organizations that have invested heavily in data analytics and artificial intelligence maximize the value of that data through discovery and reuse to make unseen connections.

2029



Scenario two: Tech titans

Industry and philanthropic foundations are the principal research funders, with far-reaching consequences for the research community. Some are feeling this impact more than others, for example, academic institutions with a focus on life sciences struggle. There have been significant advances in machine learning with sophisticated artificial intelligence (AI) products driving innovation. This has led to large technology and data analytics companies becoming the curators and distributors of knowledge.

Research articles and journals play a much reduced role, with preprint servers and analytical layers over online content replacing some of their traditional functions. The article has become atomized with each part of a research publication created and hosted separately, but all elements are linked. Large technology companies have created a market shift toward AI-driven evaluation of these research outputs; however, current systems have proved susceptible to manipulation and there is pressure to increase their security.

Not all aspects of research are open; for example, where industry is funding research, key research data is not always made available so companies can retain a competitive and financial advantage.

For researchers, the developments in technology and consolidation of analytical services have revolutionized the way research is performed, enabling many to work independently of institutes and even funders – "science-as-a-service" is emerging as barriers to entry are reduced or removed.

A number of countries are leveraging sophisticated and successful machine-learning products in their research programs to address their own priorities and challenges. However, some sectors and states are struggling to adapt. Developments in artificial intelligence (AI) are rapidly transferred to industry, e.g. automotive, aerospace and medical technology, resulting in advances, but at the cost of jobs. A significant proportion of research is also carried out by machines, funded by tech company investments. In some research areas, roles, and even teams, have been replaced by automated processes.

Over the past decade, in the European Union (EU), factors such as migration pressure and political differences have increased tensions between member states. The US is starting to recover from a period of reduced research and development (R&D) funding (both in real terms and relative to its pledges and forecasts). China's investment in R&D has steadied and it is yet to commercialize or scale up its innovation. It focuses strongly on applied research, but its research quality indicators are still lower than those of the US and Europe.

Industry and international foundations are increasing their financial contributions; in response, some nations are reducing public research funding. For example, in a number of countries, industry has replaced government as the main source of R&D funding for universities, and companies are now sponsoring research and higher education institutions.

There are few global shared solutions to international grand challenges, e.g. climate change, energy and food security, but both international philanthropists and industry have funded significant "moonshot" projects in these areas. There have been breakthroughs, particularly in personalized medicine, resulting in more of these challenge-driven funding calls. Commercial targets drive much of the industry-funded research and, consequently, some researchers feel there is reduced potential for more exploratory or blue-sky research and are publicly calling for change.

Organizations that have heavily invested in knowledge organization schemes (e.g. taxonomies and ontologies) and large-scale analytics are driving change that has enabled the emergence of "science-as-a-service". This gives researchers the opportunity to reinvent the relationship between themselves and academic institutions; they can now, at very low cost, source the materials they need to work independently. Pharmaceutical companies are the greatest funders of life sciences research and benefit most from the data gleaned and the relationships they are forming with researchers. But with competition high between companies, seldom do we see research findings shared freely.

In this world, most of the research publications are open and are increasingly atomized; research is frequently reported as discrete units throughout the process, for example, methods, data, code, and preliminary text. Online repositories built on preprint servers host these outputs and are curated by the technology companies that set them up. The popularity of these servers has led to a fall in manuscript submissions to journals, leading to the closure of some titles and the failure of some publishers.

Researchers, institutes and corporations regularly use micropayment systems to pay for access to research data and code hosted in repositories. The repositories allow data owners (including funders, content aggregators, authors and platform providers) to benefit financially, not only in terms of payments received, but by maximizing their commercial application. Some data will never be shared, frustrating researchers who are aware of its existence but are unable to access it. The most widely-used researcher workflow tools are provided by tech companies. These are interoperable and apply data analytics to create connections unseen by the human eye, which has led to some significant breakthroughs and potential innovation opportunities. AI has enabled the volume of research to increase at a steady rate, despite reduced public research funding.

Publishers have partnered with big technology companies to create an AI-based “peer review” evaluation process, powered by natural language processing (NLP), which validates research outputs without human involvement. Some researchers question how far AI can be trusted to create new research and review human-generated outputs. As a result, they insist on sense-checking assumptions made by AI systems; an added time pressure for research teams.

Public trust in research has eroded slightly over concerns about AI’s level of involvement, the way commercial companies work with data, potential privacy breaches, and the uneven dissemination of new medical advances. At the same time, the delivery of AI-fuelled advances, especially in the health sciences, are hailed in the popular press.

Funders and universities are increasingly taking note of new ways to evaluate success and there is debate about whether quality should still be the primary measure; as well as how quality can be judged beyond proxies, such as citation metrics. In some contexts, quality is measured through “output” or researcher-level metrics; in others, through commercial outcomes. There is no consensus.

With universities increasingly focused on commercial applications, graduates are following suit and selecting courses that lead to career opportunities in industry. Vacancies at industry-sponsored institutions are particularly sought after. At the same time, EdTech has changed the way that education is delivered, with improved quality of online courses and high adoption of distance and flexible learning.

A glimpse into the life of a researcher in 2029

How will researchers fare in this radical new world? We've imagined a virtual presence message from Professor José Oliveira from his base at a new industry-sponsored university in Salvador, Brazil, to a former colleague in São Paulo who is thinking of joining him.

“Hey Victor, how are you? It's been a while. I got your message this morning and thought I'd surprise you by delivering my answer in person! I hope this is reaching you OK; I haven't tried to use this service with your campus before.

To be honest, I wasn't surprised to hear that you are thinking of leaving your current role – you know how frustrated I was when I was in the aerospace department. There was so little funding, the decision-making process was so slow and it was only a matter of time before they started downsizing – in fact, I heard from Fernanda that the redundancies have started?

The department here is growing; there's a real buzz about the place and people are excited to come to work. OK, the scope of the research projects is a little more limited, but at least they are well-funded. And I'm still involved in Next GenAvionics, the international project I was working on. In fact, I can contribute more here than I could back in São Paulo – it's unbelievable the tools we've got access to. If I need to meet with aeronautics colleagues in Japan at the start of their day, I can be onsite to run a diagnostic – virtually, of course – within seconds of logging on. And the stress testing technology we've developed here is so advanced. Don't even get me started on how easy it is to run a lab class. Have I sold it to you yet? You'd love it here!

Of course, just as with any job, there are downsides. You and I are used to openly sharing our findings. That isn't always the case here. I mean, one of the reasons they are pumping money into research is because they hope to make a big return on it at some stage, so there's a lot of pressure. But, on the other hand, it does mean I benefit from the financial and technical resources available. Do you remember that idea I had for a sensor identifying micro-fissures? I submitted a proposal last week and I expect to hear next week. Who knows? Maybe we'll even end up working on it together.

By the way, on Monday I read my first fully AI-generated article that was also AI peer-reviewed. I was a little skeptical, but to be honest, I wouldn't have known if it didn't say it on the paper. There are still a few areas that concern me though.... You know, the stories we've heard about manipulation in the news, and I doubt AI would ever come up with a really novel breakthrough like my micro-fissures idea! I also worry that AI-powered peer review is not discerning enough to reject flawed papers. In fact, I was talking with a colleague about it in the canteen yesterday. He thinks that there are alerts built into the system and regular audits to stop that happening, but I'm not so sure.

Anyway, I hope I've given you some idea what it's like to work here. Once you get your interview date through, let me know. Sorry to rush off but I've got a coding class in five minutes – all that advanced data analytics and coding training I did back in Salvador is finally paying off. Although, at the rate things are developing here, it will probably be taken care of by a virtual lecturer soon! Give my regards to your family and speak soon.”

Signposts

Events that might indicate this world is emerging.

2019

Following Brexit, there is disruption in the EU leading to a recession and a reduction in public R&D spend. Federal commitment to R&D drops in the US as a consequence of funding moving to other economic priorities.

Self-driving cars meet highway safety criteria in the US and the roll-out begins.

Systemic banking conglomerate fraud is discovered. New global data protection regulations are enforced, powered by advances in blockchain technology; these advances are immediately adopted for research data management, particularly data reuse.

An advanced air traffic control system based on a study, which was peer-reviewed using AI, is implicated in aircraft crashes during its test phase; human reviewers confirm the original study was flawed. Public trust in science plummets.

Thousands of researchers sign a petition demanding that large corporations make all research data available at all stages in the research workflow.

Major tech players become a significant source of published research, often via their own research institutes.

As a result of AI-enabled research in personalized medicine, survival rates for pancreatic cancer increase substantially. Positive press coverage aids the recovery of public trust in science.

2029

Scenario three: Eastern ascendance

China's desire to transform into a knowledge-based economy has led to heavy public investment in research and development (R&D) and the systems and processes to capitalize on this in industrial and economic terms. As a result, China's level of R&D funding is proportionally much higher than the West's and continues to grow, changing the shape of scientific research. The sheer volume of investment by China, and other research nations in the region, has made the East a magnet for international researchers.

A lack of global alignment on grand challenges has resulted in inefficiencies in the international research system. Open science practices have been adopted in some countries and regions, but not all. Journal publishing is a mixed model of open access (OA) – gold and green – and subscription publishing. Individual research outputs can be accessed separately, but are always linked to the final article; for example, research findings, data and code.

Governments, industry and other research funders compete for scientific advantage through the controlled distribution and trading of data. When data is believed to hold no further commercial value, it is released so it can be linked back to its related research outputs.

In this world, alignment on tackling global societal problems proves difficult. Nations tend to tackle them in isolation, resulting in inefficiencies and a duplication of effort.

Due to China's investment in research and development (R&D), the country is now firmly established as the global powerhouse of research. The quality and citation impact of Chinese research output has surpassed the rest of the world. Beijing and other major Chinese cities are proving hugely attractive to Western researchers.

Individual nations are under pressure to retain the results of their science and technology investments for themselves, which causes rifts between internationally-collaborating institutes. Prestigious institutes in the US respond by reducing the number of projects they do in partnership with European institutes that have strong relationships with China. Meanwhile, China acquires an established publisher and encourages China-based researchers to submit their work to its journals.

While science is carried out according to open science principles, this is proving truer in some countries than others. Instead, research funders and governments jostle for advantage by imposing strict controls on the distribution of data emerging from the research they've funded – it tends to be shared only once its commercial value has been extracted. In this hyper-competitive world, open science cannot deliver completely on its promise.

Thanks to the misalignment of international funder policies, open access (OA) publishing has not enjoyed widespread uptake. As a result, green is the most common form of OA, with free access to research articles published in subscription-based journals after 6-12-month embargoes. Gold OA has been unsuccessful in the US and China, and has plateaued in Europe after gaining a limited foothold.

Despite the availability of a number of research quality measures, journal-level metrics, including the Journal Impact Factor and its successors, are still widely used by funders and universities. This is partly due to support from China, where the Journal Impact Factor remains embedded in the assessment procedures of Chinese institutes.

Although technology drives progress, it does not lead to revolution in this world. Technology companies partner with publishers to provide a range of products and services to the research community. New, virtual reality workflow tools enable collaboration over distance. Blockchain technologies have advanced and are used to check for plagiarism in research publications and, in some tech-savvy fields, are now used to track and assign credit for research outputs.

China, concerned that it is not producing an elite group of creative researchers, has opened several new institutes that mirror the innovation seen at the likes of University of Oxford and Massachusetts Institute of Technology (MIT). These new institutes, along with many existing Chinese universities, are attracting Western researchers and are becoming acknowledged as centers of creativity. In a parallel strategy, the Chinese government remains focused on educating a highly-skilled workforce and believes the teachings of the elite universities will trickle down to others.

The rising proportion of students from emerging economies in the East has prompted global education changes. Universities deliver courses with a much stronger focus on virtual interaction and online adaptive learning materials. To fund this EdTech, elite higher education institutes in both the West and East increase student fees or, in some instances, introduce them for the first time. Some mid- to lower-tier universities, unable to keep up with these developments, struggle financially. A number seek protection through partnerships with other, larger institutes. Together they create big brands and international franchises to maximize global appeal.

In the East, the most popular degrees combine physical science and engineering with management and business qualifications. The demand for work-ready graduates is so high globally that students are willing to pay more for education, as the certainty of a job when their course is complete is much higher.

Public engagement with science is mixed. People want scientific solutions to global health and environmental problems, but geopolitical agendas are in conflict: the US has taken a strong position on environmental issues, seeing any restraints as blocking industrial growth, while China is developing new technologies to reduce air and water pollution. Globally, developments such as personalized medicine or self-driving cars aren't universally available; distribution is uneven with some sectors of the public benefiting from scientific and technological advances more than others.

A glimpse into the life of a researcher in 2029

To bring this scenario to life, we have imagined an interview on the student radio station at a highly-regarded US university. It's between Jackie, a journalist who's presenting a "where are they now?" series on Summa Cum Laude graduates, and Marie, who recently graduated with the Latin Honor.

Jackie: So, Marie, tell our listeners a bit about yourself.

Marie: Hi everyone. I'm from Utah and I finished my PhD in material sciences here in Boston three years ago. Since then, I've been working at various institute labs and I'm currently thinking hard about my next move. I'm still not 100 percent sure, but it is quite likely that I am heading to China.

Jackie: Wow, that would be a big move!

Marie: I know… but this year has been a real mix of ups and downs. I've had a paper published in a great journal in my field, but I've also been struggling to find another research project to join – there's hardly anything in the US. What posts I have found offer short-term contracts and I want to move up the ladder. The employment situation won't change while funding is so tight.

Jackie: So, why China?

Marie: It just offers more opportunity. I can't believe how many jobs there are, or how well paid they are! My old tutor moved to Beijing two years ago, and he's been trying to persuade me to join his research team. What's really attractive is that they have technology that my current lab can't afford.

Jackie: If you go, what type of program will you be working on?

Marie: I expected Chinese institutes to focus on the application of research, in other words, commercialization, but that doesn't seem to be the case, especially with this program. Many of the research projects are really ground-breaking.

Jackie: Yep, I can imagine the thought of novel research must be pretty tempting. You mentioned salaries… how do they compare?

Marie: Well, I've been offered a five-year contract and, while I can't go into specifics, the salary relative to the local cost of living is very good, and it's about two times higher than what I earn here. There certainly seems to be plenty of money for research in China.

Jackie: So far, it sounds like a good opportunity – what's holding you back then?

Marie: I've heard that the government requires results to be published in an approved list of journals and I'm not sure how I feel about that. Plus, I won't be able to share the research data we generate with US colleagues – even though it would benefit them.

Jackie: If it were me, I'd also have a few concerns about the language barrier. And aren't you worried you might feel isolated?

Marie: If I do decide to go, I will try to learn some Chinese, but most academics speak English, the Chinese researchers too. And I don't expect isolation to be a problem – while there are a few social media tools the authorities block, there are still lots of conferences and other networking opportunities. There is even an ex-pat baseball league.

Jackie: Marie, you graduated Summa Cum Laude; you were in the top five percent of your year. You are exactly the type of person the US would like to keep. So, my last question; what would persuade you to stay?

Marie: Hmm, I guess it comes down to security. I'm fed up moving from one contract to the next, so getting a tenured position would be fantastic. Funding is also a problem. It's getting more competitive each time I apply, which stems from a lack of investment at government level. More R&D money would create roles and opportunities. Currently, China invests twice as much in R&D than the US – it would be good if it was at least the same!

Signposts

Events that might indicate this world is emerging.

2019

China continues to invest more in R&D. The East/West funding gap widens as the consequence of a recession that predominantly affects Europe and the US.

As economic powers start to shift, Europe and the US become more protective of their resources and the commercial applications of their research. East/West partnerships between institutes reduce in number.

Following a surge in student numbers from emerging countries in Asia, universities introduce adaptive distance learning.

Several long-established universities struggle to respond to the recession; others partner with larger, prestigious higher education institutions to secure their future. More practical courses emerge with fewer universities offering academic subjects.

The flow of research talent from West to East increases; fewer high-performing researchers apply to Western academic posts.

Chinese institutes start to dominate the top positions in the global university ranking lists.

China sends a crewed mission to Mars, having developed fuel cell technology for interplanetary travel. European and US efforts lag far behind.

2029

Conclusion – what we learned and Elsevier's plans

What is the future of research? Tipping points and virtuous cycles

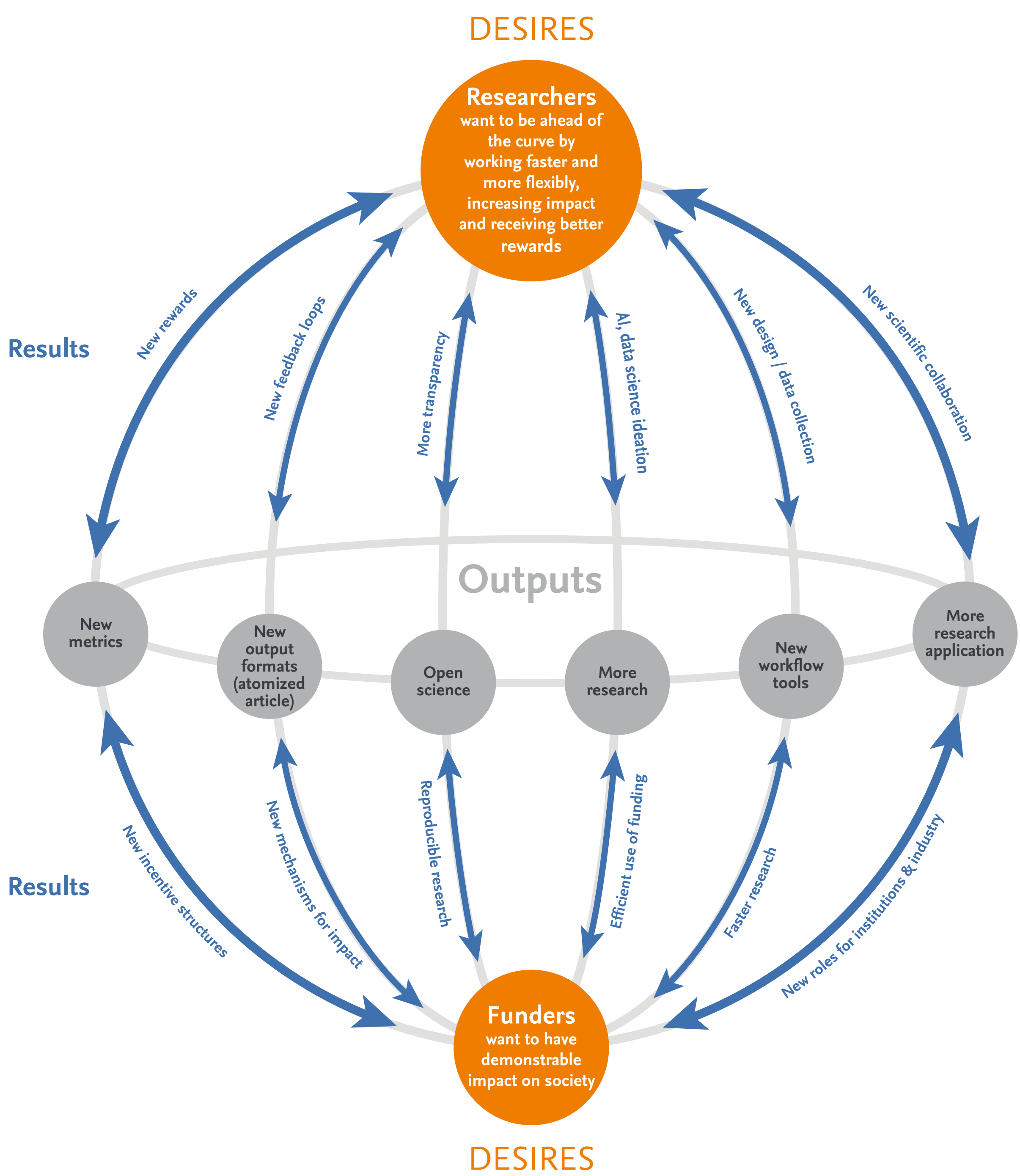
As this study has made clear, we have reached a tipping point. How research is conceived, completed and communicated will change dramatically over the next 10 years. New funding models will emerge, new methods of collaboration will develop, and new ways of conceptualizing research and measuring its impact will arise, driven by advances in technology and the ideas of a new generation. While technology advances have the potential to be disruptive, in general, we are likely to see faster, fairer, more open models of research practice and publication. Researchers are expected to benefit from greater career flexibility, better feedback on their emerging ideas and improved reproducibility.

Change will be prompted by the 19 key trends, or drivers, that we identified and used as the basis for the essays you'll find on pages 31 to 135. A summary of these drivers is included in our visual overview of the study on pages 6 to 7. Many of these drivers were visible without extensive future-scoping or scenario planning; after all, a number already play an active role in today's academic and commercial life. But in this study we have considered the interplay between them and this has informed our key findings – not only the essays, but the three scenarios you read on pages 10 to 27. Importantly, these scenarios are more than just summaries of the main trends, they are carefully-constructed, vivid stories, designed to transport us into the future. They are provocative and challenge today's norms. In each of them, it's clear that "business as usual" will no longer be possible for any of us working in the research ecosystem.

These scenarios don't claim to be predictions – how the future unfolds will depend on how the key drivers combine and the speed with which they develop. But they do provide us with "foundations" that we can build on. They demonstrate that, if positive change is to be sustainable, action will need to occur in unison across all the areas we've examined, from education to researcher workflow. They underline that all of us who work in the world of research share responsibility for creating a new environment in which science and research can flourish; no-one can do it alone and we have to be prepared to embrace change. Finally, the scenarios identify the value of "virtuous cycles" – wherever innovations support each other and are mutually beneficial, change will occur rapidly. With this in mind, we have developed a model (see following page) to show how some of these drivers could interact productively, and what their impact on the research landscape might be.

For example:

- Technology, especially AI and data science, shapes data collection, the amount of research produced, how it is reported and the speed of science. Funders require new forms of input to shape the research agenda, and create new metrics which measure impact and are tied to the rewards that drive researchers. This gives license to researchers to explore the potential of the new technology more creatively.
- Digitally-savvy researchers want to work faster, carry out research with big data at scale, and iterate their work by receiving swift feedback from collaborators and colleagues globally. Information solution providers and funders provide platforms for this to happen, and create ways in which quality can be measured and monitored, incentivizing the researchers of the future.



Elsevier's role in the virtuous cycles

Elsevier is committed to improving the "information system supporting research" – in other words, the many tools that researchers have at their disposal to execute and communicate core research tasks. The current information system has been around for more than 100 years. As this research shows, researchers today are relying on outdated tools, fragmented across a myriad of applications and resources. In fact, the system often burdens researchers instead of supporting them.

In the past, putting the researcher first meant primarily publishing high-quality journals and books. While content will remain critically important, that singular focus is no longer sufficient. Today, we have an obligation to put the researcher at the center of the entire research information system. Doing so involves addressing many challenges, including enabling effective peer review, matching collaborators seamlessly, facilitating the securing of funding, and supporting the important task of demonstrating researchers' beneficial impact on society. We are working to resolve these.

Following extensive conversations with groups throughout the researcher community, we have identified four principles that will prove critical in addressing the information system supporting research[4]:

- Source-neutrality
- Transparency
- Interoperability
- The researcher must be in control

We see ourselves in a supporting role, working jointly with researchers, research institutions and funders to develop this information system. It will have researchers at its heart and help them do their important work. The system must draw on many different sources, incorporating data and content from universities, vendors, platforms and publishers around the world. It must be interoperable ensuring that researchers can use whichever platform they prefer while maintaining a seamless workflow experience.

We recognize the importance of trust in research communications, and although research will likely become more fragmented, *trust* will remain at the heart of any new research information system as it has been for the 140 years of Elsevier's history.

Today, Elsevier is becoming a data-centric organization, which involves much more than technology; it is about embedding analytics across every aspect of decision-making. We are ready to play our part in making every aspect of the research lifecycle more connected, more transparent and more inclusive and we invite the community to jointly produce solutions that both challenge and enhance the research information system.

If you wish to partner with us to shape the future or want to find out more about the Research futures study, please contact us at newsroom@elsevier.com

4 www.elsevier.com/connect/a-vision-for-the-information-system-supporting-research

Funding the future

Setting the scene...

There has always been a close bond between economy size and research and development (R&D) spend – generally, the larger a country's economy, the greater its level of investment in innovation. While that is unlikely to change, radical shifts in population growth and economic power – particularly in Asia – and a general tightening of spending budgets have been predicted for the years ahead. We can expect to see the new economic powerhouses rewriting the research agenda, along with corporate and philanthropic funders, who are increasingly contributing to the R&D pot. In fact, some believe the future of research funding lies with the corporate sector; but tensions remain. For funders, whether private or public, collaboration and accountability will continue to grow in importance. With so much change forecast, we asked participants in our study how they think the funding story will unfold in the decade ahead.

What will be the key drivers and changes?

1. The funding mix is changing; public bodies will have less influence over research priorities

- Financial commitment to research funding will endure, but the mix of sources will continue to evolve. An increasing focus on applied research is predicted as **industry and philanthropic funding** becomes more dominant.
- A growing need to **demonstrate the (societal) impact of research** will reflect a broader climate of greater accountability; this work will fall to researchers, who will need support to deliver effectively.
- With the influence of emerging regions and countries gradually increasing, funder research priorities will change the shape of science, with greater emphasis on **"moonshots"** (e.g. cancer cure) and the role of tech starts-ups.

2. China is stepping up the funding and production of research

- The balance of economic power is shifting globally. **Funding and research opportunities will gravitate East** as China becomes a more attractive place to conduct research.
- China's increased focus on due diligence means the **standard and impact of science will rise** and its volume of scholarly output is soon expected to outpace that of the US. China has the potential to be a scientific leader in many research fields.
- However, **restrictions on freedom and cultural differences** may prove barriers to innovation and collaboration.

3. The research agenda is changing, with an increased focus on making research accessible

- **Competition for funding** will continue to increase and the rising pressure to demonstrate research impact (i.e., pressure to publish) will likely lead to a state of hyper-competition. Growth in numbers of researchers/students from Asian emerging markets will result in yet more competition.
- However, collaboration and interdisciplinary research will continue to grow in response to the increasing pressure to publish, demonstrate impact and solve societal/global problems. This poses challenges for researchers around IP and maintaining competitive advantage and they will respond in different ways.

R&D funding: how it's changing and why

Globally, commitment to research and development (R&D) funding remains strong. Much of the drive to invest stems from the conviction that we live in knowledge economies, where growth is dependent on the amount and quality of the information available and how easily it can be accessed. "Governments around the world believe that to remain competitive in a global economy they must become smarter."[1] But the level at which R&D is funded varies per region, as we can see in figure 1.1.

A key question for many is what investment levels will look like in the future when the majority of nations are being forced to look critically at how they allocate a shrinking public budget. In fact, there is broad agreement that the existing targets for R&D growth globally are unrealistic.

For example, in Europe, an interim evaluation of Horizon 2020, a research and innovation program designed to help the EU achieve its goal of investing 3 percent of GDP in R&D by 2020, found that the program, while "attractive and relevant" and contributing to growth in job opportunities, has been underfunded and needs to invest more ambitiously.[2]

For a number of countries R&D intensity (R&D expenditure as a proportion of GDP) is declining (see figure 1.2).

If, as has traditionally proved to be the case, an economy's health and wealth determine its research and development (R&D) growth, then we can expect to see radical shifts in funding influence and priorities in the years ahead. And there are other factors changing the state of play…

Region	R&D growth trend
Asia: emerging markets	High growth, driven by China
Asia: mature markets	Low but steady growth
Eastern Europe, Middle East & Africa	High growth
North America	Low but steady growth
EU	Low but steady growth

Figure 1.1: Trends in research & development (R&D) expenditure by region.

1 Harvey, C. T. The Knowledge Economy Is Real - We Just Might Not Like It. Huffington Post. 27 July 2017. http://www.huffingtonpost.co.uk/christopher-ts-harvey/knowledge-economy_b_17597610.html

2 Horizon 2020 interim evaluation: maximising the impact of EU research and innovation. European Commission. 11 January 2018. https://ec.europa.eu/transparency/regdoc/rep/1/2018/EN/COM-2018-2-F1-EN-MAIN-PART-1.PDF

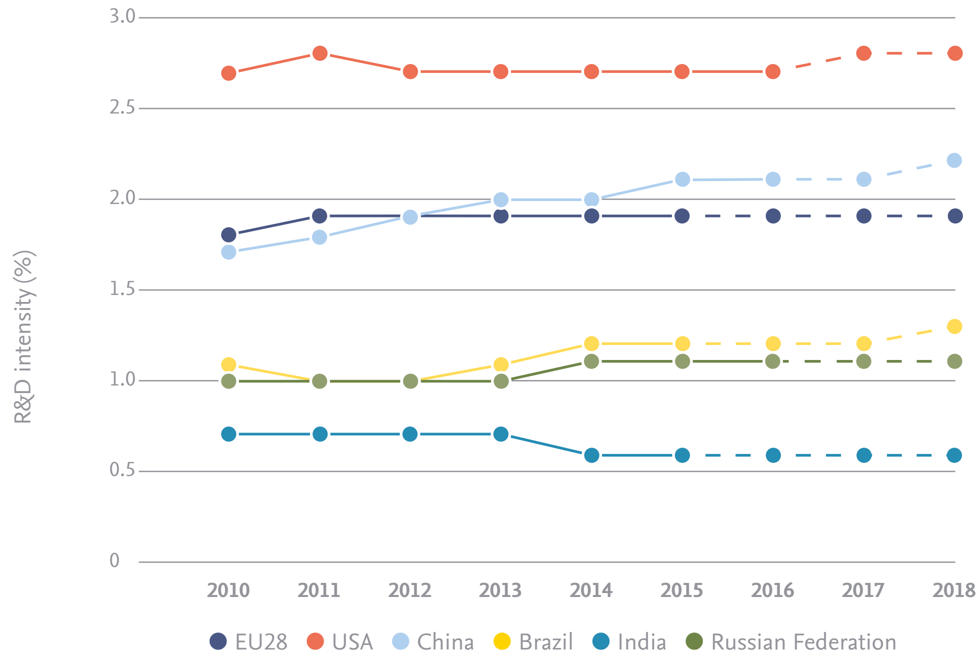


Figure 1.2: Gross domestic expenditure on research and development (GERD) as a percentage of GDP. Source: OECD, UNESCO and World Bank. Forecast data (highlighted by dashed lines) calculated through linear extrapolation and GDP growth forecasts from OECD.

Macro trends: emerging economies

To date, the US has been the leading economic force on the global stage, but there are signs its dominance is waning. If predictions by PricewaterhouseCoopers are correct, by 2030, China's middle-class could generate a consumption market of US$6 trillion, the largest in the world. And, by 2050, it could be the largest global economy by GDP PPP (see "Regional shifts: the China effect" in this essay). India is expected to take second place, with the US dropping to third place and Indonesia in fourth.[3] Asia as a whole is expected to become a greater global power than North America and Europe combined (based on GDP, population, military spending and technological investment).

In Europe, Poland is expected to be the fastest-growing economy (after Brexit).[3] It is also considered the most likely candidate to be awarded "Advanced" economy status by the International Monetary Fund (IMF)[4] – the last country to make that leap was South Korea, 20 years ago.

Elsewhere on the global stage, by 2050, Mexico is likely to exceed the UK and Germany in GDP PPP, and Colombia, Indonesia, Nigeria, South Africa, and Turkey are expected to join China, India and Brazil as key global players.[5]

These changes in global economic power are expected to have a considerable impact on the world of research and higher education. The funding priorities of emerging nations often look different to those of advanced economies – at least at first – with greater focus on areas that have the most direct impact on their populations' well-being. Later, as solutions to these problems are found, the countries' funding priorities usually shift

3 The Long View: How will the global economic order change by 2050? PwC. February 2017. https://www.pwc.com/gx/en/world-2050/assets/pwc-world-in-2050-summary-report-feb-2017.pdf

4 Sharma, R. The Next Economic Powerhouse? Poland. The New York Times. 4 July 2017. https://www.nytimes.com/2017/07/05/opinion/poland-economy-trump-russia.html

5 Global Trends 2030: Alternative Worlds. National Intelligence Council. 2012. https://info.publicintelligence.net/GlobalTrends2030-TalkingPoints.pdf

The art of comparing economies

There are two ways to measure and compare the total income – or gross domestic product (GDP) – of multiple countries.

- **GDP at exchange rate:** Convert the currencies of all countries into USD (US dollars).[6]
- **GDP PPP, or GDP at purchasing power parity (PPP):** Compare the values (in USD) of baskets that contain consumer goods available in all countries (for example, pineapple juice, pencils, etc.). If the basket costs $100 in the US and $200 in the UK, then the purchasing power parity exchange rate is 1:2. [6]

focus. As their investment in research and higher education institutions grows, and the global rankings of their universities improve, we can expect to see changes in international collaboration and student and researcher movement patterns. These will be supported by the online education opportunities we explore in our essay The academy and beyond, which are likely to play an especially important role in and around Asia. In the long term, as more nations take on "developed" rather than "developing" status, there could be a convergence of research priorities, driven, in particular, by increased international collaboration.

Macro trends: population growth

We are also seeing substantial shifts in population growth. According to a report published by the Population Division of the UN Department of Economic and Social Affairs, the total world population has grown by around one billion people over the past 12 years. By 2030, it is expected to reach 8.6 billion; by 2050, 9.8 billion.[7]

The same report predicts that the majority of the global population growth will stem from just a few countries, primarily from two continents. Africa will contribute to more than half the growth in global population between 2017 and 2050. Asia will most likely be the second largest contributor. In contrast, Europe will have a smaller population in 2050 than in 2017.

Those countries experiencing a rise in population are likely to benefit from a higher GDP, boosted by tax income, and it is expected that governments in those countries will choose to invest a healthy portion of that money in R&D. In contrast, in the West, where the population is expected to decrease over the coming decades, future GDP growth will depend on improvements to productivity and efficiency.

Accelerated population growth, especially in developing nations, brings challenges and opportunities for the research community. The potential boost to state-funded R&D is always welcome, but some of that money will likely be allocated to dealing with the impact of population changes on agriculture and food security, water and air pollution, deforestation, and more. And understanding and measuring that impact and finding suitable solutions will be the responsibility of the research community.

Global challenges: ageing populations

In many countries around the globe, an ageing population crisis is expected in the coming years or decades. By 2030, the global population aged 60 or over is projected to grow by 56 percent (from 2015) and it is expected to more than double by 2050. The population aged 80 and over is growing faster than the number of older (60+) people overall, and this trend will be more apparent in urban areas than in rural.[8] In addition, the low fertility rates seen in some regions – especially Europe – are expected to continue, which will result in decreased populations.[7]

This will have serious implications for the size of countries' workforces, economic growth, health care, and potentially R&D funding availability (as governments juggle rising pension costs with reduced funds entering the income tax pot). Education requirements are also likely to change with a move toward lifelong learning as ageing employees acquire new skills to adapt to a changing society. Immigration patterns are also likely to shift as people change country to fill skills shortages.

6 Purchasing power parity. Wikipedia. https://en.wikipedia.org/wiki/Purchasing_power_parity

7 World Population Prospects: The 2017 Revision. United Nations. June 2017. https://population.un.org/wpp/

8 World Population Ageing 2015. United Nations. 2015. http://www.un.org/en/development/desa/population/publications/pdf/ageing/WPA2015_Report.pdf

"More and more countries will have to deal with people getting older. Most countries don't know how to manage their pensions, so I can't imagine they will spend more public money on research."
Rolf Tarrach, President of the European University Association, Belgium, interviewee

The ageing population is also likely to impact which research projects are funded, with an increasing focus on those that tackle challenges faced by the elderly. In fact, the World Health Organization (WHO) has stated that: "Research needs to be better coordinated if we are to discover the most cost-effective ways to maintain healthful life styles and everyday functioning in countries at different stages of economic development and with varying resources."[9]

The researcher population won't escape the challenges facing the rest of the overall workforce: the ageing crisis will hit all industries. As a result, the researcher community may be called upon to be even more mobile or, as we see advances in travel and communication technologies, to collaborate internationally at ever greater levels (see "Collaboration – a cure for all ills?" in this essay).

Global challenges: climate change

While predictions around the impact of climate change vary, it is already driving policy and will undoubtedly shape funding priorities in the years ahead.

Earth Summit 2012, or the United Nations Conference on Sustainable Development, led to the launch of the Sustainable Development Goals.[10] Officially called "Transforming Our World: The 2030 Agenda for Sustainable Development", it contains 17 global goals, which comprise 169 targets.

While, in 2015, the historic Paris Climate Agreement (COP21) was signed. As of 2017, all countries apart from Syria (not present at the negotiations) were included in the agreement, though the US is set to withdraw by 2020. This was the first ever universal, legally-binding global climate deal. The key goals identified were: keep the increase in global average temperature to well below 2°C above pre-industrial levels; aim to limit the increase to 1.5°C; global emissions to peak as soon as possible; rapid reductions to be undertaken thereafter.[11]

The impact of climate is expected to be immense… Today, a total of 75 million people in coastal regions are exposed to the risk of storm-induced floods. Assuming a moderate climate change scenario with a sea-level rise of 0.4m by the 2080s, this figure would increase to an estimated 200 million.[12] Eight megacities in the world are located in coastal areas and may be partially or completely lost due to sea level rises by 2100.[13] Approximately 1.5 billion additional people will experience "stressed water conditions" worldwide by 2050.[14] And, by 2030, many countries will need help from other countries to avoid food and water shortages.[5]

In addition, food systems account for just under a third of all greenhouse emissions. In the future, we may need to follow a healthier, less resource-intensive (preferably vegetarian) diet.[15] However, a nutritious diet is currently a more expensive option than a calorie-dense one; this will need to change to ensure the world at large can manage and afford healthy living.[16]

World energy consumption is set to rise by 28 percent between 2015 and 2040, with most of the rise set to occur in non-OECD countries (41 percent in non-OECD countries; 9 percent in OECD countries). According to

5 Global Trends 2030: Alternative Worlds. National Intelligence Council. 2012. https://info.publicintelligence.net/GlobalTrends2030-TalkingPoints.pdf

9 World report on ageing and health 2015. World Health Organization. September 2015. https://www.who.int/ageing/events/world-report-2015-launch/en/

10 Sustainable Development Goals. United Nations. 2015. https://sustainabledevelopment.un.org/index.php?menu=1300

11 Paris Agreement. European Commission. 2017. https://ec.europa.eu/clima/policies/international/negotiations/paris_en

12 The Future Oceans - Warming Up, Rising High, Turning Sour. German Advisory Council on Global Change (WBGU). 2006. https://www.wbgu.de/en/special-reports/sr-2006-the-future-oceans/

13 Rising Sea-Level, Rising Threats. Global Military Advisory Council on Climate Change. 2017.

14 Chen, H. et al. Food, Water, Energy, Climate, Outlook: Perspectives from 2016. MIT Joint Program. 2016. https://globalchange.mit.edu/sites/default/files/newsletters/files/2016-JP-Outlook.pdf

15 Poore, J. & Nemecek, T. Reducing food's environmental impacts through producers and consumers. Science. 1 June 2018. DOI: 10.1126/science.aaq0216. http://science.sciencemag.org/content/360/6392/987

16 Benton, T. What will we eat in 2030? World Economic Forum. November 2016. https://www.weforum.org/agenda/2016/11/what-will-we-eat-in-2030/

the U.S. Energy Information Administration, this will be driven by "strong economic growth, increased access to marketed energy, and quickly growing populations".[17]

Solving these climate-related issues will require a multidisciplinary, interdisciplinary and collaborative approach, drawing on researchers with a wide range of expertise from energy storage to refugee issues. The global agreements and goals that relate to climate change (e.g. COP21 and Sustainable Energy for All (SEforALL)) will also require collaboration between governments to ensure evidence-based policy change.

In response to these global challenges, we are likely to see funders increasing their support for "moonshots"; ambitious, exploratory and ground-breaking projects that are launched without the expectation of profit or benefit in the near-term. We are also likely to see more academic-industry collaboration (see "Testing a new funding recipe" in this essay); for example, public/private partnerships are expected to play a key role in the existing Cancer Moonshot. The anticipated ageing population crisis has triggered, or can at least be linked to, a number of recent moonshot projects and national strategies, from curing dementia to helping the elderly remain in their homes,[18] as well as genome-powered research to promote a longer, healthier life.[19]

Regional shifts: the China effect

With a rising population, growing GDP, and a focus on R&D, China is poised to become a research powerhouse of the future. Its research output has been similar in size to the US' for many years, but there are clear signs that China is now edging ahead.

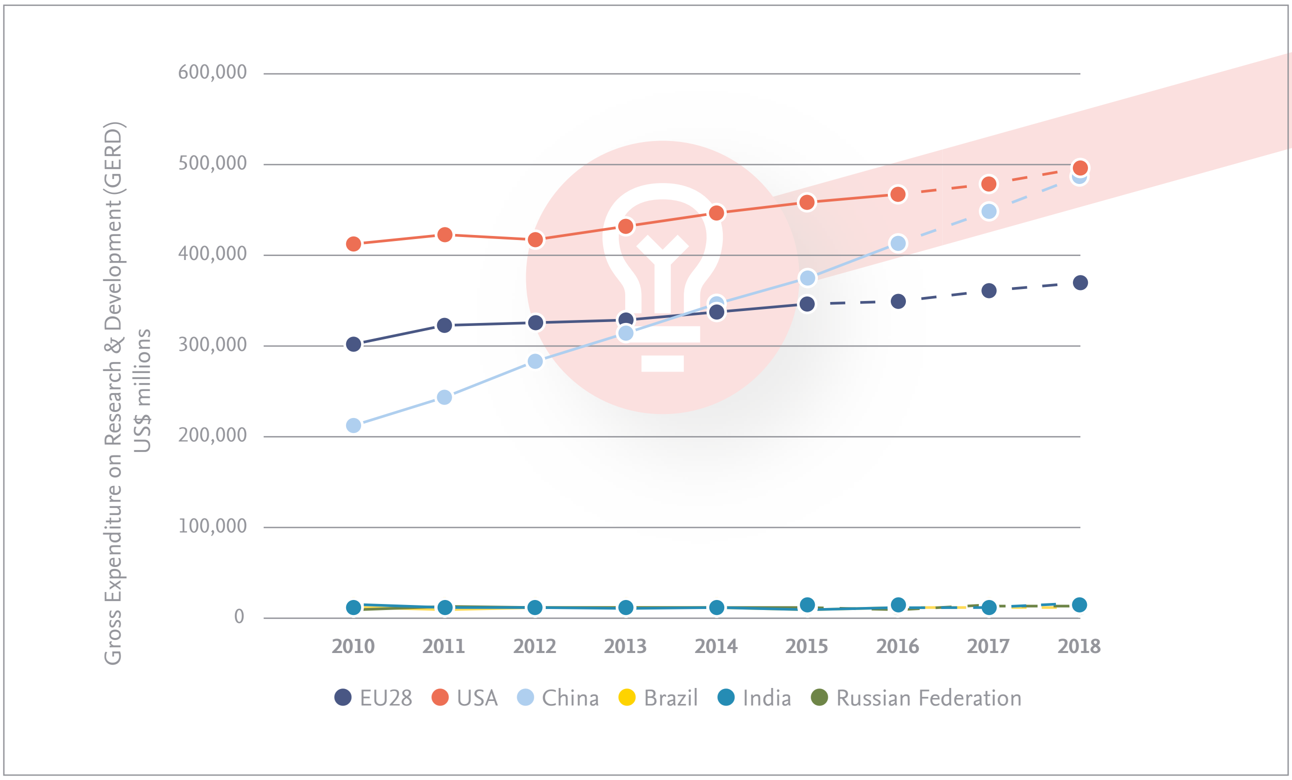


Figure 1.3: Growth of gross domestic expenditure on R&D (GERD) by country. Source: OECD and UNESCO. US$ millions, constant prices and PPP. Forecast data (highlighted by dashed lines) calculated through linear extrapolation.

17 International Energy Outlook. U.S. Energy Information Administration. 14 September 2017. https://www.eia.gov/outlooks/ieo/pdf/0484(2017).pdf

18 Government announces £300 million for landmark ageing society grand challenge. Gov.uk. 12 March 2018. https://www.gov.uk/government/news/government-announces-300-million-for-landmark-ageing-society-grand-challenge

19 HITC Staff. StartUp Health Launches 'Longevity Moonshot' to Change Face of Aging. HIT Consultant. 14 April 2016. https://hitconsultant.net/2016/04/14/startup-health-launches-longevity-moonshot/#.XF2sdVz0mUk

In the 2018 Science & Engineering (S&E) Indicators from the US' National Science Foundation (NSF), China was reported to have published more refereed S&E research papers than the US for the first time.[20] China published fewer biomedical science papers than the US and the EU, but published more engineering papers than either region.

"We are reaching a tipping point where the Western world is going to be usefully challenged by the brilliance and focus of Chinese research."
Funder, Canada, interviewee

And the rise in published research coming from the East only looks set to increase. While in many established research countries the growth of research and development (R&D) investment is stagnating, in some emerging research countries – including, crucially, China – the opposite is true (see figure 1.3).

"…in places like Korea and China, in particular, there is much less discussion about the impact of funding on innovation. They know you can only innovate with new disruptive ideas that come from science activity."
Jean-Claude Burgelman, Open Science Unit Head, European Commission, Belgium, interviewee

Technology development and innovation are key elements of China's current five-year (2016-20) plan, which focuses on more and faster R&D, improved capacity for innovation, more science and technology (S&T) programs, and faster breakthroughs,[21] while the "Made in China 2025" initiative plans to see the country become a "manufacturing powerhouse".[22]

"Research funding is increasing. There are two major sources – government and industry. Government is more focused on fundamental research and industry is more focused on short-term, commercial impact. Competition will be stronger but if you're a good researcher you should be fine."
Yun He, Dean, School of Pharmaceutical Sciences, Chongqing University, China, interviewee

Artificial intelligence (AI) is the subject of intense funding and research in China and the country is offering financial incentives to entice back experienced Chinese researchers who have spent time studying and working in the US. Two of China's universities were among the top three institutions or companies with the most frequently cited papers on the topic (published between 2012-16). The other entry, in first place, was Microsoft.[23] Many believe that, in the future, power will lie with those who were at the forefront of the AI revolution, so competition in the field is high. Other contenders making inroads into the AI space include the corporations such as Amazon, Microsoft and Apple.

"China is so far ahead [of the rest of the world] on face recognition, for example, using "face to pay", but I'm not sure we would like that here [in the UK]."
Nicola Millard, Head of Customer Insight & Futures, BT, UK, interviewee

Another factor contributing to the growth in China's research output is the high – and rising – number of researchers entering the system, particularly in proportion to other research-intensive economies. This is likely due, in part, to its investment in education: around 70 percent of the nation's scientific research funding is shared by six percent of China's 1,700 chartered institutes of higher education. Together these institutions produce about 33 percent of all Chinese undergraduate students.[24]

According to a number of the experts we interviewed for this study, the rising influence of China and other

20 Science & Engineering Indicators 2018. National Science Board. 2018. https://www.nsf.gov/statistics/2018/nsb20181/report/sections/overview/research-publications

21 The National Medium- and Long-Term Program for Science and Technology Development (2006- 2020) An Outline. The State Council, The People's Republic of China. 2006. https://www.itu.int/en/ITU-D/Cybersecurity/Documents/National_Strategies_Repository/China_2006.pdf

22 Glossary: "Made in China 2025". HKTDC Research. 26 November 2018. http://economists-pick-research.hktdc.com/business-news/article/Glossary/Glossary-Made-in-China-2025/glossary/en/1/1X338PFI/1X0A5GQY.htm

23 Arai, S. China's AI ambitions revealed by list of most cited research papers. Nikkei: Asian Review. November 2017. https://asia.nikkei.com/Tech-Science/Tech/China-s-AI-ambitions-revealed-by-list-of-most-cited-research-papers

24 Veugelers, R. The challenge of China's rise as a science and technology powerhouse. Policy Contribution(19). July 2017. http://bruegel.org/wp-content/uploads/2017/07/PC-19-2017.pdf

countries in Asia seems unstoppable. And this could have implications for the language of science.

"In the future, we'll see more research coming out of China and India, and Chinese entities are likely to make significant acquisitions in the West. The consequence is a multilingual publishing environment."
Joseph Esposito, Senior Partner, Clarke & Esposito, US, interviewee

But at least one of the China-based researchers we interviewed felt the opposite might be true.

"It's no longer good enough to publish in local Chinese journals – international journals have more impact. The local English journals are trying to become more internationally-recognized – the Chinese government is pushing for this. 10 years from now, mainstream publishing will be in international journals."
Jing Ping Liu, Founding Director, Centre of Evidenced-Based Chinese Medicine, Beijing University of Chinese Medicine, China, interviewee

While China has the potential to excel in many research fields, in terms of impact it still trails behind other countries with similar output levels (see figure 1.4). But this appears to be shifting, with the US' share of top 1 percent cited articles holding steady at 1.8 to 1.9 percent between 2000 and 2014, the EU's growing from 1.0 to 1.3 percent, and China's share more than doubling over the same period from 0.4 to 1.0 percent.[20]

In 2016, China's leader, Xi Jinping, acknowledged that "the country's S&T [science and technology] foundation remains weak".[25] While China's current five-year plan (2016-2020) does not feature impact as a priority, there is a plan to improve basic research. But some believe that restrictions imposed on Chinese researchers' access to scientific literature could prove an obstacle when it comes to improving research quality. In October 2017, publisher

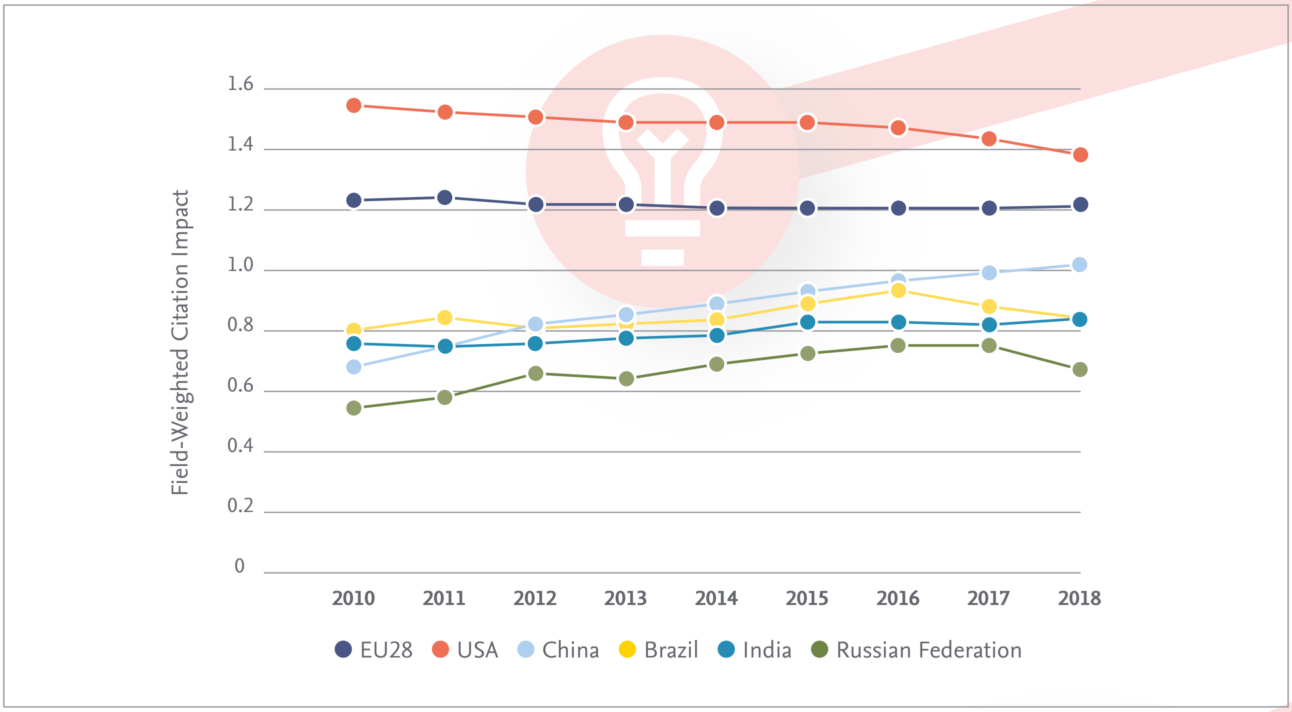


Figure 1.4: Field-Weighted Citation Impact (FWCI)* by country/region. Source: Scopus.

20 Science & Engineering Indicators 2018. National Science Board. 2018. https://www.nsf.gov/statistics/2018/nsb20181/report/sections/overview/research-publications

25 The future of Chinese research. Nature. June 2016. 534, 435. doi:10.1038/534435a

* Field-Weighted Citation Impact (FWCI) indicates how the number of citations received by a country's publications compares with the average number of citations received by all other similar publications. Similar publications are those publications in the Scopus database that have the same publication year, publication type, and discipline. An FWCI of 1.00 indicates that the country's publications have been cited exactly as would be expected based on the global average for similar publications; the FWCI of "World", or the entire Scopus database, is 1.00.

Springer Nature announced that it was removing access to a small number of articles in China deemed to be "politically sensitive".[26] Cambridge University Press did the same earlier in the year, though reinstated the papers after complaints from the research community. Springer Nature stated that, unless they blocked those papers, they "ran the very real risk of all our content being blocked". [26]

"There is a narrow focus on Chinese literature or even translated information from international journals. This means less access to newly-published studies and this is a big barrier for scientists."

Jing Ping Liu, Founding Director, Centre of Evidenced-Based Chinese Medicine, Beijing University of Chinese Medicine, China, interviewee

This lack of access could also be impacting the country's ability to innovate at the same pace as other research-intensive nations.

"Statistically, based on population, in 10-15 years, China should be number one in each field of research IF their level of creativity is the same as in the West. But it is unlikely."

Rolf Tarrach, President of the European University Association in Belgium, interviewee

According to our China-based interviewees, in order to build domestic research expertise, efforts to educate the country's future researchers outside of China have accelerated, with more funding made available for international exchanges. There is a sense among some academics that China is using international mobility and collaboration for the same expertise-building purpose.

"There have been lots of Chinese scientists going abroad to work; they thrive because they have a common approach in methodology. And there is a lot of interaction between Chinese and Australian institutions. However, China is pulling back because they believe they are good enough themselves."

Researcher, Australia, interviewee

For some industry observers, China's projected growth is far from cut and dried. George Friedman, founder and CEO of Stratfor, an American geopolitical intelligence platform and publisher, argues that historically no country has ever continued to grow economically indefinitely, and there is no reason why China should buck that trend. For example, in the 1980s, Japan was growing strongly but those growth rates were unsustainable. Friedman states that China is following in Japan's footsteps with a heavy reliance on exports and very high growth rates, which stand to collapse when the growth rates slow.[27] Bloomberg reports that China's non-performing bank loans were at a 12-year high in 2017[28] and the IMF has warned about "dangerous" levels of debt as the Chinese government focuses on reaching its 2020 GDP target.[29]

Others believe that the concept of a single ruling power will be redundant by 2030. According to the US' National Intelligence Council (NIC), which focuses on mid- and long-term strategic thinking, communication technologies will result in a multipolar world where power is spread among networks and coalitions which influence state and global actions. There will be a new age of "democratization" at the international and domestic level.[5]

5 Global Trends 2030: Alternative Worlds. National Intelligence Council. 2012. https://info.publicintelligence.net/GlobalTrends2030-TalkingPoints.pdf

26 Else, H. Nature publisher bows to Chinese censorship. Times Higher Education. November 2017. https://www.timeshighereducation.com/news/nature-publisher-bows-chinese-censorship

27 Friedman, G. The Next 100 Years. Allison & Busby. 2009.

28 China Bad Debt Prices Up 30% as New Gold Rush Gets Under Way. Bloomberg. June 2017. https://www.bloomberg.com/news/articles/2017-06-21/china-bad-debt-prices-surge-30-as-new-gold-rush-gets-under-way

29 People's Republic of China: 2017 Article IV Consultation.International Monetary Fund. 2017. http://www.imf.org/en/Publications/CR/Issues/2017/08/15/People-s-Republic-of-China-2017-Article-IV-Consultation-Press-Release-Staff-Report-and-45170

Regional shifts: political upheaval in Europe

Brexit – the exit of Britain from the European Union – will not only result in difficult to predict shifts in the UK research landscape, it has consequences for the whole of Europe.

Although the UK has been holding steady in terms of output and impact, UK and EU researchers expect that Brexit will have a very, or fairly negative impact on the UK and its research community. In particular, Brexit is expected to negatively affect the mobility of UK-based researchers, the ability of the UK to attract foreign researchers and UK access to research funding and international collaboration.[30]

Shortly after the results of the referendum, the Chief Executive of the UK Science and Technology Facilities Council, John Womersley, stated that getting a guarantee that the UK could remain part of Horizon 2020 should be the single objective.[31] 15 non-EU countries do have access to Horizon 2020 already – but access will likely depend on restrictions on immigration. The science community has been vocal, with a letter signed by 1,600 scientists sent to the government about a month after the referendum result, and an online petition that attracted 15,000 signatures within 10 days of its launch.

But while the UK has said it wants to maintain a close and special relationship with the EU and Horizon 2020, at the time this report was written, there were very few details available about how that might work – and so very little reassurance for the community.

The shift in EU membership could also impact policy. For example, EU regulation around human embryonic stem cell research was influenced significantly by the UK's stand on the subject; in the future, the UK may not have the same level of influence on such decisions. [31]

It could also change the criteria for funding in the EU. The UK is known for its research excellence and with the region removed from the equation, funding may simply be divided equally between other member states. On the plus side, this will mean more funding for others, particularly Eastern European countries, but we could see a drop in the quality of research produced in the EU.

Making science accessible – and accountable

There is a growing feeling that if research studies are funded by tax payers' money – and many of them are – then the people paying those taxes should be impacted by the study outcomes. As a result, many funders now require applicants to demonstrate how the research proposed will benefit society and explain the resulting findings in a way that's easy to follow. In addition, a number require that the results are made freely available in some form (see Pathways to open science essay).

"Research is funded by society, therefore this investment must return benefits to the society."

Materials science researcher, Greece, aged 36-45, respondent to researcher survey

This move toward open science has the potential to not only influence what is being funded, but increase the existing pressures on researchers, who must now also learn to communicate their findings in a way that will engage people, whatever their level of scientific knowledge. Some already see potential benefits and are active in this area.

30 Brexit: Global researchers' views on opportunities and challenges. Elsevier/Ipsos MORI. November 2017. https://www.elsevier.com/connect/brexit-resource-centre

31 Abbott, A., Cressey, D., & Van Noorden, R. UK scientists in limbo after Brexit shock. Nature. June 2016. 534, 597-598. doi:10.1038/534597a

"Researchers are not insensitive to public opinion: public perceptions would help with controversial research with animals, genetic modifications, things that affect the environment, etc. In many instances, researchers actively engage in the public debate to inform the public with real, technical information about a subject of interest."
Frédérick Gosselin, Associate Professor, Department of Mechanical Engineering, Polytechnique Montréal, Canada, interviewee

For some, this will not only require extra hours of work but a radical change in thinking as "most established researchers have been practicing closed science for years, even decades, and changing these old habits requires some upfront time and effort".[32] But many feel it is a skill that researchers will have to develop – or outsource.

"The public increasingly wants to better understand where the money goes and why … scientists themselves must become better at communicating their own value and contribution."
Researcher, Asia Pacific, interviewee

Another factor fuelling increasing calls for public engagement is the rise in global challenges with the potential to transform the way we all live. As a 2016 paper by Dunn *et al*. notes: "Historically… one could argue that most important decisions made with regard to science were made by relatively few stakeholders: the powerful few. Increasingly, however, the big decisions with regard to climate change, public health, water resources, and agriculture are being made by everyone who votes or chooses what to purchase. As a result, the future of the life we depend on very much depends on democratizing not only scientific knowledge but also science itself."[33]

"In Australia, there are 9-10 research themes but none of them describe social problems like inequality or community well-being. They are all very narrow and science-driven … This will change in the next 10-15 years so that research will become more involved in actually solving social issues."
Researcher, Australia, interviewee

Open science is also seen as a vital step toward restoring the faith of the public, which has taken a knock over the past few years. Some of this lack of confidence can be placed at the door of negative publicity, for example, the crisis around the MMR vaccinations, the rejection of the views of experts, and, more recently, senior public figures questioning the legitimacy of core scientific projects, such as monitoring, and finding a solution to, climate change.

"There's a fragmented information space. It occurs at the highest levels and stems from people in the UK and US who have no business speaking about science, but the bar is so low that anybody can throw around words and convince people. There is too much scientific information, there's no good away to separate the good from the bad right now and that's really harmful."
Kent Anderson, CEO, Redlink & Redlink Network, US, interviewee

What do researchers themselves think? While 79 percent of those we surveyed for this study feel it is desirable that the majority of their research has an impact on society 10 years from now, only 51 percent expect that it will. Some believe research doesn't have immediate impact, especially if it is fundamental research (e.g. maths, physics and astronomy). Yet, there is opportunity to change this; some studies indicate that "scientists' participation in public communication, particularly social media, may increase scientific impact".[34]

32 Gilbert, E. & Corker, K. What Is "Open Science"? (And Why Some Researchers Want It). Futurism. June 2017. https://futurism.com/what-is-open-science-and-why-some-researchers-want-it/

33 Dunn, R. R. et al. The Tragedy of the Unexamined Cat: Why K-12 and University Education Are Still in the Dark Ages and How Citizen Science Allows for a Renaissance. Journal of Microbiology & Biology Education. March 2016. 17(1), 4-6. doi: 10.1128/jmbe.v17i1.1049

34 Why Public Engagement Matters. American Association for the Advancement of Science. 2018. https://www.aaas.org/pes/what-public-engagement

Money is being made available to support these engagement activities. For example, the Wellcome Trust is "giving £13 million in funding to five science centres around the UK to encourage new and different ideas that will help to make science more accessible".[35] However, there is much debate around how successful efforts to date have been, perhaps because "citizens and scientists often see science-related issues through different sets of eyes".[36]

"Even brilliant people don't have a great understanding of how science works; this is a challenge. There is a science-society disconnect."
Funder, Canada, interviewee

Several of our interviewees recognized that a more local approach can have positive outcomes.

"Universities [in Chile] are becoming more involved in issues that are important to their community."
Researcher, Chile, interviewee

One stumbling block many researchers have identified is the lack of training they receive for this form of communication: "...doctoral students and postdoctoral researchers are not encouraged to use their training and expertise outside academia..."[37] Another hurdle could be the mindsets of researchers themselves. In our survey, around half of respondents currently consider increasing public knowledge and understanding part of their work's impact (see figure 1.5). But as funders continue to make it a requirement of grants, that could soon change.

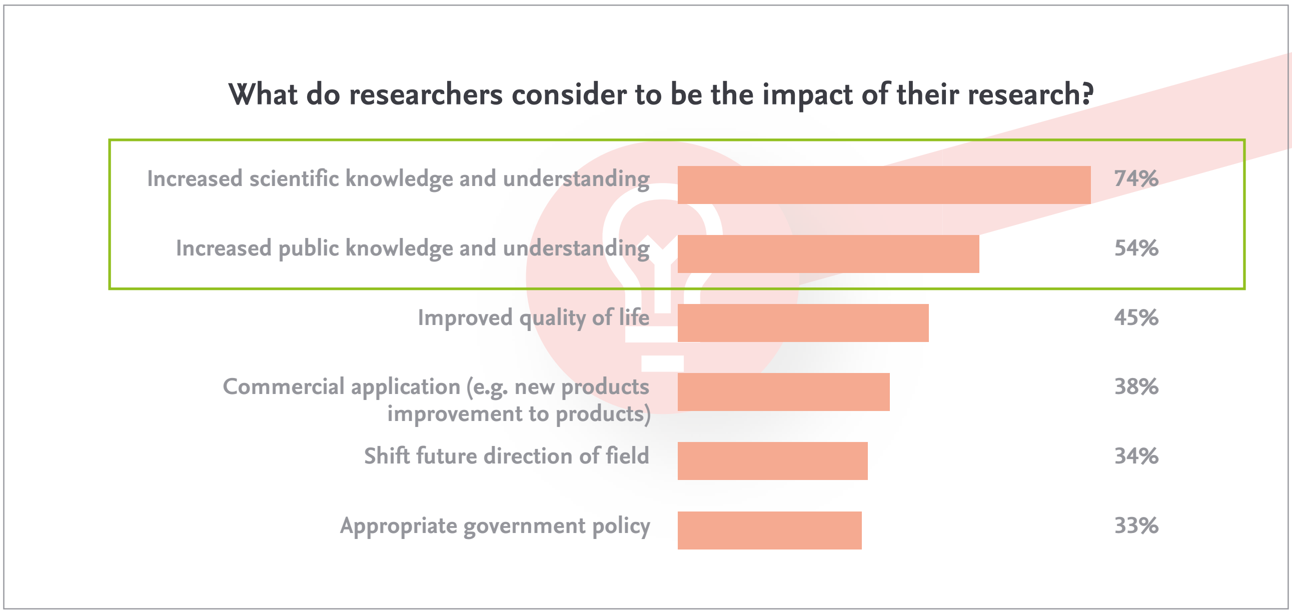


Figure 1.5: What researchers consider to be the impact of their research. Source: Researcher survey for this study. n=2055

35 UK science centres get £13 million for public engagement. Wellcome. August 2017. https://wellcome.ac.uk/news/uk-science-centres-get-13.1-million-public-engagement

36 Funk, C. & Rainie, L. Public and Scientists' Views on Science and Society. Pew Research Center. January 2015. http://www.pewinternet.org/2015/01/29/public-and-scientists-views-on-science-and-society/

37 Pham, D. Public engagement is key for the future of science research. npj Science of Learning. 2016. 1. doi:10.1038/npjscilearn.2016.10

Collaboration – a cure for all ills?

An uncertain science funding landscape is not without consequences, for example, long-term studies can end prematurely resulting in lost jobs.[38] Some areas, such as fundamental or basic research and the arts and humanities, already struggle to attract government funding. The humanities, in particular, has reported a crisis with large budget reductions in recent years – although, more recently, there have been calls for closer links between STEM (science, technology, engineering and mathematics) disciplines and the humanities. A new hybrid discipline, "humanics", has even been proposed.[39]

"The emphasis in the West on applied research is penny-wise and pound-foolish and that's something to keep an eye on."
Kent Anderson, CEO of Redlink & Redlink Network, US, interviewee

As new fields gain prominence, established fields can find it harder to secure public funding at the level they are used to. And, as we've seen, there have been increasing calls for researchers (and the bodies that fund them) to demonstrate the societal impact of research – this is also likely to influence the projects that funders choose to invest in.

The technology and equipment required to conduct science and handle the large volumes of data generated is generally agreed to be adding to costs, driving a need for increased funding. This was a factor identified by a number of our researcher survey respondents from as far afield as Italy, South Korea and Norway.

Many see collaboration as the answer to these funding challenges, in fact, there is broad agreement it could prove the future of research.[40] The past few years have witnessed a rise in collaborations spanning international borders, institutions, and disciplines. We explore these in more detail in "Collaborating in a cyber world" in our How researchers work: change ahead essay.

Researchers on the future of public funding

As part of this study, we asked researchers for their thoughts on the status of public funding 10 years from now.

Their answers showed that there is a considerable gap between the proportion of researchers that want more funding and those that expect there to be more funding.

78 percent of respondents think it is desirable that public research funding (in real terms) is greater than it is now; and a similar proportion, 79 percent, feel they will need it. In contrast, only 56 percent think it is likely they will receive it.

One of the benefits of collaboration is that more participants can mean a diversity of funds and a greater likelihood that the research will be completed. At the American Chemical Society (ACS), the average paper published in their journals has funding from two sources.[40] For developing or less research-intensive economies, collaboration can be particularly helpful, aiding access to much-needed funding, equipment or knowledge.

"In the field of research in which I work, very expensive equipment is used. Often in my country it is absent or very busy. In addition, in different countries, approaches and methods of work are very different. To take this experience is useful."
Chemist, Russian Federation, aged 26-35, researcher survey respondent

Studies have shown that collaboration can boost the impact of the research produced, which represents better value for money for funders. Importantly, collaboration also has support at a policy-level – and it

38 Jahnke, A. Who Picks Up the Tab for Science? Boston University. 2015. http://www.bu.edu/research/articles/funding-for-scientific-research/

39 Livsey, A. In the age of machines, what will become of the liberal arts? Financial Times. January 2018. https://www.ft.com/content/2eb4231c-f7ac-11e7-8715-e94187b3017e

40 Discover the Top Ten Trends Driving Science. ACS Axial. ACS Publications. January 2017. http://connect.acspubs.org/toptentrends

seems to be working. A previous Elsevier study looked at national- and European-level mechanisms to encourage cross-country collaboration in Europe. It found that the percentage of inter-country collaboration was on the rise. Furthermore, collaboration was found to be very inclusive in these regions: in 2011, every US state and every European country collaborated with every other state or country within the two regions.[41] How this might be impacted by the political upheaval we explore earlier in this essay remains to be seen.

Many see interdisciplinary research (IDR) and multidisciplinary research as forms of collaboration that offer promising opportunities to solve the key challenges facing society today. Increasingly, governments and funding bodies require researchers to demonstrate an IDR approach; in particular, a focus on mission-driven projects that bring economic or societal benefits.

"Consortia, groups of different backgrounds will be needed to answer the complicated questions in the medical field. What's applicable to cancer might also be applicable to infection. There's also collaboration by skill set - the people good at in vitro cell modelling need to be connected with people who can do mouse modelling, and so forth, to create better outcomes."
Taylor Cohen, US, interviewee

The IDR trend has spawned new initiatives such as the Belmont Forum, "a partnership of funding organizations, international science councils, and regional consortia committed to the advancement of interdisciplinary and transdisciplinary science". Its vision is to deliver "international transdisciplinary research providing knowledge for understanding, mitigating and adapting to global environmental change".[42]

There is speculation that the pressure on regions to increase the intensity of R&D expenditure will lead to a rise in academia-industry collaboration.[43] That could well be the case; for example, the Higher Education Funding Council for England (HEFCE) has announced that the Research Excellence Framework (REF) in 2021 will include "an explicit focus on the submitting unit's approach to supporting collaboration with organisations beyond higher education".[44] We take a closer look at the role of these partnerships in the section below.

Testing a new funding recipe: corporates and philanthropists

Corporate and philanthropic funding is growing in importance and there is more of it making its way into the academic community than ever before.

BERD (business enterprise expenditure on R&D) has long formed the majority of many nations' R&D budgets – typically around 70 percent. Large and powerful technology companies have been contributing considerable funds to science and technology research; Amazon, Apple, Facebook, Microsoft and Alphabet (Google's parent company) collectively spend about as much money as the US federal government does on non-defense research.[45] In the US, corporate entities provided $5 billion in funding in 2014. It is in industry that some see the future of funding[38] although this could prove more true for some disciplines than others.

"Private funding will drive certain science. For example, space exploration was almost exclusively government-driven, now some of the biggest innovations are taking place in the private sector."
Andrew Till, VP – Technology & Marketing, HARMAN Connected Services, US, interviewee

38 Jahnke, A. Who Picks Up the Tab for Science? Boston University. 2015. http://www.bu.edu/research/articles/funding-for-scientific-research/

41 Comparative Benchmarking of European and US Research Collaboration and Researcher Mobility. Elsevier; Science Europe. 2013. https://www.elsevier.com/__data/assets/pdf_file/0019/53074/Comparative-Benchmarking-of-European-and-US-Research-Collaboration-and-Researcher-Mobility_sept2013.pdf

42 The Belmont Forum. Belmont Forum. 2018. http://www.belmontforum.org/about/

43 Reid, G. The government has promised more R&D. Where will the money come from? The Guardian. January 2018. https://www.theguardian.com/science/political-science/2018/jan/04/the-government-has-promised-more-rd-where-will-the-money-come-from

44 Initial Decisions on the Research Excellence Framework 2021. Higher Education Funding Council for England. 2017. https://webarchive.nationalarchives.gov.uk/*/http:/www.hefce.ac.uk/

45 Renault, M. Technology helps science advance, but the U.S. could struggle. The Columbus Dispatch. 2017. http://gatehouseprojects.com/cbusnext/the-future-of-research/site/dispatch.com/

For some, corporates not only offer much-needed funding, but the opportunity to increase the speed of discovery.

"If everything is funded top down, the main part of the research will be always late: climate change was identified as a problem in the 1950s, but it didn't become a big topic until, let's say, 30 years later."

Researcher, Sweden, interviewee

Among those reaping the benefits of company investment are institutions; for example, at Harvard University in the US, corporate funding tripled between 2006 and 2013 to $41 million. The university also now helps researchers set up meetings with potential donors.[38]

The growing funding from industry goes hand in hand with a corresponding rise in academic/industry collaboration; a tried and tested formula with benefits to both parties. We can expect to see these collaborations increase in number in the decade ahead – particularly if the right infrastructure can be put in place.

"Everybody wants to work together and everybody wants to collaborate. It needs somebody to come up with an ecosystem within which we can do research together. We all have the same goals – but, a lot of the time, we just aren't very coordinated."

David Gavaghan, Professor of Computational Biology, University of Oxford, UK, interviewee

However, sometimes goals differ and that's when tensions arise. For industry, the focus is often on short-term results[45] as well as applied science, increasing the existing pressure on basic science and the arts and humanities. And there are concerns around intellectual property (IP) issues.

"Already there is a lot of industry/corporate funding at Utah, and this will grow. The problem is that this funding reduces the impetus to share and be open and reproducible: there is less transparency, and everything is proprietary."

Melissa Rethlefsen, Associate Dean, George A. Smathers Libraries, US, interviewee

"Increased competition among institutions for funding forces them to pursue collaborations with industry, which goes against open science; intellectual property becomes a competitive weapon, not necessarily to be shared."

Funder, US, interviewee

There are also concerns about the potential for industry to influence how science is conducted – in 2014, more than half of US corporate funding came from just 50 firms, with the result that a large percentage of research was determined by a small number of companies. For some, maintaining independence of the scientific process in the face of increasing private funding will be a key challenge.

"Science should be directed towards solving society's problems so it should be funded by the government. If we leave it all to private funders it could happen that they decide not to fund it any more – we would then fully depend on a few rich individuals who volunteered to contribute to society."

Thomas Crouzier, Assistant Professor, Royal Institute of Technology, KTH, Sweden, interviewee

For one of our interviewees, a change in mindset is all that is required to improve the relationship between industry and academia, and it's already happening.

38 Jahnke, A. Who Picks Up the Tab for Science? Boston University. 2015. http://www.bu.edu/research/articles/funding-for-scientific-research/

45 Renault, M. Technology helps science advance, but the U.S. could struggle. The Columbus Dispatch. 2017. http://gatehouseprojects.com/cbusnext/the-future-of-research/site/dispatch.com/

"20 years ago, industry money was considered dirty because of motivations and agenda – if it came from a company, it was seen as impure. That's changing. There needs to be a better understanding that companies can be approached for money, and for truly collaborative research; a sharing of ideas."

Taylor Cohen, US, interviewee

A number of industry watchers believe that the new generation of researchers won't have the same reservations around the ethics of corporate funding, having never experienced a time when there weren't shortages and competition. In our researcher survey, 58 percent of respondents aged under 36 years think it is desirable or highly desirable that corporates and philanthropic organizations fund a higher proportion of research in the next 10 years, compared to just 51 percent of those aged 36 years and over. As an engineering and technology researcher in Belgium aged 26-35 commented: "If they provide funding that makes it possible for my research to have a higher impact on society, I will apply for it." A UK-based chemistry researcher aged 26-35 added: "Private funding is an important avenue for supporting research and in my field the organizations often have goals aligned to my research goals and ethos."

There is a belief among some of our interviewees that governments should play a role in how corporate funding is allocated, even taking on responsibility for its distribution. Others feel we could see funding agencies consolidate and move from being just funders to controlling the entire research process. In this scenario, we could see funding agencies issue mandates that may have unintended consequences such as narrowing diversity in research or publishing.

Meanwhile, philanthropists are playing an increasingly active role in funding the discoveries of the future. In the US, $41 billion of US funding came from independent foundations in 2014 (e.g. the Bill & Melinda Gates Foundation). This grew from $32.5 billion in 2010.[46] Over in the UK, in 2015-16, annual philanthropic donations to universities exceeded £1 billion for the first time.[47]

There is no doubting the power of philanthropists; as Martin A. Apple, biochemist and former head of the Council of Scientific Society Presidents highlighted back in 2014: "They target polio and go after it until it's done — no one else can do that. In effect, they have the power to lead where the market and the political will are insufficient."[48]

Philanthropic foundations have large pots of money available and grand targets; for example, the Chan Zuckerberg Initiative has allocated $3 billion to "cure all disease" by the end of the century. And these long term goals mean that research doesn't always have to deliver within a couple of years – it's understood that "pay off" could take 20, or even 50 years.[49]

"Philanthropic organizations usually promote funding to solve real-world problems and develop technologies that are not economic-driven."

Researcher in engineering and technology, Japan, aged 26-35, respondent to researcher survey

While many of the largest foundations are based in the US and Europe, their targets are often global or focused on developing regions; for example, the Bill & Melinda Gates Foundation is committed to "improving the quality of life for individuals around the world".[50] Governments can also benefit from work done by philanthropists. An early example is the Robert Wood Johnson Foundation, which invented and piloted the emergency medical and 911 system in the US.[51] And, in 2017, Bill Gates pledged

46 Foundation Stats. Foundation Center. 2014. http://data.foundationcenter.org/#/foundations/all/nationwide/top:giving/list/2014

47 Weale, S. Annual donations to UK universities pass £1bn mark for first time. The Guardian. 3 May 2017. https://www.theguardian.com/education/2017/may/03/annual-donations-to-uk-universities-passes-1bn-mark-for-first-time

48 Broad, W. J. Billionaires With Big Ideas Are Privatizing American Science. The New York Times. March 2014. https://www.nytimes.com/2014/03/16/science/billionaires-with-big-ideas-are-privatizing-american-science.html?_r=1

49 Letzter, R. Here's what's behind Mark Zuckerberg and Priscilla Chan's $3 billion plan to cure all disease. Business Insider. 21 September 2016. https://www.businessinsider.com/mark-zuckerberg-cure-all-disease-explained-2016-9?r=UK&IR=T

50 Bill & Melinda Gates Foundation website. https://www.gatesfoundation.org/Who-We-Are

51 Roots and Wings. Robert Wood Johnson Foundation. 3 May 2012. https://www.rwjf.org/en/library/research/2012/05/roots-and-wings.html

$50 million of his own money to the Dementia Discovery Fund, a private-public research partnership.[52] Gates' goal to cure dementia could greatly ease the burden on health systems facing an ageing global population.

But these super-wealthy philanthropists can also be selective over what they fund or invest in – and there is always the possibility that they will change their minds. As we saw in the previous Harvard example, it's often the wealthiest universities that benefit the most – in the UK in 2015-16, Oxford and Cambridge were "the biggest winners from charitable giving by a huge margin… Together they account[ed] for 46% of new funds secured and 34% of total donors".[47] And when it comes to research topics, there is a danger that the media-friendly themes dominate; basic science could be left behind in favor of more topical or exciting fields, e.g. applied environmental sciences and space exploration.[48]

What's next?

In the decade ahead, researchers can expect an increasingly competitive funding environment with grant sources shifting. This is likely to be accompanied by a growing need to demonstrate societal impact, changes in funding priorities, and new mandates to meet. But thanks to the rise of alternative funding sources, a global acknowledgement that knowledge and development go hand in hand, and the opportunities offered by new ways of working, funding appears to be secure – at least in the short term.

47 Weale, S. Annual donations to UK universities pass £1bn mark for first time. The Guardian. 3 May 2017. https://www.theguardian.com/education/2017/may/03/annual-donations-to-uk-universities-passes-1bn-mark-for-first-time

48 Broad, W. J. Billionaires With Big Ideas Are Privatizing American Science. The New York Times. March 2014. https://www.nytimes.com/2014/03/16/science/billionaires-with-big-ideas-are-privatizing-american-science.html?_r=1

52 Gates, B. Why I'm Digging Deep into Alzheimer's. Gates Notes. 13 November 2017. https://www.gatesnotes.com/Health/Digging-Deep-Into-Alzheimers?WT.mc_id=20171113144800_Alzheimers_BG-TW&WT.tsrc=BGTW&linkId=44664256&linkId=44664547

Pathways to open science

Setting the scene…

The movement toward open science is underway. Ambitious plans are being developed to make science more transparent; not only to other researchers, but to society at large, particularly in light of concerns around research efficiency and reproducibility. While discussions around an exact definition of open science continue, it's clear the concept has support at all levels – from governments and funders to higher education institutions and researchers.

Technology is enabling open science, but there is also a cultural shift required; it will only continue to grow if the right components are in place. For example, open access publishing will prove a decisive factor – for open science to succeed, researchers must have the freedom to choose an open access journal for dissemination, supported by the necessary funding. In addition, researchers must have the opportunity (and the will) to supply sufficient detail about their methods and share data without jeopardizing career opportunities. In this essay, we hear what role industry experts and researchers think these factors will play in the decade ahead and how the measurement system must evolve to support further open science growth.

What will be the key drivers and changes?

1. Research grants will increasingly have open science conditions attached

- Key state and philanthropic funders already **embrace aspects of open science** and there are signals this **commitment is long-term**. While there is no accepted definition of open science, and no clear plan on how it can be achieved, the pace of funder policy interventions will accelerate, and the conditions they attach to research funding will increase.
- **Open access publishing is growing**, but not as quickly as some predicted and funders have yet to agree on a preferred model. This has resulted in guidelines and rules that vary by region and sector. However, factors such as more cohesive mandates, increasing alignment and evaluation based on open science activities, mean uptake is expected to continue.
- An increasing number of platforms will enable researchers to **openly publish their various research outputs** from preprints, to data and code.

2. Researchers are expected to spearhead adoption of open science, but not without experiencing conflicts of interests

- Though pressure from funders **to publish open access (OA) is intensifying**, to secure funding and career progression, researchers will likely choose established journals recognized by their research communities. This, along with a lack of funds to cover the costs of publishing gold OA, will result in some choosing to submit to journals that don't charge a publishing fee.
- This pressure to publish is felt particularly keenly by early career researchers (ECRs). Some don't fully understand the various OA options or the benefits of choosing them and this also forms a **barrier to wider OA adoption**.

3. Metrics will continue to expand, enabled by new technology

- Interest in **alternative metrics continues to grow**, supported by technologies. With a range of metrics to draw on, this is expected to broaden the way research activities are measured.
- It remains difficult to demonstrate or measure **societal impact** but many view this as key to the future of evaluation. Very few existing metrics capture whether the attention that a publication has garnered is positive or negative – it is likely the focus will shift to include sentiment.
- Despite the availability of other options and a desire to move away from Journal Impact Factors, there is still resistance in key areas: **grant funding and hiring policies** are often based on publications in journals with Journal Impact Factors and this is expected to continue (especially in China).

Demystifying open science

Since the open science snowball started rolling, it's been gaining momentum, picking up mass and speed as it advances through the lecture halls and laboratories of scholarly research. But what do we mean by the term? There are various schools of thought. The Open Science Foundation describes it as "...the idea that scientific knowledge of all kinds should be openly shared as early as is practical in the discovery process".[1] Building on this definition, FOSTER states that it is practising science in "such a way that others can collaborate and contribute, where research data, lab notes and other research processes are freely available, under terms that enable re-use, redistribution and reproduction of the research and its underlying data and methods".[2]

While an agreed definition may still be lacking, many believe that open science is already proving a game-changer in the world of scholarly publishing. But whether those winds of change bring benefits or disadvantages may depend on where you sit in the research ecosystem.

"The biggest questions are how does this work and who pays for it all? How does this become viable economically? It's not like there are a lot of incentives built into it."

Kent Anderson, CEO, Redlink & Redlink Network, US, interviewee

Driving adoption from the top down

The movement certainly has support at the highest levels. For example, in Europe, "open science" is one of three policy goals set by EU Commissioner for Research, Science and Innovation, Carlos Moedas, in 2015 (along with "open to the world" and "open innovation"). Together, these have led to initiatives such as the European Open Science Cloud, which will host and process research data and be free at the point of use.[3] The EU has also launched the Open Science Monitor, which tracks open science trends in Europe (the drivers, incentives and constraints) drawing on data from a range of organizations, including Elsevier.[4]

Meanwhile, in the US, the Center for Open Science was launched in 2013, a non-profit with a vision of a scholarly community "in which the process, content, and outcomes of research are openly accessible by default".[5]

Worldwide, grants with open science conditions are becoming increasingly common. Funders – including some of the big philanthropic organizations – are not only mandating that research articles be made openly available (via OA publishing), but data and software too (see "Making science accessible – and accountable" in our Funding the future essay).

And there are signs that funding bodies are working to align their open science activities, particularly in Europe. In late 2018, a group of national research funding organizations announced the launch of cOAlition S, an initiative to make "full and immediate open access to research publications a reality" by 2020[6] (see "The launch of Plan S" in this essay). Although participating funders have agreed a general approach, they have yet to align their policies.

The importance of grass roots support

The desire for open science is also strong among researchers. Several industry experts we interviewed for this study point to a growing appetite for greater transparency in that group. This is driven, in part, by the will to tackle the perceived reproducibility issues troubling science, as well as the perception that openly-available work leads to increased discovery.

1 Gezelter, D. An informal definition of OpenScience. The OpenScience Project. 28 July 2011. http://openscience.org/an-informal-definition-of-openscience/

2 Open Science Definition. FOSTER. https://www.fosteropenscience.eu/foster-taxonomy/open-science-definition

3 Open Innovation, Open Science, Open to the World. European Commission. 2016. doi:10.2777/061652. http://www.openaccess.gr/sites/openaccess.gr/files/Openinnovation.pdf

4 Open Science Monitor. European Commission. 2018. http://ec.europa.eu/research/openscience/index.cfm?pg=home&section=monitor

5 Center for Open Science website – Our mission page. https://cos.io/about/mission/

6 cOAlition S website – About page. https://www.coalition-s.org/about/

"Our users care a lot about open access, but they have a very broad definition; it just means free and unfettered access to content. Open access is the means by which they are discovered and their brand is recognized."
Jean-Gabriel Bankier, Managing Director, bepress, an Elsevier company, US, interviewee

Interviewees also note that while researchers may want to see more open science, they are currently being held back by the limitations of the infrastructure on offer.

"As a generous researcher you want to share your data, uploading it so that others can use it, re-analyse it and maybe combine it with other data sets to get new insights. Enabling that process is really important, and there are data repositories popping up all over the place, but there is still a lack of cohesion and it's not easy to track down data that you may need."
Keith Cogdill, Library Director, NIH Library, US, interviewee

And until a structural shift takes place, some enterprising researchers are seeking their own solutions.

"If you can see your results and other people's, the whole scientific cycle speeds up… Currently, researchers are finding ways to share themselves, but there is a role for better content aggregators."
Jane X. Wang, Senior Research Scientist, DeepMind, UK, interviewee

Technological tools to support open dissemination are gradually increasing in scope and number, a trend that is certain to continue in the decade ahead. For example, new platforms have emerged to support open access publishing, open data sharing and open peer review – in the case of F1000Research, all three bases are covered. Platforms such as Academia.edu, ResearchGate and Mendeley support document sharing, while Mendeley Data and Figshare enable data sharing. The use of preprint servers (see "Beyond the four publishing pillars" in the Building the future research information system essay) is also on the rise in select disciplines. These servers help researchers openly share manuscripts, ahead of peer review, increasing the visibility of research and supporting early registration. In addition, sites like Sherpa/Juliet help researchers and librarians keep track of funders' open access policies and their requirements on open access publication and open data archiving.

Open science and research integrity: A match made in heaven?

At a time when funding for research is stretched (see "R&D funding: how it's changing and why" in our Funding the future essay), delivering value for money has never been more critical and researchers are under pressure to publish research that displays "integrity". Some believe open science is the key to achieving that goal.

According to the University of Bath in the UK, integrity in a research context means working "in a way which allows others to have trust and confidence in the methods used and the findings that result from this".[7] In practice, that means publishing reproducible research, disseminating negative results, following ethical standards, applying best practice, and abiding by confidentially requirements, among other things.

Reproducibility is a vital strand of the research integrity story. Ensuring that another researcher can "duplicate the results of a prior study using the same materials and procedures as were used by the original investigator",[8] is seen as not only crucial for the verification of results, but an important way to drive a field forward. As Steeves noted in 2017: "If a work is reproducible, others in the field can easily build upon it."[9]

7 Definition of research integrity. University of Bath. https://www.bath.ac.uk/corporate-information/definition-of-research-integrity/

8 Bollen, K. et al. Social, Behavioral, and Economic Sciences Perspectives on Robust and Reliable Science. Report of the Subcommittee on Replicability in Science Advisory Committee to the National Science Foundation Directorate for Social, Behavioral, and Economic Sciences. May 2015. https://www.nsf.gov/sbe/AC_Materials/SBE_Robust_and_Reliable_Research_Report.pdf

9 Steeves, V. Reproducibility Librarianship. Collaborative Librarianship. November 2017. 9(2). https://digitalcommons.du.edu/cgi/viewcontent.cgi?article=1343&context=collaborativelibrarianship

In recent years, several studies have called into question the reproducibility of science.[10, 11] In 2016, *Nature* made headlines with a survey in which 70 percent of respondents said they had failed to reproduce another scientist's experiment. 52 percent of respondents also said there was a "crisis" of reproducibility, although the majority said they still trusted published literature.[12] While most agree that reproducibility is one of the key challenges facing science today, thoughts on the severity of the situation vary. Writing in 2018, Fanelli suggested: "While these problems certainly exist and need to be tackled, evidence does not suggest that they undermine the scientific enterprise as a whole."[13]

In the researcher survey element of this study, we asked participants how many times they have tried to reproduce an existing study (including their own) over the past year. More than half of respondents say they have attempted to reproduce one or more studies. As can be seen in figure 2.1, 37 percent of those who tried were successful, and nearly two thirds were partially successful, while six percent indicate they were unsuccessful. While the outright failure rate is not as high as in previous studies, the high proportion of partial successes does suggest the academic community is right to be concerned.

Working together with journal editors, funders and publishers have responded with policies on sharing data and code. Some encourage, or mandate that data is openly shared. In some cases, authors who can't, or won't share their data are required to give their reasons via a published data statement.

But, for researchers, even if the availability of more robust and open data makes it easier to reproduce experiments, the question is, will they want to? Respondents to our researcher survey indicate that there is a lack of incentive to replicate previous studies.

"Those types of work take the same amount of time as an original work but [are] viewed much less favorably by journals and the profession. Nobody gets tenure through replication projects."

Researcher in economics from the US, aged 26-35, respondent to researcher survey

We also found that, over the past year:

- Researchers in Asia (54 percent) and Eastern Europe (66 percent) were the most likely to have attempted to replicate a study.
- If we break down the responses by country, researchers in the UK were the least likely to reproduce another study (42 percent), while researchers in China were the most likely (58 percent); in fact, a fifth undertook three or more.
- The likelihood of trying to reproduce a study decreases with the respondent's age.

	Desirability	Likelihood	Willingness
Researchers' views on whether the replication of studies in 10 years' time is both desirable and likely, and whether they will replicate them themselves. *n=2055*	**75%**	**48%**	**62%**

Figure 2.1: Source: Researcher survey for this study.

10 Libgober, J. False Positives and Transparency in Scientific Research. 2015. https://scholar.harvard.edu/files/jlibgober/files/fpforupload.pdf

11 Ioannidis, J. P. Why most published research findings are false. PLOS Medicine. August 2005. 2(8). doi:10.1371/journal.pmed.0020124

12 Baker, M. 1,500 scientists lift the lid on reproducibility. Nature. 25 May 2016 | Corrected: 28 July 2016. https://www.nature.com/news/1-500-scientists-lift-the-lid-on-reproducibility-1.19970

13 Fanelli, D. Opinion: Is science really facing a reproducibility crisis, and do we need it to? PNAS. 13 March 2018. https://doi.org/10.1073/pnas.1708272114

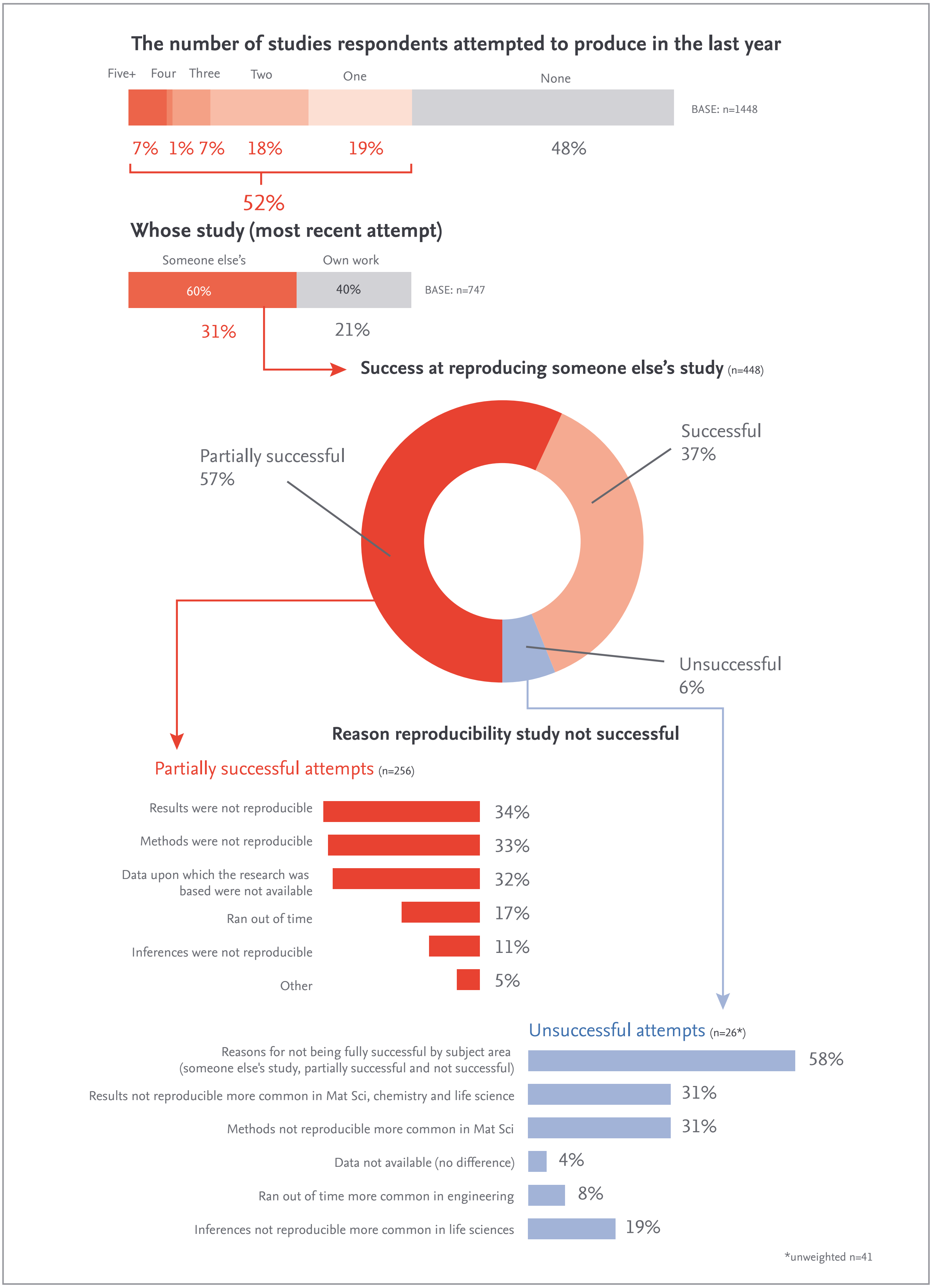


Figure 2.2: Success rates for reproducing prior studies. Source: Researcher survey for this study.

Another aspect of research integrity that has led to much debate is the publication of negative results; studies where the anticipated or desired effect was not observed. Beyond the research community, a lack of success is often seen as a virtue:

"In start-ups, failure is praised and is seen as part of the journey… this is something that should be part of the ethos of open sciences."
Physician and technologist, UK, interviewee

But even though sharing negative research results could save others from heading down the same, unsuccessful route, publications that feature them don't necessarily earn citations. Editors, under pressure to fill their journals with important break-throughs, are less likely to accept them; knowing this, researchers are unlikely to submit them.

"We need new ways to publish… studies where the hypothesis is not supported by the data... And we need to find impact measures to validate this so that academics' careers can benefit."
Robert Kiley, Head of Open Research, Wellcome Trust, UK, interviewee

While a high proportion of respondents to our researcher survey (66 percent) want to see negative results published in the future, and a similarly high percentage (64 percent) are willing to submit them, a smaller proportion of respondents (46 percent) believe that they will be accepted for publication.

Researchers have stepped forward with suggested solutions to these research integrity issues, for example, pre-registration of randomized clinical trials[14] has been encouraged for some years now and is even mandatory for publication in some high-impact journals. Some would also like to see other forms of clinical studies pre-registered. The idea is that researchers who pre-register their plans are much more likely to see them through. In addition, decisions are made about the data analysis before work is started – not once the results are available.

Funders, too, are pushing for research integrity with new guidelines, instructions and measurement programs. In Europe, an alliance of European academies (ALLEA) revised the European Code of Conduct for Research Integrity in 2017.[15] And, in 2018, the multi-center Brazilian Reproducibility Initiative was launched to measure the reproducibility of biomedical research throughout the country.[16] In the UK, a concordat to support research integrity has been produced by Universities UK, which represents the higher education sector.[17]

Open access to research publications

A key component of open science is open access (OA) – the publication of content in either gold or green form. This ensures it's freely available to anyone with an internet connection (see the sidebar "open access (OA) publishing models explained"). How that content can be re-used is typically decided by a license, e.g. one of the CC-BY attribution licences, which permit re-use – sometimes even commercially – with credit for original creation.

More and more journals now offer gold or green OA options, or a mixture of gold OA and subscription publishing in hybrid journals. With green OA, the cost of publishing the article is covered by journal subscription charges, so there is no additional fee for the author. With fully open access journals and hybrid journals, the costs of publishing an article gold open access are covered by an APC (article publishing charge), usually paid for by the author, their funder or their institution.

Funders are increasingly demanding that papers are made accessible via one OA form or another; in 2016, this resulted in gold OA publications comprising 25 percent of all articles published globally. Take publications made available through green open access (after an embargo period) into account, and 32 percent were available open access within 12 months of publication, and 33 percent within 24 months.[18]

14 Chambers, C. & Munafo, M. Trust in science would be improved by study pre-registration. The Guardian. June 2013. https://www.theguardian.com/science/blog/2013/jun/05/trust-in-science-study-pre-registration

15 The European Code of Conduct for Research Integrity: Revised Edition. ALLEA - All European Academies. Published in Berlin. 2017. http://www.allea.org/wp-content/uploads/2017/04/ALLEA-European-Code-of-Conduct-for-Research-Integrity-2017.pdf

16 Brazilian Reproducibility Initiative website. https://www.reprodutibilidade.bio.br/home

17 The Concordat to support research integrity. Universites UK. 2012. http://www.universitiesuk.ac.uk/policy-and-analysis/reports/Documents/2012/the-concordat-to-support-research-integrity.pdf

18 Monitoring the transition to open access. Universities UK. December 2017. https://www.universitiesuk.ac.uk/policy-and-analysis/reports/Documents/2017/monitoring-transition-open-access-2017.pdf

To discover how researchers feel about these funder mandates, see “Making science accessible – and accountable” in our Funding the future essay.

For many, OA publishing has enormous potential, from revolutionizing the practice of scholarly communications to fuelling new ideas and discoveries that could accelerate progress toward solving some of society’s key challenges. According to Science Europe, “Open Access and data re-use increase the circulation of knowledge, spark innovation and foster collaboration on a global scale”.[19] Others believe it improves access to scientific research in developing countries by complementing the free, or discounted access to subscription content provided by Research4Life.[20] Yet, despite these wide-ranging benefits, open access publishing has not grown at the rate many predicted.

Bumps on the road to an open access world

OA publishing is currently facing a number of challenges that it will need to overcome to reach the ambitious targets set by governments and funders.

While many state funders support open access, differences in regional policies and priorities mean that there is little global alignment at present. The federal government in the US prefers a green approach and has supported the development of the CHORUS and PubMed Central repositories. In contrast, China’s academic culture tends to favor prestigious journals with high Journal Impact Factors; often subscription journals. The Chinese Academy of Sciences (CAS) primarily encourages green OA publishing, but its support for gold OA is growing and it is willing to fund APCs.

Open access (OA) publishing models explained

Fully gold journal: Every article in the journal is published open access. Publishing costs are covered by the author (or someone on their behalf) paying an article publishing charge (APC). These APCs vary per journal.

Hybrid journal: Largely funded by subscription fees, these titles also offer authors the option to pay an APC to publish their individual article (gold) open access.

Diamond or platinum journal: Every article in the journal is published (gold) open access. The journal receives sponsorship or subsidies that allows it to make publishing and reading free.

Delayed open access journal: The final version of the article is free to access in a subscription journal after an embargo period. These periods vary per journal.

Green open access (self-archiving): Under this model, the author can post online the peer-reviewed version (not the final version) of their subscription article after an embargo period. These periods vary per journal.

“Open access journals are welcomed in China… however, China is still behind on this trend. For example, in my institution, Chinese researchers don’t understand the importance of exposing their original data. This may change if more scientists are educated in Western countries.”

Jing Ping Liu, Founding Director, Centre of Evidenced-Based Chinese Medicine, Beijing University of Chinese Medicine, China, interviewee

In Europe, both gold and green forms are favored by different funders and there are tensions surrounding

19 Position Statement: The Framework Programme that Europe Needs. Science Europe. October 2016. https://www.scienceeurope.org/wp-content/uploads/2016/10/SE_Position_Statement_H2020.pdf

20 Research4Life website. https://www.research4life.org/

the direction and uptake rate of OA publishing. For example, the UK's 2012 Finch report deemed OA the future of academic publishing and progress,[21] but OA publications have not reached the numbers expected and the cost has been higher than some anticipated (or feel is sustainable).

For philanthropic funders, gold OA appears to be the preferred route; for example, the Bill & Melinda Gates Foundation now requires all articles from funded research to be made immediately and freely available with no embargo period. Data must also be made immediately available to all.[22]

Another challenge, highlighted by the Institute of Development Studies, is that researchers' awareness of OA varies by location. In many parts of the world, some publishers waive, or reduce APC fees for authors in developing countries, but this isn't well known. In lower-income countries, "the OA movement is... likely to be driven by high-profile individual advocates, grass roots movements, and institutional libraries".[23]

There is also a question of "trust" in the process. The hybrid journal model was introduced to facilitate a more rapid transition from subscription to gold OA models, but there have been claims of overpricing by publishers and "double dipping" (the concept that publishers are paid for the same article twice: once via the APC and then again via library subscription fees).

Initiatives are underway to accelerate open access (OA) adoption and smooth out these "road bumps"; for example, the steps taken by cOAlition S (see "The launch of Plan S" sidebar) and recommendations by the EU (see "How the EU plans to improve OA uptake" sidebar). And, in 2015, a new global initiative was introduced – OA2020 – delivering an economic rationale for publishing to transition to OA.[24] To date, 99 scholarly organizations have endorsed the project.

Elsewhere, more than 200 universities and more than 80 research funders around the world (including Harvard

How the EU plans to improve OA uptake

In May 2016, the EU Competitiveness Council set a goal for all scientific papers to be OA by 2020, "without embargoes or with as short as possible embargoes".[25] However, a 2017 report[26] found that, at the current rate, reaching the point where even half of Europe's scientific publications are published immediate OA will not be achieved until 2025 at the earliest. The report identified a number of barriers, including "cultural inertia" and concerns from both researchers and publishers. Where progress has been made it's because the community is receptive – for example, in physics, preprint sharing was adopted some years ago – or funder mandates and support for APC payments have driven gold OA uptake, as can be seen in life sciences and medicine. The report made a series of recommendations to improve progress including:

- Strengthening incentives for OA publication and archiving
- Providing subscription journals with a viable route to flipping to OA
- Developing a robust infrastructure to allow open access to scale more rapidly

21 Accessibility, sustainability, excellence: how to expand access to research publications. Report of the Working Group on Expanding Access to Published Research Findings. 2012. https://www.acu.ac.uk/research-information-network/finch-report-final

22 Bill & Melinda Gates Foundation Open Access Policy. Bill & Melinda Gates Foundation. 2018. https://www.gatesfoundation.org/How-We-Work/General-Information/Open-Access-Policy

23 Nobes, A. Open Access plays a vital role in developing-country research communication. INASP. March 2016. http://blog.inasp.info/open-access-plays-vital-role-developing-country-research-communication/#three

24 Open Access 2020 website – Be informed page. https://oa2020.org/be-informed/

25 Council Conclusions on the Transition towards an Open Science System. Council of the European Union. May 2016. http://data.consilium.europa.eu/doc/document/ST-9526-2016-INIT/en/pdf

26 Open Access. OpenAIRE & Research Consulting. 2017. https://blogs.openaire.eu/wp-content/uploads/2017/03/OA-market-report-28Final-13-March-201729-1.pdf

and the US National Institutes of Health) have already mandated green open access (self-archiving). And more than 90 percent of journals have adopted a green OA policy, with over 60 percent of them endorsing the immediate self-archiving by authors of the final refereed draft in their own open access institutional repositories.[27]

56 percent of the researchers we surveyed for this study think all research will be published open access in 10 years' time. As we can see in figure 2.3, researchers aged 36 years and under – those at the beginning of their research career and most dependent upon publication to demonstrate their success – are the least likely to support this point of view (48 percent). And they are also more likely to believe that most research data will not be made available upon publication in the decade ahead (31 percent vs. 22 percent overall).

Figure 2.3: Views of researchers on the prevalence of open access and data 10 years from now. Source: Researcher survey for this study.

27 Harnard, S. The post-Gutenberg open access journal. In B. C. Phillips, The Future of the Academic Journal. 2014. 2e (2 ed., pp. 179-193). Elsevier. doi:10.1533/9781780634647.179

The launch of Plan S

13 national research funding organizations and three charitable foundations from 13 countries have joined forces in a bid to accelerate the transition to full and immediate open access. The group, known as cOAlition S, is led by Science Europe, an association of major research funding and research performing organizations.

In September 2018, the coalition published Plan S[28], which contains one key target: "After 1 January 2020 scientific publications on the results from research funded by public grants provided by national and European research councils and funding bodies, must be published in compliant open access journals or on compliant open access platforms." This target is supported by 10 principles that touch on topics such as APCs, OA licences, and hybrid journals.[29]

The European Commission is not a signatory, though Plan S has been endorsed by Commissioner for Research, Science and Innovation, Carlos Moedas, and the European Commission will be involved with implementation.

In November 2018, researchers worldwide responded with an open letter to the research community,[30] which, at the time of writing this report, had more than 1,700 signatories. While they support the idea of open access, they feel that the current Plan S proposal "goes too far, is unfair for the scientists involved and is too risky for science in general".

For many of the sources we consulted for this study, how open access develops over the coming 10 years will be a deciding factor in the future success of open science: "… as the trend toward open access expands to data sharing and replication, the pressure to change how academia does business will reach a breaking point where change will become inevitable."[31]

But for OA to continue to grow, there are still key pieces of the jigsaw puzzle that need to fall into place. One of the remaining questions seems to be around speed. Pollock notes: "…at current rates of change, it will be decades before open access articles and monographs form the majority of scholarly output. Opinions vary as to whether the transition to open access is frustratingly slow or reassuringly measured."[32]

Another question is around how it will be funded. A number of the national consortia that negotiate with publishers over access to subscription content want to see the cost of publishing open access (the article publishing charge or APC) offset against the price paid for subscriptions. To date, in the majority of cases, a compromise deal has been reached. But, if a situation arises where money is made available on a large scale to pay for APCs, and researchers are mandated to publish immediate OA papers, then we may see significant shifts in uptake.

Open data: to share or not to share

Open data – that is, research data that can be freely accessed and used – is increasingly seen as a crucial element of open science.

As with other aspects of open science, the term means different things to different people: for example, "data"

28 cOAlition S website – Plan S page. https://www.coalition-s.org/

29 cOAlition S website – 10 principles page. https://www.coalition-s.org/10-principles/

30 Reaction of Researchers to Plan S: Too Far, Too Risky. Plan S Open Letter. https://sites.google.com/view/plansopenletter/open-letter

31 Leetaru, K. The Future of Open Access: Why Has Academia Not Embraced The Internet Revolution? Forbes. April 2016. https://www.forbes.com/sites/kalevleetaru/2016/04/29/the-future-of-open-access-why-has-academia-not-embraced-the-internet-revolution/#7705577145eb

32 Pollock, D. Ever so slow maturation for the open access sector. Euroscientist. November 2017. https://www.euroscientist.com/ever-so-slow-maturation-for-the-open-access-sector/

might cover figures, transcripts, sound recordings or images; it can be quantitative or qualitative, or raw, primary or secondary; and there are varying levels of openness.

Increasingly, governments, as well as organizations in the health and education sectors, see the value of opening up (non-personal) data, which has resulted in large volumes being made publicly available.[33] This has been driven, in part, by the moves toward transparency, accountability and improved research integrity and reproducibility we explore in this essay and Funding the future. There is also an expectation that opening up data could boost collaboration and innovation.

That desire for improved reproducibility chimes with one of the 10 characteristics of "highly-effective research data" that Elsevier has identified[34] (see figure 2.4).

Viewed as a whole, the characteristics align with many of the initiatives to improve data openness taking place at all levels of the research community. For example, a number of state funders have introduced mandates requiring researchers to not only publish data associated with experiments, but deliver detailed data management plans alongside their funding applications. And, in 2016, a UK-based group of funders and higher education bodies released the Concordat on Open Research Data,[35] which lays out principles to promote re-use of research data.

Figure 2.4: The 10 characteristics of highly-effective data identified by Elsevier.

33 Duus, R. & Cooray, M. The importance of open data. World Economic Forum. 11 February 2016. https://www.weforum.org/agenda/2016/02/the-importance-of-open-data/

34 Elsevier website – Research data page. https://www.elsevier.com/en-gb/about/open-science/research-data

35 Concordat on Open Research Data. UK multi-stakeholder group. 28 July 2016. https://www.ukri.org/files/legacy/documents/concordatonopenresearchdata-pdf/

There are also mandated moves to ensure that the technology required to support open data is in place. In Europe, this is being led by the Knowledge Exchange program.[36] Globally, the Open Data Institute (ODI) was opened in 2012 by Sir Tim Berners-Lee and Sir Nigel Shadbolt to, among other things, provide leadership and strategy, develop policy and give training.[37]

Data repositories such as Mendeley Data and Figshare now provide DOIs (digital object identifiers) for published data, helping to satisfy the discovery and citation aspects highlighted in figure 2.4. Because open data is generally understood to be more complex to deliver than open access publishing, the right technological solutions are critical, so these data repositories have an important role to play. For example, as well as catering for different types and volumes of data, these solutions must support discovery and re-use. According to a 2017 Horizon article, with the wealth of data associated with scientific research continuing to multiply, the challenge is finding "a way of extracting the nuggets of valuable information. More data across multiple domains means an enormous task ahead for a project that aims to link it all together".[38]

And sharing data on its own is also not always enough to make it re-usable: it should always be linked to findings and, where applicable, the code and tools used for analysis. There is also the "long-term care" of data to be considered, so other researchers can continue to benefit from it.[39] As a result, publishers are increasingly partnering with existing repositories, or are building their own to satisfy these requirements and help researchers comply with funder mandates (see our Technology: revolution or evolution essay).

Aside from these technological considerations, there are conflicts for researchers: although a study has found that research articles with underlying data openly available receive more citations,[40] there is some tension around who owns that data once it's been shared with the world.

"Researchers say people might run off with my data… well, there are not so many PhDs who use the data that lead to their PhDs over and over again. So, if others can use my open data, why not? You might be able to use someone else's."
Jean-Claude Burgelman, Open Science Unit Head, European Commission, Belgium, interviewee

The introduction of DOIs for open data is one step toward allaying researcher fears that their work could be claimed by others. And, in recognition of their concerns, funder policy wording around sharing data is often a little softer and less prescriptive than it is for OA. For example, in the Netherlands, the data management policy implemented by the NWO (the national research council) requires that data is "open where possible, protected where needed".[41] Similarly, the European Commission states that data should be "as open as possible and as closed as necessary".[42] However, risks or concerns around security, personal information and cost mean that it may never be possible to openly share all research data.

In 2017, Elsevier and CWTS (at University of Leiden, the Netherlands) produced a global report on open data. It found that we are still in the early stages of adoption and growth will depend on a willingness by researchers to support, or even lead the changes required. But, for that to happen, "… a change in the scientific culture is needed, where researchers are stimulated and rewarded

36 Knowledge Exchange website – About us page. http://www.knowledge-exchange.info/about-us

37 Open Data Institute – About page. https://theodi.org/about

38 Nine things we now know about the European open science cloud. Horizon: The EU Research & Innovation Magazine. November 2017. https://horizon-magazine.eu/article/nine-things-we-now-know-about-european-open-science-cloud_en.html

39 Wilkinson, M.D. et al. The FAIR Guiding Principles for scientific data management and stewardship. Nature. 15 March 2016. https://www.nature.com/articles/sdata201618

40 Piwowar, H. A., & Vision, T. J. Data reuse and the open data citation advantage. PeerJ. 2013. 1, e175. doi:10.7717/peerj.175

41 Open Science. NWO. https://www.nwo.nl/en/policies/open+science

42 H2020 Programme - Guidelines on FAIR Data Management in Horizon 2020 | Version 3.0. European Commission Directorate-General for Research & Innovation. 26 July 2016. http://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/oa_pilot/h2020-hi-oa-data-mgt_en.pdf

for sharing data and where institutions implement and support research data sharing policies, including mandates".[43]

Some of the experts we interviewed for this study feel that institutional libraries also have an important role to play, not only in supporting open data adoption, but in improving the value of the data delivered.

"Many of my colleagues are passionate about open data but data sets are often poor quality - poorly described, unorganized and with poor metadata/codebooks. With open data starting to grow, the implication is that the problems of poor quality will grow alongside it. The library's role in this environment will move more towards training/educating users on preparing better data sets."
University librarian, US, interviewee

More than half of the respondents to our researcher survey (52 percent) expect data to be available with the published article 10 years from now, a further 22 percent think it is unlikely, while the rest are undecided. In our essay, Building the future research information system, we look at how the existing rise in data publication is reshaping journals and articles and explore the potential for change in the decade to come. While in How researchers work: change ahead, we consider the growing need for researchers to learn data science skills to tackle the rising volume of data. If they don't, the bottleneck to the growth of open data may turn out to be a shortage of skills and tools to manage it.

Lifting the curtain on open peer review

Traditionally, peer review has been a very closed process, with limited information shared between editor, reviewer and author, and even less with the wider research community. Single blind peer review, in which reviewer names are not revealed to the author, but the author name and affiliation is shared with the reviewer, remains by far the most popular form.[44] However, some feel the time is ripe for change; writing in 2017, Preston suggested there is a "need to break out of the silo, coordinate and invest in peer review".[45]

Open peer review is one of the innovations we've seen in recent years and it can take on many forms, including:

- Varying levels of transparency around the pre-publication review
- Publishing reviewer names and/or the full peer review reports (with DOIs)
- Post-publication review (supplementary to, or instead of the pre-publication process)
- Collaborative peer review, where reviewers and editors conduct the review process in partnership

As with many aspects of open science, the goal is to bring greater levels of transparency and accountability, as well as "further incentivize peer reviewers by making their peer review work a more visible part of their scholarly activities (thus enabling reputational credit)".[46]

The concept of open peer review is not particularly new. The *British Medical Journal* has been telling authors who reviewed their manuscript since 1999.[47] However, the number of journals offering, encouraging or experimenting with open peer review has increased in recent years. And a 2016 report (conducted by Elsevier

43 Open Data: The Researcher Perspective. CWTS; Elsevier; Universiteit Leiden. 2017. https://www.elsevier.com/__data/assets/pdf_file/0004/281920/Open-data-report.pdf

44 Mulligan, A., Hall, L., & Raphael, E. Peer review in a changing world: An international study measuring the attitudes of researchers. Journal of the Association for Information Science and Technology. 4 December 2012. https://doi.org/10.1002/asi.22798

45 Preston, A. The Future of Peer Review. Scientific American. August 2017. https://blogs.scientificamerican.com/observations/the-future-of-peer-review/

46 Ross-Hellauer, T. What is open peer review? A systematic review. F1000Research. August 2017. doi: 10.12688/f1000research.11369.2

47 Smith, R. Opening up BMJ peer review. The BMJ. 2 January 1999. doi: https://doi.org/10.1136/bmj.318.7175.4

and others) found that there has been a marked increase in the likelihood of an author submitting to a journal where the reviewer's name will appear next to the article (in 2011, 45 percent were in favor but by 2015 this had risen to 52 percent).[48]

Despite these encouraging signs, overall, uptake of open peer review remains fairly low at present: the research community needs to be fully convinced of its value and the right incentives need to be in place. As with increased transparency of any process, there are associated risks and concerns, as a 2017 *Nature* paper identified: "…some researchers and editors fear that referee identification encourages positively biased or softened peer review."[49]

In recent years, new peer review services have emerged; for example, platforms that help researchers showcase their contribution to the advancement of science by capturing their peer review activity and adding qualitative and quantitative indicators. As these services become more automated, engagement is growing, and may result in a community with a greater awareness and adoption of open peer review: receiving recognition for peer review becomes easier when aspects of the peer review process are shared openly.

The use of machine learning – and, potentially, blockchain technology – (see the Technology: revolution or evolution essay) could also see the move toward transparency in peer review increase in pace.

Holistic metrics: developing new performance measures

Open science is helping to fuel a new generation of metrics. Traditionally, research impact measurements have focused on the research article, with counts of citations to articles particularly common. These counts are aggregated in various ways to show, for example, how a researcher or a journal is performing.

Since journal content moved online, alternative metrics, or "altmetrics", have emerged, which map online activity around research outputs more broadly than traditional citation-based metrics. For example, they look at mentions on certain social media platforms, news outlets and blogs, as well as bookmarks in reference managers. They also draw on other data such as usage, and citation of research articles in clinical summaries and policy documents. We explore alternative metrics in greater detail in "Technology meets metrics" in our How researchers work: change ahead essay.

Alternative metrics are still relatively new and evolving and, for some, have yet to address the fundamental problems of measuring impact. For example, alternative (and indeed citation-based) metrics don't measure whether attention is positive or negative – and as Twitter is the largest source of data for alternative metric scores, this is particularly problematic.[50] Devising an indicator that can measure sentiment is high on the wishlist of many, not just in the research community, and work is ongoing.

For institutions and funders, there is growing pressure to demonstrate the impact of their research at a societal level. Alternative metrics are starting to do this at the article level, but higher education institutions in several countries (at least 14),[51] have also introduced performance-based research funding systems (PRFSs). These programs evaluate the output and impact of the research performed at a national level and they aim to understand the wider societal impact of research in a climate where there is growing pressure on public funding and a desire for greater accountability and transparency (see The academy and beyond essay).

There are also calls from scientometricians and the wider academic community to make cited references in publications freely available as part of the open science movement. In 2017, a number of organizations in the academic world joined forces to launch the Initiative for Open Citations (I4OC), with the aim of establishing a "global public web of linked scholarly citation data to enhance the discoverability of published content, both

48 Publishing Research Consortium Peer Review Survey 2015. Mark Ware Consulting. May 2016. http://www.publishingresearchconsortium.com/index.php/134-news-main-menu/prc-peer-review-survey-2015-key-findings/172-peer-review-survey-2015-key-findings

49 Steps towards transparency in research publishing. Nature. September 2017. 549, 431. doi:10.1038/549431a

50 Pool, R. The rise and rise of almetrics. Research Information. November 2017. https://www.researchinformation.info/feature/rise-and-rise-altmetrics

51 Hicks, D. Performance-based university research funding systems. Research Policy. 2012. 41(2), 251-261. doi:10.1016/j.respol.2011.09.00

subscription access and open access".[52] Citation data is used for "assessing scholars' influence and making wise decisions about research investment".[53] Ultimately, while other metrics are still evolving and gathering engagement, citations will continue to play a role in determining careers and funding opportunities for researchers.

But, as our interviewees for this project identified, the growth of open science brings opportunities for new metrics in its wake, for example, the measurement of a researcher's open activities.

"We should reward scientists who are more open with data and for collaboration and contribution to the community."

Philanthropic funder, US, interviewee

Others feel it is time to take a more holistic approach by measuring overall contribution to research.

"If you accept that the whole workflow becomes open, you can put metrics on every part of it, from destination to impact. Then you get a dashboard of what you do as a scientist. That will become very interesting for funding and promoting purposes."

Jean-Claude Burgelman, Open Science Unit Head, European Commission, Belgium, interviewee

And, for many, metrics need to provide an incentive for researchers to perform activities that benefit science, but for which they currently receive no credit; for example, the publication of negative results.

"It can be very difficult to get null or negative results published, even though they're often very important. That has created an opportunity for predatory publishers, who don't care about the significance or even the validity of findings, just about selling a fake publishing credential to authors."

Rick Anderson, Associate Dean, University of Utah, US, interviewee

As open science continues to grow and mature, metrics, platforms, and guidelines will need the flexibility to evolve alongside it and deliver the more holistic approach open science requires. For example, while the "publish or perish" phenomenon persists (see the How researchers work: change ahead essay) and researchers are measured by indicators based on the research article alone, there are few incentives to be open.

Beyond metrics, the emergence of research information databases and research knowledge graphs such as Digital Science's Dimensions, Springer Nature's SciGraph and Informa's wizdom.ai – all of which are reliant on open science – are moving the community a step closer to a greater understanding of the research being performed.

Leveraging the knowledge of the masses with citizen science

One area of public engagement and open science that is experiencing a lot of positive attention is citizen science. Also known as crowd science, civic science or networked science, citizen science covers any scientific research conducted by amateur scientists, as well as indirect activities such as crowd funding. For some, citizen science is also about making research easier to access and understand (see "Making science accessible – and accountable" in our Funding the future essay). Importantly, researchers such as Kullenberg and Kasperowski see citizen science as a way of "democratizing science, aiding concerned communities in creating data to influence policy and as a way of promoting political decision processes involving environment and health".[54] It also provides opportunities for data collection that would otherwise be impossible to achieve.

Citizen science is nothing new. Researchers have collaborated with the public for many years and big players are involved, from NASA to Wellcome Trust. In particular, astronomy research has benefited from it for decades. While the initial focus of many citizen science projects was observation and recording, it has become many other things: entertainment (Stargazing

52 Initiative for Open Citations website – About page. https://i4oc.org/#about

53 Shotton, D. Funders should mandate open citations. Nature. 9 January 2018. https://www.nature.com/articles/d41586-018-00104-7

54 Kullenberg, C. & Kasperowski, K. &. What Is Citizen Science? - A Scientometric Meta-Analysis. PLOS One. January 2016. doi:10.1371/journal.pone.0147152

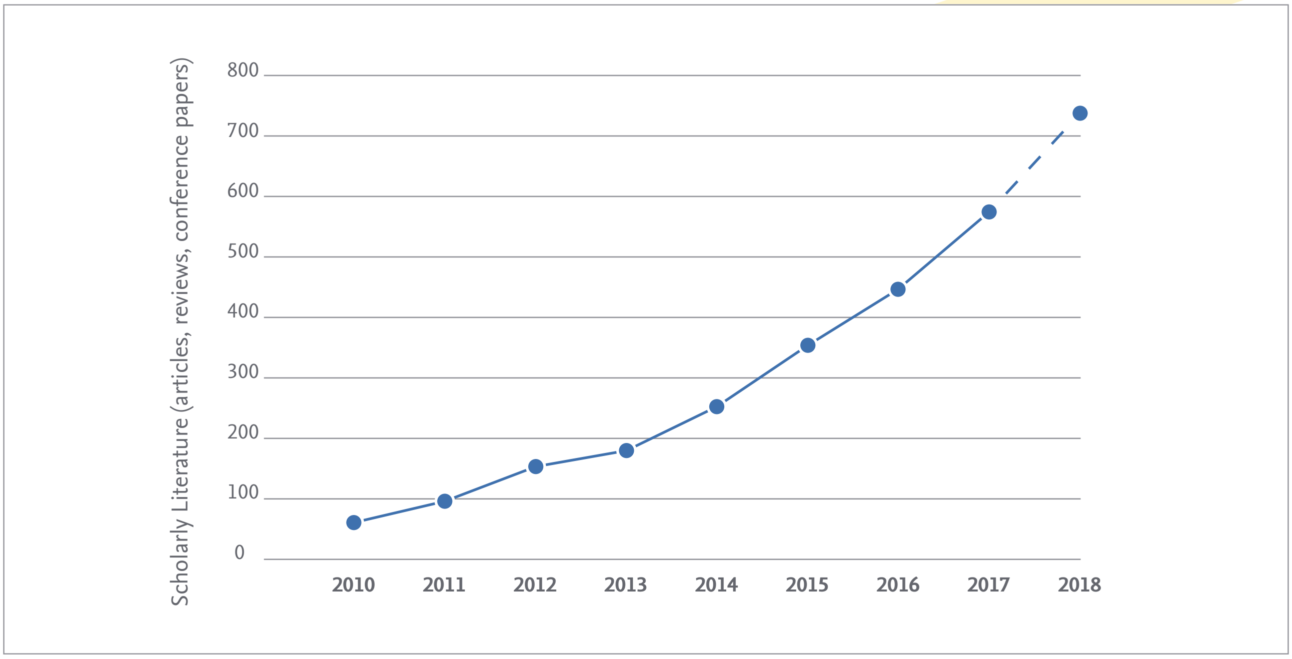


Figure 2.5: Growth in scholarly literature on citizen science. Quantity for 2018 has been forecast (see dashed line). Source: Keyword search in Scopus.

Live); nationwide educational events (Pint of Science); protests (March for Science, 2017); and large-scale social communities (Zooniverse). In 2015, the Citizen Science Association was launched following the Public Participation in Scientific Research conference; the event also resulted in the launch of the first journal devoted to citizen science. Since December 2012, PLOS has had a CitizenSci blog. There are also now sites available to assist citizen science projects, e.g. CitSci.org, crowdcrafting, Zooniverse, and iNaturalist.

What's next?

The research community is moving in the direction of openness and transparency, that much is clear. But, as we've seen in this essay, for open science to become the norm and fully sustainable, there are tensions and challenges that still need to be overcome. Some believe that the key to speeding up its adoption is pulling levers at all stages across the system to create a tipping point, and that researchers in the East will be the ones who escalate change (explored in more detail in "Regional shifts: the China effect" in the Funding the future essay).

"If China goes for open science then it could all happen very quickly as they would mandate it and it would actually happen. If China says no, it will impact progress."

Robert Kiley, Head of Open Research, Wellcome Trust, UK, interviewee

It's also clear that researchers need to be supported as they navigate the various options, policies and practices that surround open science. Funders, publishers and higher education institutions already play a critical role here and that will likely become more important in the decade ahead. In parallel, the right technology needs to be in place: in the case of dissemination, this involves easing – and preferably automating – the path for researchers to share big data, code, and articles; link their various research outputs; and ensure easy, ongoing discovery of all outputs.

Ultimately, many share the philosophy of Universities UK: "...progress in the transition to open science is best achieved by working collaboratively and in coordination with all stakeholder communities associated with scholarly communication, and to tackle challenges with a shared purpose."[55]

55 Universities UK website – Open science page. https://www.universitiesuk.ac.uk/policy-and-analysis/research-policy/open-science

How researchers work: change ahead

Setting the scene...

Over the past decades, there has been one unchanging constant in a researcher's life: the pressure to produce high-quality, validated research. While that is unlikely to diminish in the coming 10 years, how they conduct research and develop and maintain skill sets will transform. In particular, how they collaborate is likely to see dramatic change. All these moving parts will have implications for their research output – but just how will their work be affected? And with researchers under increasing pressure to demonstrate impact, what will "success" look like in the future? The answers to these questions will be determined by the factors explored in this essay.

What will be the key drivers and changes?

1. **New technologies are expected to transform the researcher workflow over the coming 10 years**
   - Mastering **data science skills** will become increasingly important. Much hypothesis development is expected to be **data-driven**, rather than ideas-led.
   - Researchers will require **tools** (e.g. databases) that satisfy their evolving needs and can be **customized** to meet their requirements.
   - Researchers will need to work **faster** and **smarter**, find new ways to increase article **discoverability**, and demonstrate **impact**, as the hyper-competitive nature of the research ecosystem increases.

2. **Behaviors and skill sets will change as a new generation of researchers arrives on the scene**
   - **Career progression** and securing a permanent position will remain a challenge, especially as older/late career researchers are expected to remain in position longer.
   - The number of **young researchers leaving academic research** is likely to accelerate as they seek job security/opportunities, notably among research-focused tech companies.
   - Generation Z (those born mid-1990s to early 2000s) will represent a substantial proportion of researchers 10 years from now and is likely to accept the need for **lifelong learning** to keep abreast of developments within, and across disciplines.

3. **Collaboration will drive research forward**
   - Ways of working are evolving and will continue to evolve; for example, collaborations with the public (citizen science) will grow in number and ambition. In response to funder demands, and supported by technology, **interdisciplinary projects will become the norm**, along with research across international boundaries and institutes.
   - Academic collaboration will likely be with select institutes from approved “partner” countries: **tensions between competing countries** and institutions will increase in what is shaping up to be a hyper-competitive future.

Seeking ways to thrive in a hyper-competitive environment

Researchers certainly don't have it easy. Whether they are vying for funding, competing for laboratory resources, balancing research activities with teaching, attempting to be the first to uncover new findings, or trying to get published, competition is fierce. Once an article has been accepted for publication, there's also the challenge of getting it seen and read.

Alongside these research activities, many are trying to determine, or secure the next step in their academic career, while others are simply seeking the security of a permanent position. The effect of these pressures can vary by field and career stage, but very few researchers escape unscathed.

The "publish or perish" phenomenon

Few would disagree that researchers are operating in a "publish or perish" environment and have been for many years. In order to secure funding and/or career progression, they must ensure their research articles are accepted by (preferably high impact) journals; a situation our expert interviewees expect to continue in the decade to come.

"The notion that a person needs to have lots and lots of 'objects' credited to them to get tenure is not going to change. It's going to continue to be what counts when making the judgment call, 'is this person ready to get tenure?'"

Sarah Pritchard, Dean of Libraries, Northwestern University, US, interviewee

What is "Publish or perish"?

It describes the pressure on researchers to publish research articles early in their career and then continue to publish high-impact papers at regular intervals. The perception is that failure to do so will negatively impact their career and research funding opportunities.

73 percent of the researchers we surveyed for this study feel that pressure to publish is likely, or very likely to increase in their field over the coming 10 years, mainly driven by funding organizations, research administrators and potential employers, respectively (see figure 3.1). If we break down those figures by age group, we can see that researchers aged under 36 years are more likely than average to feel pressure from line managers and potential employers.

Many believe that we will also see an increase in the number of publications per researcher in the years ahead, driven, in part, by the anticipated "atomization" of the article, with elements such as methodology, data, findings and discussion, all published separately. Just over half (53 percent) of the respondents to our researcher survey think they will be publishing more papers per project in the future. In contrast, 38 percent think this is desirable, perhaps due to the anticipated consequences (see figure 3.3).

More publications will mean an increased workload for researchers, who must not only prepare the extra papers and attempt to get them noticed, but keep up-to-date with the findings of their peers. This can be particularly challenging in fast-moving fields.

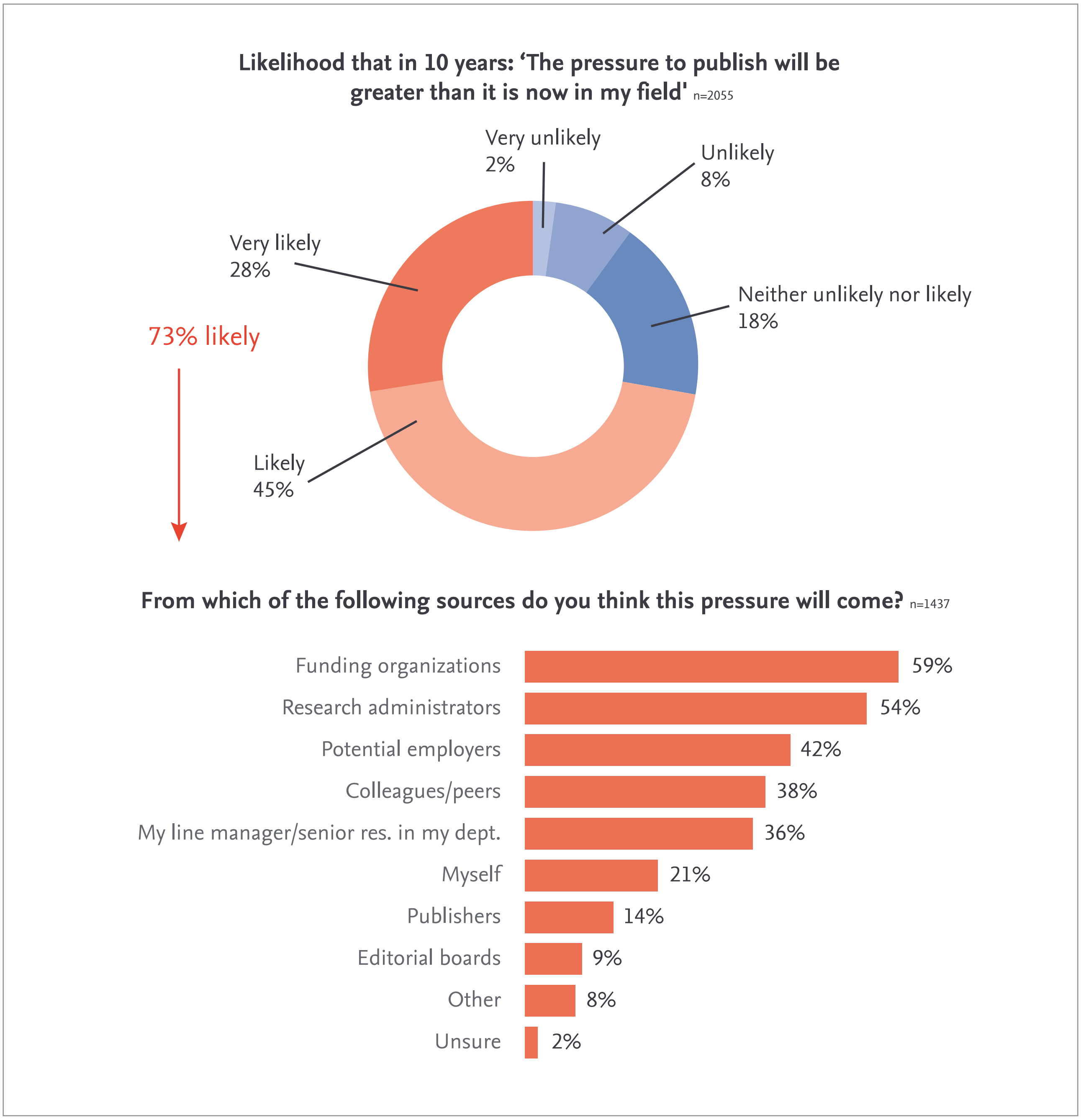


Figure 3.1: Researchers' views on whether the "pressure to publish" is likely to increase. Source: Researcher survey for this study.

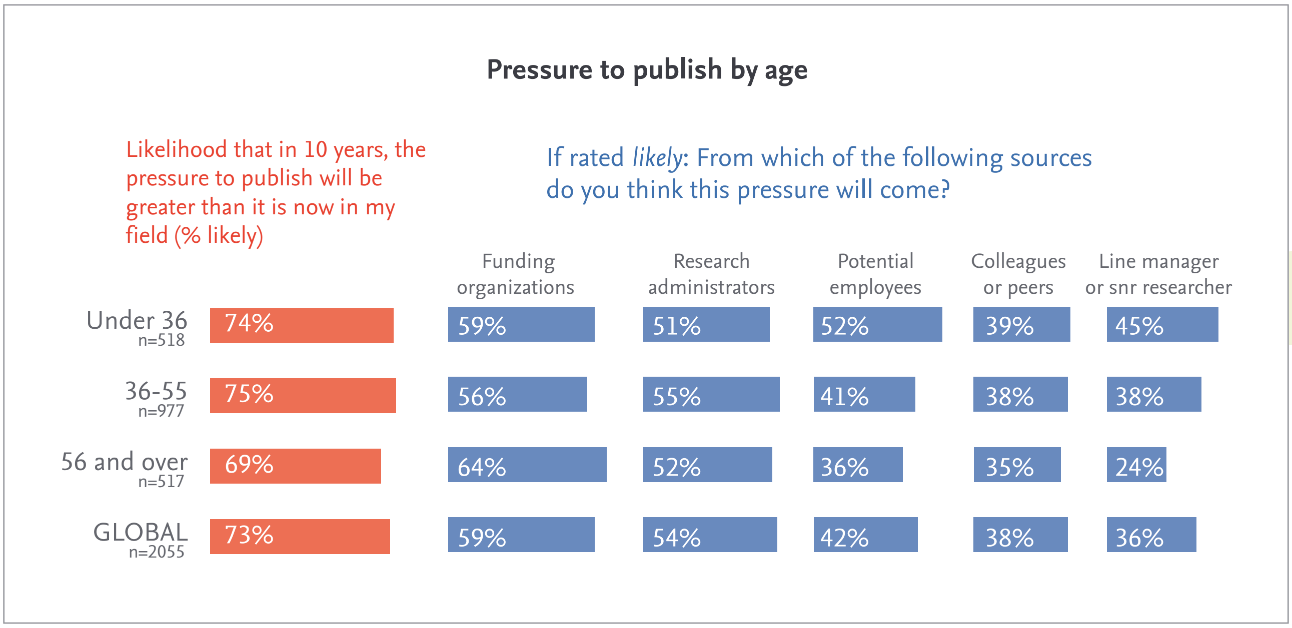


Figure 3.2: Researchers' views on whether the "pressure to publish" is likely to increase (broken down by age-group). Source: Researcher survey for this study.

> *"In my field of interest, neuroscience and AI [artificial intelligence] are hot topics and the time between successive breakthroughs is so short we can't filter the sheer volume of papers coming out."*
>
> **Postdoc in computational science, UK, interviewee**

The search for job security

The hunt for a role – particularly a permanent one – is already proving challenging for many recent graduates and there are signs this pressure will continue to rise in the years ahead. In academic research, this is driven by a range of factors.

Economic pressures play a major role. Universities and institutions award permanent positions to established researchers with experience, strong networks, high-impact research projects and leadership skills, as these are what help them to secure funding. But, as the pressure on funding increases, especially government funding, competition grows stronger, making research positions harder to come by. With this unlikely to change in the coming decade, new researchers can "expect to enter a field where the procurement of funding will continue to be a key factor for career evaluation and promotion".[1]

This comes at a time when the number of university enrolments – and therefore graduates – is increasing. In addition, there is steady growth in the number of full-time researchers globally, particularly in China. We explore the impact of these factors in the essay Funding the future.

As a result, "...too many people are chasing too little money to support increasingly expensive research", creating a "hypercompetitive environment".[2] While healthy competition for resources, positions and funding is considered positive, some believe that this move toward a state of hyper-competition "suppresses the creativity, cooperation, risk-taking, and original thinking required to make fundamental discoveries".[3]

1 Eastlack, S. How scare funding shapes young scientists. Phys Org. March 2017. https://phys.org/news/2017-03-scarce-funding-young-scientists.html

2 Alberts, B. et al. Opinion: Addressing systemic problems in the biomedical research enterprise. PNAS. 17 February 2015. 112(7), 1912-1913. doi:10.1073/pnas.1500969112. https://www.pnas.org/content/112/7/1912

3 Alberts, B. et al. Rescuing US biomedical research from its systemic flaws. PNAS. 22 April 2014. 111(16), 5773-5777. doi:10.1073/pnas.1404402111

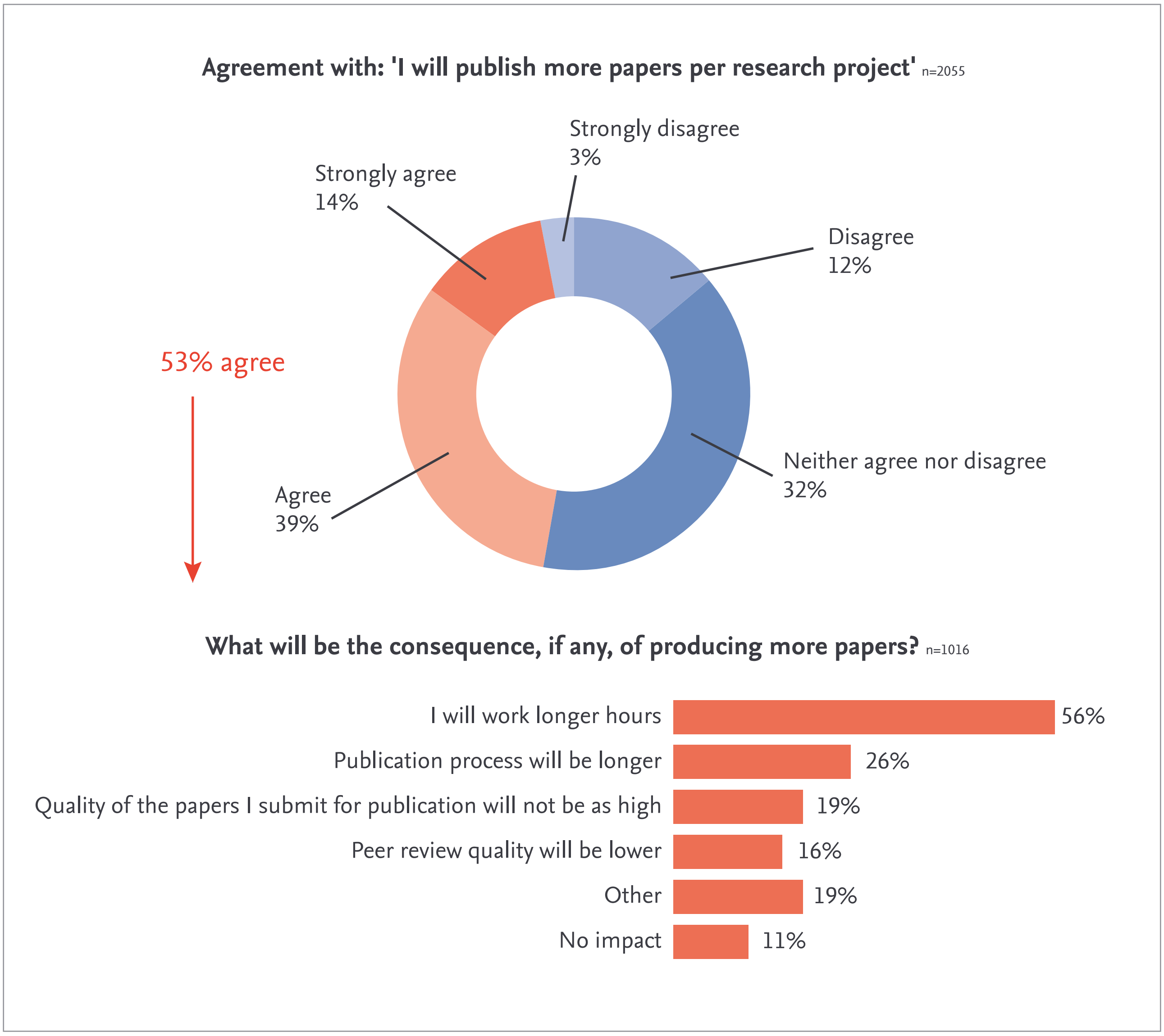


Figure 3.3: Researchers' views on whether they will publish more papers a decade from now. Source: Researcher survey for this study.

"I have many investigators in my institute who are fabulous, and they're doing brilliant transformative work, and they're nervous about getting their next grant, or getting scooped. That's an evil consequence of the increasing competitiveness internationally."

Funder, Canada, interviewee

As we discuss in the essay The academy and beyond, there are also real concerns that existing university courses aren't meeting the needs of today's job market, increasing the pressure on graduates seeking work.

Global improvements to health care also have a role to play. They have delivered a population that is living and working longer than ever before – as a result, senior researchers are remaining longer in their posts.

"Old researchers are holding on to their reins far past their sell by dates because they're too afraid to let go… Currently, there is only sporadic adoption of technology but increasing its uptake is not the challenge; it's creating stable jobs for younger researchers."

Kent Anderson, CEO of Redlink & Redlink Network, US, interviewee

This trend may not only inhibit the ability of younger researchers to secure roles; some of our interviewees believe it could impact the future direction of research.

"Ageing faculty have a negative impact on ability to conduct research. They're slower to adapt to change."

Fabio Figueiras, postdoc researcher, CICECO, Universidad de Aveiro, Portugal, interviewee

As technology becomes more sophisticated, more repetitive tasks are likely to become automated, including aspects of laboratory experiments. But while technology has the potential to reduce the burden on researchers, it will likely prove a double-edged sword: in a study published in 2016,[4] Carl Benedikt Frey and Michael Osborne found that 47 percent of workers in America were in roles likely to be impacted by automation. Although individuals that work in more creative fields are less likely to be affected, the rise of artificial intelligence could result in a further reduction in researcher jobs – and even greater competition for those that remain (see Technology: revolution or evolution essay).

"Our unique value in a world where computers are smarter is that we're best at interacting with other humans. I believe, and maybe this is just hope, that when computing systems take over the cognitive workload, we will discover something new to do. I'm sure there will be something!"

Technology expert, US, interviewee

As a result of these challenges, "…future researchers will need to be more resourceful and imaginative than their predecessors".[1] However, many believe that the lack of job and funding security is prompting younger researchers to leave research earlier than they would normally do. In many cases, they are moving to the private sector, and once that move is made, they are unlikely to return.

This particular tension between academia and industry is unwanted, but expected to continue over the coming decade. Companies like Google and Apple are hiring researchers, particularly experts in artificial intelligence (AI), and that gives academia two big headaches: who will teach the next generation and how will the findings of research conducted by a private company be shared to enhance the knowledge of all researchers, or even society?[5]

At the same time, many academic institutes want closer relationships with industry and have forged fruitful collaborations that aim to address key health and social issues and develop technologies and products. We take a closer look at these partnerships in our Funding the future and The academy and beyond essays.

The effect of this hyper-competitive job environment on the researcher varies, depending on their career stage. Many researchers, including both early and mid career researchers, can expect to spend years working on temporary contracts, often in a variety of institutions in different countries. This can prove a vicious circle – researchers on short-term contracts often struggle to demonstrate the requisite levels of credentials that would help them secure a permanent role.

Add all these elements into the mix, and it's clear that researchers are under pressure to work faster and smarter and be more resourceful and enterprising than their predecessors. That tension is only expected to increase as the decade progresses.

1 Eastlack, S. How scare funding shapes young scientists. Phys Org. March 2017. https://phys.org/news/2017-03-scarce-funding-young-scientists.html

4 Frey, C. B. & Osborne, M. A. The future of employment: How susceptible are jobs to computerisation? Technological Forecasting and Social Change. January 2017. https://doi.org/10.1016/j.techfore.2016.08.019

5 Ian Sample. 'We can't compete': why universities are losing their best AI scientists. The Guardian. 1 November 2017. https://www.theguardian.com/science/2017/nov/01/cant-compete-universities-losing-best-ai-scientists

Technology to the rescue?

The advances taking place in technology are currently proving to be a researcher's closest ally in their quest to get ahead in the increasingly competitive landscape (see the Technology: revolution or evolution essay).

Already, early career researchers in particular rely on social media for communication, discovery and sharing information[6] and Google is part of their everyday life.

In 2017, Allan Thygesen, President Americas at Google, claimed that we're living in the Age of Assistance: research undertaken by Google found that people expect relevant information – quickly. They want brands to know more about them and to use that knowledge to provide a better experience.[7]

In its 2018 Information Industry Outlook report,[6] Outsell noted that what consumers (including researchers) really want at work is the same ease of use, flexibility, speed, and adaptability they expect at home. Outsell identified key themes critical for successful product development, which can be summarized as follows:

- Content delivery should be integrated with workflow.
- Developers should observe user behavior (not just ask about it).
- Discovery should be quick, easy, timely – and serendipitous.
- User statistics should be aggregated, and individual needs identified so offerings can personalized.

So, it's not only researchers who need to work smarter – their tools should too. Some see integration of existing processes as the key.

"Electronic notebooks should help search scientific literature, websites and patents, organize protocols, manage data, and publish results while also improving the options for communication and project preparation: researchers need a one-stop-shop, seamless solution."

Odile Hologne, Delegate for Scientific Information, INRA, France, interviewee

"If we could have a tool like Overleaf on a preprint server, then we would start to get a joined-up workflow solution: results could be instantly published online, even at their drafted stage, and quality control could be done more collaboratively with broader stakeholders. ... This would improve the speed of publication and change the process of publication (or quality control) itself eventually."

Kazuhiro Hayashi, Senior Research Fellow, Science and Technology Foresight Center, NISTEP, Japan, interviewee

While 76 percent of the researchers we interviewed for this study want integrated end-to-end research workflow tools 10 years from now, a smaller number – 61 percent – believe they will actually be available and used by most researchers in their field. For some, the key to improving those statistics lies with giving researchers a louder voice.

"If we want the situation to change, we need to put researchers closer to the technology companies and developers. Right now, there is too much noise because of intermediaries."

Josh Nicholson, co-founder and CEO, scite.ai, US, interviewee

New tools have already been introduced to simplify the writing process for academic authors. Writing services such as Authorea, Overleaf and F1000Workspace are growing in number and capability, with developments particularly focused on enabling research teams to write collaboratively. These are supported by other workflow solutions including Mendeley, ReadCube and EndNote, which offer reference manager functionality and more. And there are web and PDF annotation services, which can often be used in conjunction with other tools.

While these services are multilingual, English is still considered the language of science, despite the fact that it's not the first language of many researchers. Software is being developed to meet the translation needs and expectations of academia and beyond. Logbar, a Japanese company, has created a widget that translates

6 Healy, L.W. Information Industry Outlook 2018. Outsell. 4 October 2017. https://www.outsellinc.com/product/the-outsell-information-industry-outlook-2018/

7 Solis, B. WTF: What's the Future of Marketing in the Age of Assistance. Forbes. 11 October 2017. https://www.forbes.com/sites/briansolis/2017/10/11/wtf-whats-the-future-of-marketing-in-the-age-of-assistance/#60f4cf974de6

English into Japanese and Chinese,[8] while, in November 2016, Google launched the Google Neural Machine Translation, designed to improve fluency and accuracy in Google Translate.[9]

The development of tools supporting authors in the promotion of their work has also been gathering pace as academics seek ways to get credit for their research.

"The majority of scholarly output will never be found or used because there is too much and the methods to bring it to the user are not good enough."

Oscar Jarabo, co-founder, Innotholic, Spain/Netherlands, interviewee

With the ever growing volume of scholarly literature and no end to the publish or perish phenomenon in sight, these tools will be crucial. In fact, information overload is a problem that companies both inside and outside academia have long been seeking to resolve.

"It's a major trend for the tech companies – that's the grail we are all after. Not just the ubiquity of information, but of access. Currently, we have all these different ways of getting at it, it's overwhelming."

Technology expert, US, interviewee

Many companies have turned to machine learning to get a deeper understanding of their customers' needs so they can provide them with tailored, customized products or content (whether that content is proprietary or not). In the case of information providers, this includes pointing researchers toward new, or perhaps even lesser-known findings that best match their research interests. As machine learning, particularly deep learning, continues to develop, these tools will become increasingly sophisticated, for example, they could tailor the language to suit the scientific knowledge of the viewer (see Technology: revolution or evolution essay). The challenge that remains is ensuring a level of serendipitous discovery, as this has proved a critical element of scientific progress to date.[10]

Easy and immediate access to research has become a key commodity for researchers and they want that access to be at their fingertips. Even though many can read and download article and book content via their institutions, we have seen the emergence of "access brokers"; services and tools such as Kopernio, launched in 2018, and Unpaywall, offer browser extensions that give researchers access to legal, full-text copies of scholarly papers. The focus on simplifying access is a trend likely to continue, fuelled by developments in open science (see Pathways to open science essay).

Researchers' evolving needs bring challenges and opportunities for companies previously focused primarily on publishing. If publishers are able – and willing – to adopt drastic changes to their business model, they can play a key role in providing the new tools required. Already, some are expanding their solutions for the researcher (and institution and funder) workflow, moving beyond simply supporting "read" and "search" requirements to increasingly focus on "do". For example, Elsevier has a growing number of products like Mendeley and SSRN that provide customized services; Springer Nature founded Digital Science (a separate company, but with a shared co-parent), which focuses on developing researcher solutions; and Wiley is developing a range of journal and expert finder tools. We are also seeing the emergence of a growing number of start-ups in this space (see the Building the future research information system essay). Over the next few years, we can expect to see these trends continue.

"There is a lot of self-definition work going on within the publishing community and it's happening in parallel with the evolution we see in libraries. We share an aspirational vision to move beyond being providers of books and journals, to become sources for information solutions more generally."

Keith Cogdill, Library Director, NIH Library, US, interviewee

8 Siciliano, L. This device instantly translates Japanese and Chinese. Business Insider UK. 13 February 2017. http://uk.businessinsider.com/japanese-company-instant-translation-device-travellers-ili-words-languages-chinese-english-2017-2?r=US&IR=T

9 Wu, Y. et al. Google's Neural Machine Translation System: Bridging the Gap between Human and Machine Translation. Research at Google. 2016. https://research.google.com/pubs/pub45610.html

10 The story of serendipity. Understanding Science. https://undsci.berkeley.edu/article/serendipity

Technology meets metrics: moving beyond journal measures

As we explored in "The "publish or perish" phenomenon" in this essay, researchers must publish on a regular basis; preferably in high-impact and prestigious journals. At this moment in time, many of the most prestigious journals operate a subscription business model (although often with a green – self-archiving – option or with a gold open access (OA) option). This is unlikely to change while the costs of running a high-calibre journal remain so high – Alan Leshner, Executive Publisher of *Science*, has shared that its publishing costs are $50 million a year. Generally, fully gold OA titles have yet to receive the high Journal Impact Factors of their subscription stablemates, although many publish high-impact research.

"There's still a journal hierarchy and prestige of the journal remains important. It's being challenged by funding sources and open access, but in reality, if you have a really ground-breaking piece of research, you'll still look for the prestigious journal stamp of approval."
Saul Tendler, Acting Vice-Chancellor, York University, UK, interviewee

This has created a "Catch-22" situation for researchers caught in the publish or perish spiral. Funders are pushing for more open access publishing and open science (see Pathways to open science essay). But those same funders tend to consider the publishing history of an applicant, and the impact of the journals they've published in, when deciding whether to award a grant. Moreover, institutions are using those same measures to make career progression decisions about their researchers.

It is generally agreed that in an ecosystem of ever-increasing volumes of research and rising levels of accountability, research metrics do have an important role to play and that view is unlikely to change. Where opinions differ, however, is whether those measures could – and should – be adapted to change the incentive system.

For many years, the Journal Impact Factor has reigned supreme among journal metrics. This has been particularly true in China, where career advancement often relies on publishing papers in journals with Journal Impact Factors, and researchers receive cash rewards based on the level of that Journal Impact Factor.[11, 12]

But, some years ago, the tide, started to turn against metrics being used in this way, particularly the Journal Impact Factor. By 2015, misuse of the metric meant some considered that it was "no longer credible".[13] In 2013, the San Francisco Declaration on Research Assessment (DORA) was released with 6,000 individual signatories – at the time of writing this report, the number of signatories exceeded 13,500. In 2015, the report, *The Metric Tide* was published by the Higher Education Funding Council for England (HEFCE). Both the declaration and the report recommended a reduced emphasis on Journal Impact Factors as a promotional tool. The HEFCE report advocated the use of a "variety of journal-based metrics that provide a richer view of performance";[14] a view supported by many bibliometricians.

Alternative approaches have been put forward,[15] among them the Relative Citation Ratio, launched in the US by the National Institutes of Health (NIH) in 2016. In the same year, Elsevier launched CiteScore metrics and, in 2017, R-factors were proposed – a metric to highlight the successful reproducibility of a study.[16] To help researchers understand and navigate these scattered resources and metrics, we've seen the launch of tools such as the Metrics Toolkit.

But, at the same time, developments in technology are powering new, alternative metrics that broaden the way

11 Don't pay prizes for published science. Nature. July 2017. 547, 137. doi:10.1038/547137a

12 Emerging Technology. The Truth about China's Cash-for-Publication Policy. MIT Technology Review. 12 July 2017. https://www.technologyreview.com/s/608266/the-truth-about-chinas-cash-for-publication-policy/

13 Journal impact factors 'no longer credible'. Times Higher Education. 2015. https://www.timeshighereducation.com/news/journal-impact-factors-no-longer-credible

14 The Metric Tide. Higher Education Funding Council for England. 2015. http://www.hefce.ac.uk/media/HEFCE,2014/Content/Pubs/Independentresearch/2015/The,Metric,Tide/2015_metric_tide.pdf

15 Lariviere, V. et al. A simple proposal for the publication of journal citation distributions. bioRxiv. 11 September 2016. doi:10.1101/062109

16 Grabitz, P. et al. Science with no fiction: measuring the veracity of scientific reports by citation analysis. bioRxiv. 9 August 2017. doi:10.1101/172940

research activities can be measured. These include tools such as Plum Analytics and Altmetrics.com, which map the attention that an article receives; not only counts of citations, but activity on social media, news outlets, blogs, and reference manager sites. They also consider usage and clinical and policy citations.

These metrics have experienced a sharp rise in usage in recent years and, while some have welcomed them as an additional way to understand attention, others continue to seek a metric that can not only measure attention, but the sentiment behind it. Development work is ongoing.

The majority of the researchers we surveyed believe that citations will remain the key indicator of success in the decade ahead, as seen in figure 3.4; most likely due to the "publish or perish" pressure they experience. Alternative metrics as a measure of a researcher's value were less valued by this group, but with growing calls from funders to demonstrate wider impact on society, we could see that change. It is likely there will be an uncertain transition period in the coming years with researchers, keen to satisfy the various metrics' requirements, remaining unsure of the best way to get funding, structure their research articles, or even which publication channel to choose.

"Metrics and performance are difficult. Most people are not satisfied with the current status, but it is not obvious what the alternative solutions are; wider, societal impact is becoming more important and scientists themselves must become better at communicating their own value and contribution."

Researcher, Asia Pacific, interviewee

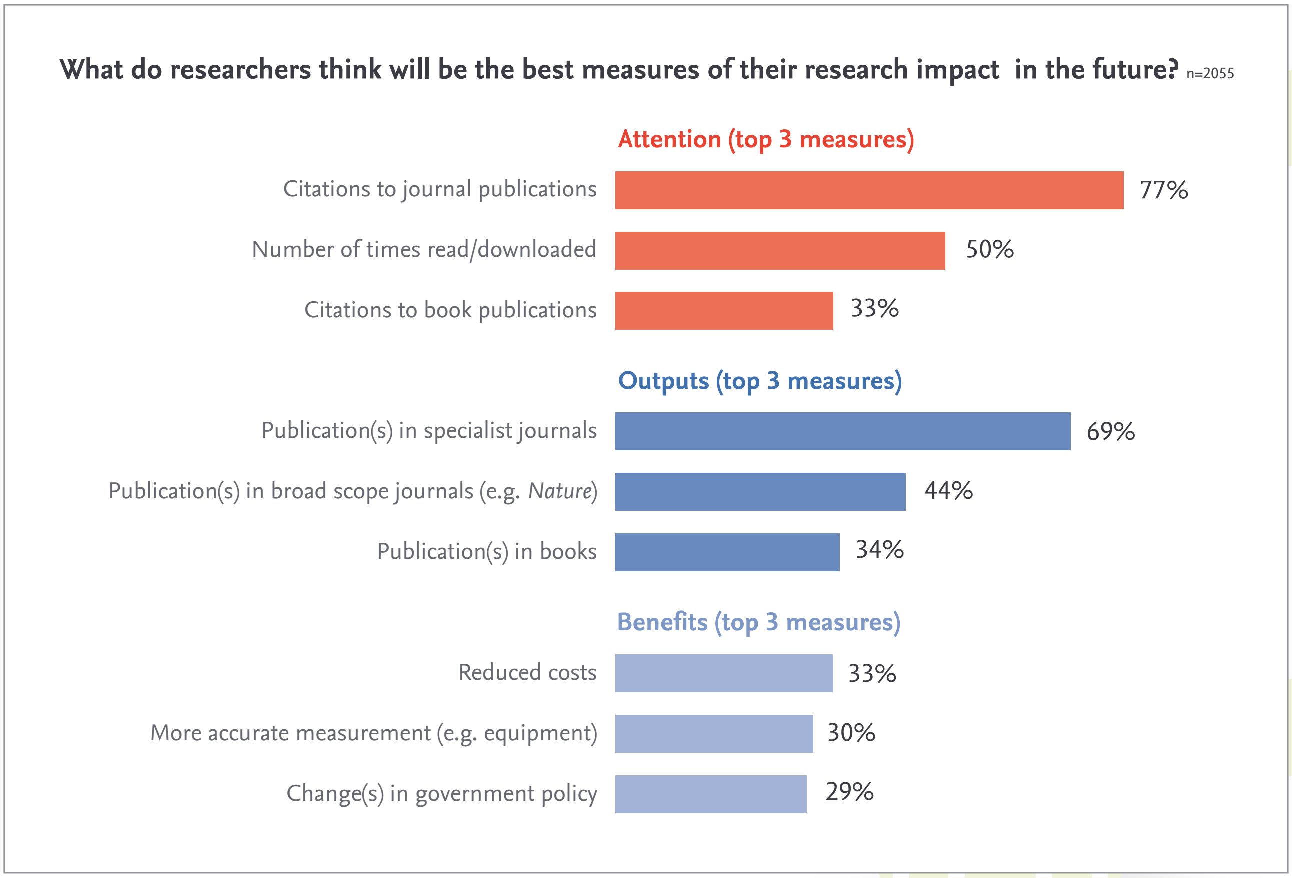


Figure 3.4: Researchers' views on how impact will be measured a decade from now. Source: Researcher survey for this study.

"The future will contain a broader number of metrics, but development will be slower than many people believe. Activism concerning new metrics is coming from others. Reputation structures of the past have the money and they don't want the metrics to be changed. And new metrics don't remove interest in the past ones."
Joseph Esposito, Senior Partner, Clarke & Esposito, US, interviewee

When it comes to peer review, initiatives such as Publons and Elsevier's Reviewer Recognition Platform allow researchers to demonstrate their reviewer contributions with indicators around the quantity and quality of peer review performed. However, there has been no widespread agreement on reviewer metrics, despite a strong community desire to recognize researchers' efforts in this area.

Not surprisingly, companies, and even researchers themselves, have responded to the pressing need for researchers to showcase their work with a range of support tools that use a variety of metrics. Scholarly collaboration networks (SCNs) such as ResearchGate, Mendeley, SSRN and Academia.edu, are playing a key role in boosting the visibility of research articles (see Building the future research information system essay). SCNs are based on collaboration and content sharing, and usage on these platforms is driving metrics that researchers can use to demonstrate impact.

Collaborating in a cyber world

Collaborative research is on the rise. Projects now span multiple locations and time zones and we are seeing ever-growing links between academia and industry.

"Much research is already conducted over the internet and country is irrelevant."
Computer science / IT researcher, US, aged over 65, respondent to researcher survey

We are also seeing a rise in citizen science, i.e., collaborations between academia and society – we explore this phenomenon in our Pathways to open science essay.

In fact, there is broad agreement that collaboration could prove the future of research.[17] Its growth is fuelled, in part, by new technology which powers tools from web annotation services to collaborative writing tools, but that isn't the only reason for its rising popularity. Some believe it improves the diversity of the researcher population. It also helps in terms of outreach and inclusion of the public,[18] an important consideration for researchers under pressure to make science more accessible and prove its societal impact. Others point out that it can help attract funding and has support at policy level (see "Collaboration – a cure for all ills?" in the Funding the future essay).

Thanks to the move toward open science, it's now easier to share data than ever before. And, from a researcher-perspective, studies have shown collaboration can boost the impact of the research produced – crucial in the hyper-competitive environment they find themselves operating in. Though the reasons behind this trend are difficult to identify, it has been put forward that diverse research teams may benefit from a wider set of perspectives than a less diverse team or the wider network around that set of collaborating authors might mean that the article is seen by more people: so the higher impact may be driven by the improved quality of the work, the increased number of people who see it – or both.[19]

Mega-science is also driving collaboration: projects like the Square Kilometre Array (SKA), the Large Hadron Collider (LHC), the International Thermonuclear Experimental Reactor (ITER), Galileo, European Union's Global Satellite Navigation System, and the Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME) are vast, both in terms of cost and the numbers of countries involved.

17 Discover the Top Ten Trends Driving Science. ACS Axial. ACS Publications. January 2017. http://connect.acspubs.org/toptentrends

18 Nelissen, E. The future of science lies in collaboration – and other findings from ESOF 2016. Elsevier Connect. 18 August 2016. https://www.elsevier.com/connect/the-future-of-science-lies-in-collaboration-and-other-findings-from-esof-2016

19 Freeman, R. B., & Huang, W. Collaboration: Strength in diversity. Nature. 16 September 2014. 513, 305. doi:10.1038/513305a

In our researcher survey, 84 percent of respondents say they want to see more projects conducted across international boundaries 10 years from now. A slightly higher proportion, 86 percent, expect to conduct research projects with colleagues in other countries, although only 64 percent expect the majority of projects in their field to be international in the future.

"Knowledge is global and expertise is scattered throughout the globe. Hence there will be more international collaborations, especially on impactful projects."

Researcher in agriculture, Malaysia, aged 56-65, respondent to researcher survey

But if science plans to continue embracing collaboration, it needs to adapt in the decade ahead. For many of the large-scale projects, agreements and mechanisms are needed. And, in the case of academia-industry collaboration, there are concerns around intellectual property. We look at these elements in more detail in our Funding the future essay, while in Technology: revolution or evolution, we consider the potential of developments like blockchain to offer support. At the individual level, there are also some unresolved issues around credit that could deter researchers – at least in the short term.

"When you have 30 authors of a paper, what is the value for one of the authors? Is it a publication divided by 30, is it a publication divided by the square root of 30? I mean, is it just the same as a publication published by a person who publishes alone?"

Rolf Tarrach, President of the European University Association, Belgium, interviewee

While recommendations on how to handle credit for authorship are discipline-, and sometimes journal- or society-specific, there are moves afoot to overcome this issue at a broader level, for example, the CRediT Taxonomy,[20] which proposes a simplified list of contributor roles.

Crossing the discipline borders...

Another key factor in the growth of collaboration is the rise in interdisciplinary and multidisciplinary research. Many believe it could be our best option for solving some of society's key challenges.

"It is increasingly an essential ingredient for success. Some fields are just too complex/ expansive to tackle without both broad and deep collaboration."

Researcher, Asia Pacific, interviewee

Since the mid-1980s, research papers have increasingly cited work outside their own disciplines. A 2015 *Nature* paper noted: "The fraction of papers that mention interdisciplinarity in their title has fluctuated, perhaps reflecting the priorities of funders, but the twenty-first century saw that proportion reach an all-time high."[22]

Interdisciplinary... multidisciplinary... what do these terms mean?

In her article "Advancing the social sciences through the interdisciplinary enterprise",[21] Marilyn Stember gives the following definitions:

- **Transdisciplinary:** creating a unity of intellectual frameworks beyond the disciplinary perspectives.
- **Interdisciplinary:** integrating knowledge and methods from different disciplines, using a real synthesis of approaches.
- **Multidisciplinary:** people from different disciplines working together, each drawing on their disciplinary knowledge to solve a problem or issue.
- **Crossdisciplinary:** viewing one discipline from the perspective of another.
- **Intradisciplinary:** working within a single discipline.

20 CRediT. CASRAI. https://casrai.org/credit/

21 Stember, M. Advancing the social sciences through the interdisciplinary enterprise. The Social Science Journal. 1991. https://doi.org/10.1016/0362-3319(91)90040-B

22 Van Noorden, R. Interdisciplinary research by the numbers. Nature. 16 September 2015. 525, 306-307. doi:10.1038/525306a

One of the signs that the interdisciplinary trend is on the rise is the increase in the number of co-authors on papers.[17] The same *Nature* paper suggested that one of the driving factors could be funder priorities – an increasing number require evidence that researchers are adopting an interdisciplinary approach in their work.

"Very few people call themselves a geneticist, a biochemist, or a cell biologist anymore. Many of the great advances are at the interface between science disciplines. And team science is becoming much more predominate than it has been historically."
Funder, Canada, interviewee

A 2015 study looked at the relationship between interdisciplinary research (IDR) and citation impact – the results show it's not easy to define. "Very low or very high degrees of IDR are found to decrease citation impact, whereas some middle degree of IDR, which we characterised as proximal interdisciplinarity, tends to have higher citation impact. More research is needed to further develop robust characterisations of this middle degree of IDR and compare their predictive capacity."[23]

IDR has also been found to have an interesting effect on researchers: "Scholars with greater involvement with IDR are indeed prominent (as indicated by citations), but also less productive."[24] This is perhaps due to the difficulties interdisciplinary research faces in navigating the current peer review and publishing system. And yet it has also been suggested that IDR is beneficial, forming a foundation for new ideas and receiving higher visibility. In a 2017 essay,[24] Erin Leahey noted that:

- "It is more difficult to produce and successfully publish scholarship that spans unrelated fields… than related fields… Spanning unrelated fields improves citations, but spanning related fields does too (if only slightly), presumably by broadening one's prospective audience."
- "A comparison of working papers obtained from arXiv [a preprint server] reveals that eventually published working papers are actually more interdisciplinary than working papers that remain unpublished. IDR papers do not appear to be hindered in the review process."
- IDR "stifle[s] productivity because the process of producing interdisciplinary scholarship—learning new concepts, literatures, and techniques, working with a diverse group of collaborators—is challenging".
- Yet: "Scholars who engage in 'repeat collaborations' with the same set (or subset) of authors experience a smaller productivity penalty than we see overall."

Again, the rise in interdisciplinary research is closely linked to developments in technology. Social media and other networking tools allow researchers to be in contact with an array of scientists in their field and beyond, exposing them to "new perspectives and ideas, and providing them with practical experience of cross-disciplinary communication".[25]

Some support the school of thought that in the future, "the notion of discrete fields of study will become obsolete… As our understanding becomes ever more sophisticated, phenomena must be examined holistically, in context, from sub-atomic to macro levels of organization".[26]

The impact of inclusivity

The future researcher population is likely to look very different to the one we know today.

Gender equality is one of the United Nation's Sustainability and Development Goals.[27] As the World Economic Form

17 Discover the Top Ten Trends Driving Science. ACS Axial. ACS Publications. January 2017. http://connect.acspubs.org/toptentrends

23 Yegros-Yegros, A., Rafols, I., & D'Este, P. Does Interdisciplinary Research Lead to Higher Citation Impact? The Different Effect of Proximal and Distal Interdisciplinarity. PLOS ONE. 12 August 2015. doi:10.1371/journal.pone.0135095

24 Leahey, E. Interdisciplinary research may lead to increased visibility but also depresses scholarly productivity. LSE Impact Blog. 19 January 2017. http://blogs.lse.ac.uk/impactofsocialsciences/2017/01/19/interdisciplinary-research-may-lead-to-increased-visibility-but-also-depresses-scholarly-productivity/

25 Brindle, H. et al. Preparing for an interdisciplinary future: A perspective from early-career researchers. Futures. September 2013. 53, 22-32. doi:10.1016/j.futures.2013.09.003

26 Batelle Insider. The Future of Research. Batelle. 16 October 2017. https://inside.battelle.org/blog-details/the-future-of-research

27 Sustainable Development Goals. United Nations. https://sustainabledevelopment.un.org/?menu=1300

states, “achieving gender equality isn’t just a moral issue – it makes economic sense… the proper participation of half the world’s population is so important for the well-being of both businesses and countries”.[28]

Work is already underway to combat gender imbalance in universities. In the UK, the Equality Challenge Unit launched the Athena SWAN charter in 2005, to encourage and recognize commitment to advancing the careers of women in higher education and research. But, globally, there is much still to be done, also in the countries experiencing the fastest population growth, which have the potential to become the research powerhouses of the future. For example, to date, India “has no comprehensive national programme for encouraging institutions to undertake active gender-equality measures”.[29]

As reported in a Fast Company’s future of work report, by 2020, 40 percent of the total population and 50 percent of the population aged under 18 will be in racial minorities.[30] Researcher jobs of the future will be filled by an increasingly multiracial population.

These factors, along with the rise in interdisciplinary and multidisciplinary research and the increase in international projects, could see science benefiting from a greater diversity of opinions and views; this is likely to not only impact how research is conducted, but also the quality and focus of that research.

The rise of the data scientist

For researchers, mastering data science skills will be a key requirement to help them manage the rising volume of data generated by developments such as the Internet of Things (see Technology: revolution or evolution essay).

“Large data sets are commonly accrued in my field of research but our expertise in the application of modelling techniques (in particular) is still lagging behind expectations. This is partly due to the nature of our education.”

Researcher in earth and planetary sciences, Germany, aged over 65, respondent to researcher survey

They will be called upon to learn programming – or will simply be better informed of the benefits of programming.[31, 32, 33] Some fields are already proving adept at jumping onto this moving train. For example, in medicine, doctors are “taking a more active role in identifying clinical problems and developing workable solutions through programming”.[34]

In the US, programming jobs are experiencing the most growth – 50 percent faster than the market overall – and scientists and engineers are among the five major job categories identified as needing coding skills.[35]

Those data skills won’t just be required to manipulate data during the research phase, but will even determine what that research should be. It is likely that hypothesis development will increasingly rely on hard evidence, not ideas.

28 Breene, K. Will the future be gender equal? World Economic Forum. 18 January 2016. https://www.weforum.org/agenda/2016/01/will-the-future-be-gender-equal/

29 Ovseiko, P.V., Godbole, R.M., & Latimer, J. Gender equality: Boost prospects for women scientists. Nature. February 2017. 542, 31. doi:10.1038/542031b

30 Lorenzo, G. How The Generation Born Today Will Shape The Future Of Work. Fast Company. 15 January 2016. https://www.fastcompany.com/3055407/how-the-generation-born-today-will-shape-the-future-of-work

31 Guo, P. Why Scientists and Engineers Must Learn Programming. Communications of the ACM. 18 July 2013. https://cacm.acm.org/blogs/blog-cacm/166115-why-scientists-and-engineers-must-learn-programming/fulltext

32 Dreyfuss, E. Want to make it as a biologist? Better learn to code. Wired. 3 October 2017. https://www.wired.com/2017/03/biologists-teaching-code-survive/

33 Baker, M. Scientific computing: Code alert. Nature. 25 January 2017. 541, 563-565. doi:10.1038/nj7638-563a

34 Bargiela D. & Verkerk, M. M. The clinician-programmer: designing the future of medical practice. BMJ. 25 July 2013. 347:f4563. https://doi.org/10.1136/bmj.f4563

35 Beyond Point and Click: The Expanding Demand for Coding Skills. Burning Glass. 2016. https://www.burning-glass.com/research-project/coding-skills/

Is learning to code really so important?

Some believe coding may become redundant in the future. According to Richard Kalvar, a tech columnist for *Newsweek*: "We're approaching an interesting transition: Computers are about to get more brainlike and will understand us on our terms, not theirs. The very nature of programming will shift toward something closer to instructing a new hire how to do his or her job, not scratching out lines of C++ or Java."[40]

There are already efforts to make this a reality. DARPA has created the Mining and Understanding Software Enclaves (MUSE) program which aims to "make significant advances in the way software is built, debugged, verified, maintained and understood".[41] However, the day that a computer can fully understand plain English, for example, is still understood to be a long way off.[42]

"In the future, the question is not 'where can I find my data, here's my question' but 'here's my data, what is my question?' In an Internet of Everything world, I will have data on mostly everything which means I can correlate anything to anything. In such a scenario, the critical thinking is in knowing what I want to know, and why, and if it does make sense."

Jean-Claude Burgelman, Open Science Unit Head, European Commission, Belgium, interviewee

For some of the researchers that are well established in their roles, this shift could prove daunting.

"I am too late in my career to learn new advanced data modelling techniques."

Academic working in business, management and accounting, Canada, aged 46-55, respondent to researcher survey

But it's a challenge that future generations are likely to feel happier embracing. Governments have recognized the need to equip pupils with data skills from an early age. In the US, elementary students are taking up programming courses. In the UK, ICT (information and communications technology) classes were replaced in 2014 by a new computing curriculum, which includes coding lessons for children as young as five.[36]

We are also seeing private companies stepping in to arm future workers with the tech skills they require. In 2016, Facebook pledged $15 million over a five-year period to Code.org, a non-profit founded in 2013 to "expand the availability of computer science (CS) education".[37] And Apple has announced that it will "accelerate" its efforts across the US in support of coding education and programs focused on science, technology, engineering, arts and maths (STEAM).[38] We examine this EdTech trend in more detail in The academy and beyond essay.

Already, Generation Z, (those typically born between the mid-1990s and early 2000s), who will be researchers a decade from now, accept the need for lifelong learning to keep on top of developments within and across disciplines. And, Generation Alpha (those born between 2010 and 2030 who will have never known a world without tablets, smartphones and social media), will use that learning to become the "most transformative generation ever", according to futurist and demographer, Mark McCrindle.[39]

36 Dredge, S. Coding at school: a parent's guide to England's new computing curriculum. The Guardian 4 September 2014. https://www.theguardian.com/technology/2014/sep/04/coding-school-computing-children-programming

37 Montgomery, B. Facebook Donates $15M to Code.org to Diversify Computer Science Education. EdSurge. 14 July 2016. https://www.edsurge.com/news/2016-07-14-facebook-donates-15m-to-code-org-to-diversify-computer-science-education

38 Apple accelerates US investment and job creation. Apple. 17 January 2018. https://www.apple.com/newsroom/2018/01/apple-accelerates-us-investment-and-job-creation/

39 Sterbenz, C. How will the next generation use technology? World Economic Forum & Business Insider. 18 December 2015. https://www.weforum.org/agenda/2015/12/how-will-the-next-generation-use-technology/

40 Kalvar, R. Computing Programming is a Dying Art. Newsweek. May 2014. http://www.newsweek.com/2014/06/06/computer-programming-dying-art-252618.html

41 Neema, D. S. Mining and Understanding Software Enclaves (MUSE). DARPA. 2017. https://www.darpa.mil/program/mining-and-understanding-software-enclaves

42 Davis, G. M. Do we really need to learn to code? New Yorker. June 2014. https://www.newyorker.com/tech/elements/do-we-really-need-to-learn-to-code

71 percent of the respondents to our researcher survey aged 36 years and under believe they will use advanced data modelling techniques and become expert in statistics over the next 10 years. For researchers aged 36-55, that figure falls to 66 percent, while for those aged 56 and over, it drops to 57 percent. Perhaps the latter can be explained by some respondents' plans to step back from active research in the decade ahead.

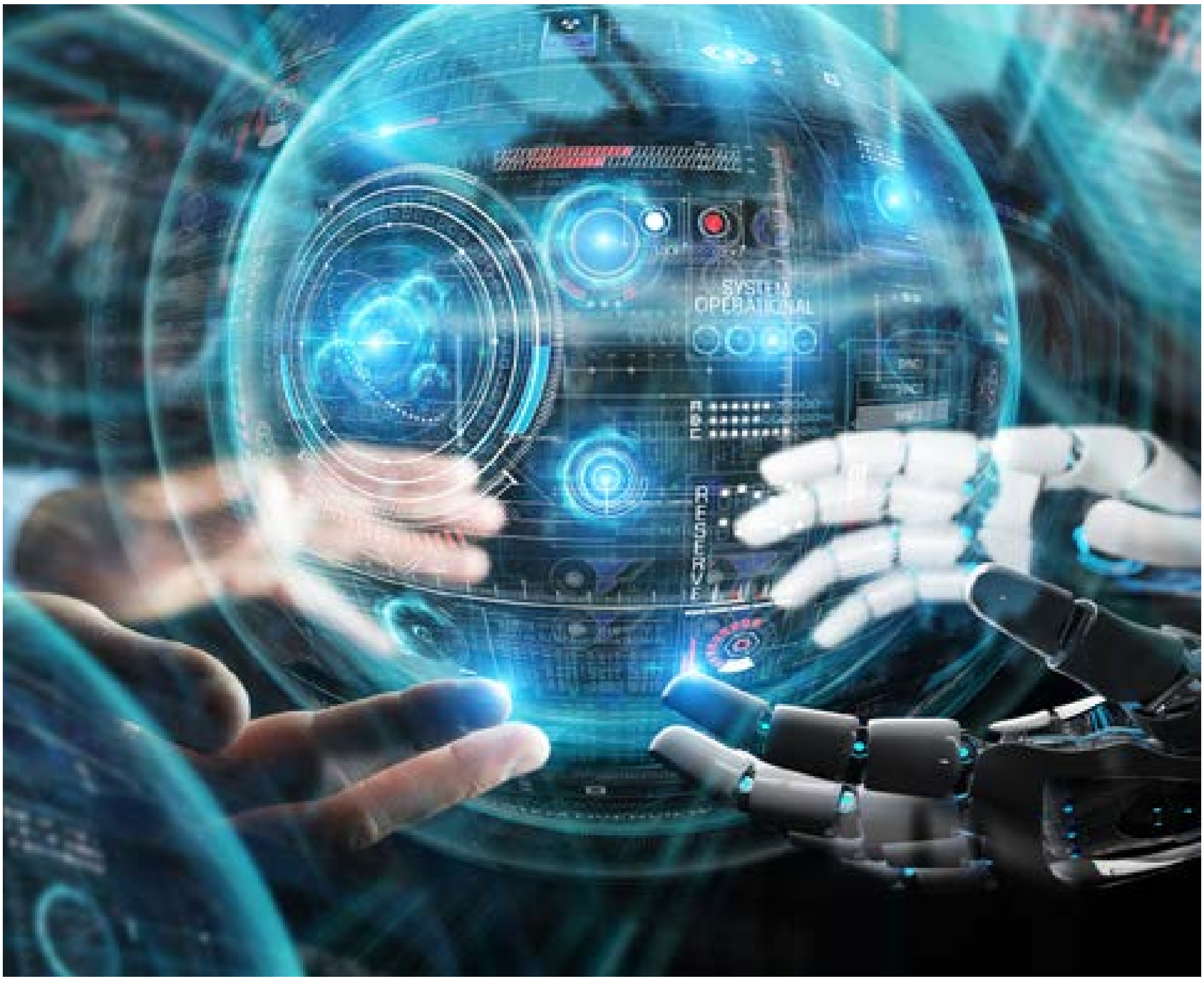
"Why do I imagine the next 10 years will be very different from any of the previous 10 years? It has to do with technology and the ability to imagine what technology can do for you. I believe that these young folks will imagine a different world and move more quickly into it."

Jean-Gabriel Bankier, Managing Director, bepress, an Elsevier company, interviewee

Many believe that lifelong, or renewable learning, will be vital if society is to continue adapting to what lies ahead; whether that's retraining as existing roles become automated, or taking on board new knowledge as we live and work longer. We explore this trend in the "Moulding a workforce for the future" section of our essay The academy and beyond.

What's next?

While it's impossible to predict the extent to which the role of the researcher will change over the coming 10 years, one thing is certain – it will, and that change is likely to be profound. Finding solutions that will ease the pressure on researchers as they navigate this transition are likely to prove key; from creating the integrated workflow tools they need, enabling open science, facilitating communication with the public, to considering how metrics can help us move beyond a hyper-competitive publish or perish environment. Job and funding security are also areas that will need to be understood and addressed – developing a securer work environment for younger researchers will create a stronger bedrock for future academic research and equip them with the skills they need to succeed in that future.



Technology: revolution or evolution

Setting the scene...

Technology has the power to transform. It is the major factor driving change in all five of the other themes we explore in this report, fuelling advances in education, how researchers work, open science and more. According to many, we are still in the early stages of the technology journey and its potential to continue remodelling the world of academia and beyond is enormous – and not always easy to anticipate. Job losses are forecast, but so too is the creation of new roles, driven by artificial intelligence and other advances. In fact, artificial intelligence, the rise of big data and our increasing skill in exploiting these are key to continuing development in the decade ahead. With the help of the existing literature and our study participants, we look at the potential highs – and lows – of the coming 10 years.

What will be the key drivers and changes?

1. Big data is fast becoming the lifeblood of nearly all research

Big data can be (and is) used throughout the research cycle; for example to **understand research processes, analyze and share data sets**, link **interactive articles** to data sets and **create efficiencies**.

- With the volume of research data increasing, the skills that many researchers require are continuing to change, and the **demand for services and technologies** that can help use and interpret big data is growing.
- **Data engineering** will become much more important than data science, particularly in the early stages of the adoption of digital techniques. The development of knowledge organization schemes (e.g. taxonomies and ontologies) will increase dramatically. Building the infrastructure for science and medicine will be arduous.

2. Artificial intelligence (AI) and machine learning tools are changing the shape of science

AI tools already in development can:

- **Sift and analyze** data
- Provide **personalized and predictive** services
- Aid **peer review**
- Identify **plagiarism**
- **Predict and evaluate** research impact

The role of AI will increase, but tension will develop around how it is deployed; not only the ethics but the balance between human and machine, as well as the potential for bias and manipulation.

3. Blockchain has the potential to facilitate open science, but the technology is still in its infancy and may not fulfil its promise

The concept has yet to prove itself in the world of research. It requires very strong computational power and sometimes regulation by intermediaries is needed for the good of society. *If* it delivers, it could potentially:

- Aid **reliability and reproducibility** by documenting the research process transparently in a single platform on the blockchain
- Increase **collaboration** by enabling sharing across geographies
- Inspire more **creativity**: anonymity means hypotheses can be shared without risk to reputations

4. Augmented reality (AR) and virtual reality (VR) will become key learning tools for a number of institutes

AR and VR have the potential to increase their contribution to research and education by:

- **Enabling scientific experiments** that are not easily experienced in the real world
- Bringing to life knowledge and **abstract concepts**
- Enhancing student learning through practical use (e.g. **teaching surgery**)
- Helping to simulate real-world stimuli to aid with the **diagnoses** of certain illnesses

The impact on research outputs is less direct than other technologies, but, as AR and VR advances, we may see new applications, e.g. the AR-enabled article.

Big data – big bang?

According to some, the world no longer revolves around the sun – it revolves around data. Since the start of the internet in the 1990s, the amount of data available has exploded. This has been particularly true since 2007 when the iPhone was launched, and the mobile web, social media and app usage became an integral part of many people's lives.

In its report, *The Digital Universe in 2020*, the International Data Corporation (IDC) estimated that the amount of information stored in the world's information technology systems is doubling every two years. By 2020, the total amount will be enough to fill a stack of tablets that reaches from the earth to the moon 6.6 times.[1]

The rise of smart objects – products that send their data to the internet – is partly responsible; together, these connected items create the **Internet of Things** (explored later in this essay). Another contributing factor is the adoption of more universal technologies and languages, which make it easier to connect and share data. As a result, there is no shortage of data and storing, managing and gaining insights from it has become a priority for companies.

Reaching a consensus on what the term "big data" means isn't easy. Some see it as a "loosely defined term used to describe data sets so large and complex that they become awkward to work with using standard statistical software".[2] Others claim it refers to developing new insights or creating new values at a large scale (rather than a small one).[3]

Understanding the terms

Big data: Generally agreed to refer to data sets that are too large and complex to be processed by traditional database management tools.

Metadata: Data that describes or provides information about other data.

The Internet of Things (IoT): The growing network of devices connected and exchanging data.

Whatever the definition, big data brings a host of opportunities. But these go hand in hand with challenges, which affect all industries, including academia. In a 2016 blog post,[4] marketer Ashley DeVan identified these as the "7 V's of big data". They are:

1. **Volume**, or how much data we have. What used to be measured in gigabytes (1 billion bytes) is now measured in zettabytes (1 sextillion bytes) – or even yottabytes (1,000 zettabytes). While all industries are seeking solutions to the volume problem, for some research fields the challenge is particularly pressing; for example, the amount of data involved in modern-day simulations of the evolution of the universe at cosmological scales is so vast that it will take years to sift through.[5]
2. **Velocity**, or the speed with which data is accessible. We have become used to almost instant access, but big data sets require both computing power and time to process.
3. **Variety**: This is one of the biggest hurdles. Data can be unstructured and comes in many formats from XML to video to SMS. Much of it doesn't live in databases. Organizing it in a meaningful way is not easy, especially when the data itself changes rapidly.

1 Gantz, J. & Reinsel, D. The Digital Universe in 2020: Big Data, Bigger Digital Shadows, and Biggest Growth in the Far East – United States. IDC. February 2013. https://www.emc.com/collateral/analyst-reports/idc-digital-universe-united-states.pdf

2 Snijders, C., Matzat, U., & Reips, U-D. "Big Data": Big gaps of knowledge in the field of internet science. International Journal of Internet Science. 2012, 7(1), 1-5.

3 Mayer-Schönberger, V. & Cukier, K. Big data: A revolution that will transform how we live, work, and think. Houghton Mifflin Harcourt. 2013. ISBN: 9781848547926

4 DeVan, A. The 7 V's of Big Data. Impact. 7 April 2016. https://impact.com/marketing-intelligence/7-vs-big-data/

5 Simons Foundation. Astrophysicists release IllustrisTNG, the most advanced model of its kind. Phys.Org. 1 February 2018. https://phys.org/news/2018-02-astrophysicists-illustristng-advanced-universe-kind.html

"Scholarly research also includes humanistic research that is a lot of diverse information. Non-book material, non-text, and non-paper material (film, audio, images, fabric, 3D objects...). How are you going to be able to document that in an increasingly digital environment?"

Sarah Pritchard, Dean of Libraries, Northwestern University, US, interviewee

4. **Variability**: If the meaning of data is constantly changing, that has a huge impact on consistency.
5. **Veracity**: Accuracy of data is vital. It's the classic "garbage in, garbage out" challenge.

"Big piles of poor data is the danger with big data – statistical packages are needed to help us weed out the good data. They need to be more and more rigorous and learn what's real and what's not. That's going to be the learning curve."

Taylor Cohen, US, interviewee

6. **Visualization**: As the volume and complexity of data grows, charts and graphs can be a valuable way to help us visualize it.
7. **Value**: This is the true goal for any organization. Once all the other challenges have been addressed – which takes time, effort and resources – organizations want to know that all that data is serving some useful purpose. The number of companies offering analytical solutions to extract useful insights is growing.

In addition, there are issues around storage space... and security, as is clear from recent hacking and ransomware incidents, such as the one that hit the UK's National Health Service in 2017.[6] Continuing developments in technology will be key to addressing these challenges.

For academia, the implications of big data – and the computing tools used to manage and analyze it – are immense. While solutions developed by internet companies don't always meet the research community's needs, those that do are already transforming the researcher workflow (see How researchers work: change ahead essay). Analysis software is tackling the data-intensive tasks common to so many research fields. This is freeing up researchers to focus on other aspects of their work, including those growing in importance, such as public engagement.

"If you're a single researcher, you're just you – if you can add big data attributes and approaches to your work you'll duplicate yourself… in 10- or 20-years' time, if you have a big quant data set, you can set the machine to reason over it while you spot insights you'd not have been able to before."

Technology expert, US, interviewee

The new computing tools not only evaluate multiple data sets from a variety of sources faster than humans can, they also identify trends with higher than usual levels of certainty. And the unique perspectives offered by mining those various data sets can spark new avenues of scientific exploration. Increasingly, the hypotheses driving new research projects are determined by data, not ideas.

"The technology itself leads to the development of questions which people had not considered before."

Funder, Canada, interviewee

Big data, the sharing of data and rapid advances in technology are also fuelling collaborations and new kinds of partnerships (see the Funding the future essay). These include joint initiatives in the area of biology and medicine, including, for example, the Cancer Moonshot, which unites a group of experts with a common goal to "make more therapies available to more patients, while also improving our ability to prevent cancer and detect it at an early stage".[7] And without big data, we wouldn't

6 Graham, C. NHS cyber attack: Everything you need to know about 'biggest ransomware' offensive in history. The Telegraph. 20 May 2017. https://www.telegraph.co.uk/news/2017/05/13/nhs-cyber-attack-everything-need-know-biggest-ransomware-offensive/

7 Cancer MoonshotSM – About page. National Cancer Institute. https://www.cancer.gov/research/key-initiatives/moonshot-cancer-initiative

have mega-science collaborations like the Square Kilometre Array (SKA),[8] which has "radio telescopes sited in Australia and South Africa, with a HQ near Manchester and a consortia of engineers gathered from 17 different countries. The level of collaboration needed for this project would be impossible without an e-infrastructure to ensure the fast and safe data transfer between the equipment and the processing sites".[9] In all these projects, the ability to share, access and analyze the vast amount of data produced is crucial.

To navigate the emerging data-driven landscape, the skills needed by researchers are changing. As Chivers noted in 2018, "to be a biologist, nowadays, you need to be a statistician, or even a programmer. You need to be able to work with algorithms".[10]

Some believe that the coming decade will see researchers reach beyond the boundaries of their fields and disciplines to develop new areas of expertise.

"There might be more specialization in research: people who are extremely good in doing experiments and creating data sets, but are not as strong at writing papers and vice versa."

Gregory J. Gordon, Managing Director, SSRN, an Elsevier company, US, interviewee

In the essay How researchers work: change ahead, we explore the rise of the data scientist, while in Pathways to open science, we consider the potential impact of open data on researchers and their workflows.

For companies working in the research ecosystem, a pressing need at these early stages of adoption is data engineering expertise to manage the practical applications of data collection and analysis. Big data also spawns the need for more sophisticated knowledge organization schemes, such as taxonomies and ontologies, bigger and more complex than those designed to support library science. Getting the right data infrastructure and pipelines in place for science and medicine will take time and investment.

"Scholars are looking at fascinating patterns in numbers and data they couldn't see before and are asking questions they couldn't ask before. …We're looking at more demand for tools to analyze big data (analytics, data visualization, text mining...)."

Sarah Pritchard, Dean of Libraries, Northwestern University, US, interviewee

In turn, this has created opportunities for those already involved in research, including publishing companies, to invest in developing the new tools required, and take on more of a data analytics role. And that flexible approach could prove crucial according to some of our interviewees, who believe that businesses involved in the "enterprise of science" that can't, or won't adapt, face a very uncertain future.

"More and faster CPUs [computer central processing units], new software and equipment technologies can help us to do more design and simulations, that can, in turn, help us do more research."

Researcher in engineering and technology, Taiwan, aged 36-55, respondent to researcher survey

It has also created opportunities for established companies owning huge volumes of data, such as Amazon and IBM, to release the power of the information contained in their data stores. In addition, start-ups and other companies are emerging to serve the rapidly-evolving needs of the market. These include "data brokers" such as Acxiom and CoreLogic, which sell consumer profiles to the largest companies. It's an attractive space to enter – the future Internet "moguls" will have access to more data

8 Square Kilometre Array – About the project. https://www.skatelescope.org/the-ska-project/

9 Feldman, P. Jisc Futures: what next for the UK's international research collaborations? Times Higher Education. 4 July 2017. https://www.timeshighereducation.com/blog/jisc-futures-what-next-uks-international-research-collaborations

10 Chivers, T. Big data has transformed how we do science. World Economic Forum. 3 October 2018. https://www.weforum.org/agenda/2018/10/how-big-data-is-changing-science/

and information than most governments and, by 2030, non-state players, e.g. private companies, are expected to influence behavior at a similar level to state players.[11]

Privately-held data is already delivering new insights and benefits to several scientific and health fields. For instance, using data drawn from queries entered into search engines, scientists at Microsoft and Stanford and Columbia universities in the US were able to detect evidence of unreported prescription drug side effects before they were found by the Food and Drug Administration's warning systems.[12]

In social sciences, platforms like Facebook have databases with many variables that explain human behavior in a social context. These could offer much more robust insights than common survey methods, e.g. questionnaires, providing an objective view of how someone feels as they interact.

The Internet of Things

As mentioned earlier in this essay, one of the factors closely linked to the rise of big data is the growth of the Internet of Things (IoT), also known as the Internet of Everything. Writing in 2016, Meola described it as "the rapidly growing network of connected objects that are able to collect and exchange data using embedded sensors. Thermostats, cars, lights, refrigerators, and more appliances can all be connected to the IoT".[13] Legal scholars suggest we should regard "things" as an "inextricable mixture of hardware, software, data and service".[14] In a broader context, things can also refer to people and data sets.

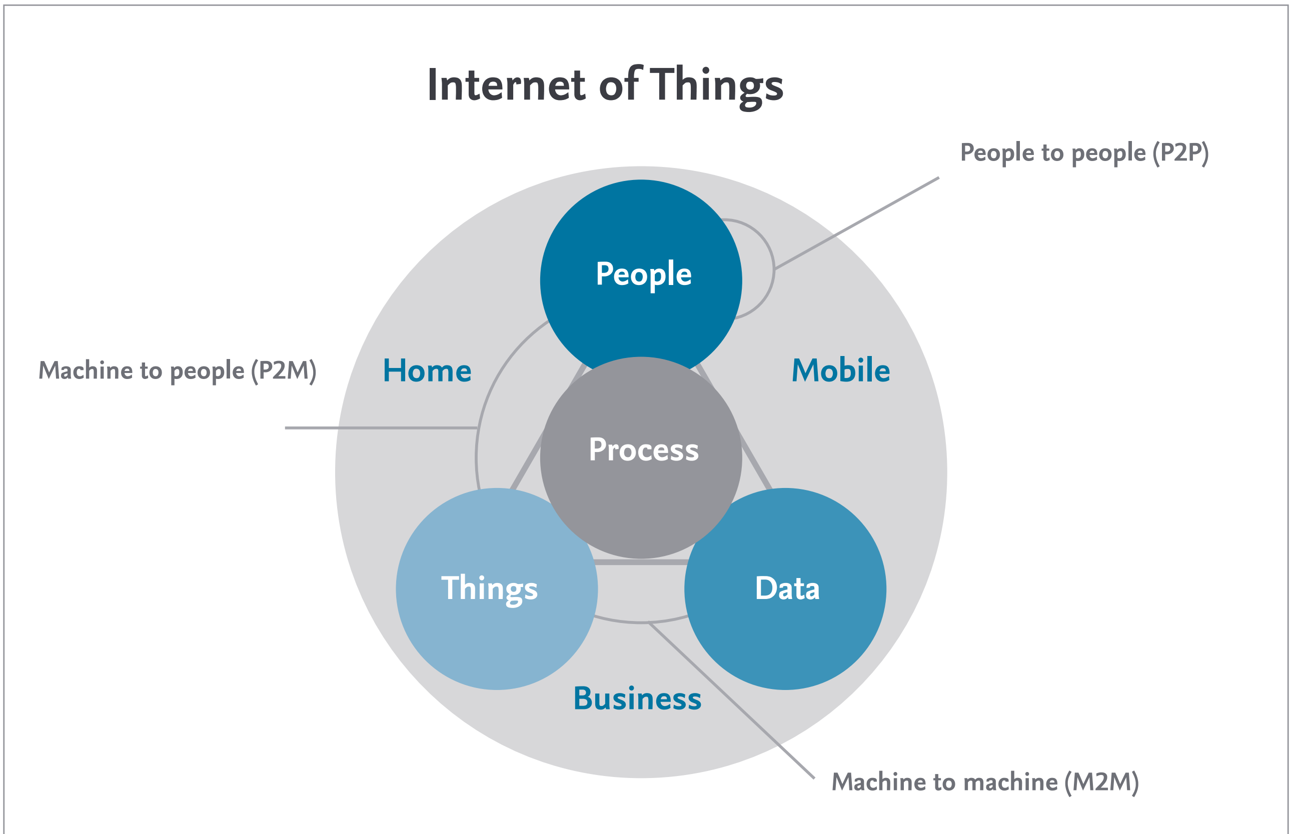


Figure 4.1: The Internet of Things unites a variety of elements.

11 Global Trends 2030: Alternative Worlds. National Intelligence Council. December 2012. https://www.dni.gov/files/documents/GlobalTrends_2030.pdf

12 Kosinkski, M., Stillwell, D., & Graepel, T. Private traits and attributes are predictable from digital records of human behavior. PNAS. 9 April 2013. 110(15), 5802-5805. doi: 10.1073/pnas.1218772110

13 Meola, A. Internet of Things devices, applications & examples. 19 December 2016. https://www.businessinsider.com/internet-of-things-devices-applications-examples-2016-8?international=true&r=US&IR=T

14 Noto La Diega G. & Walden I. Contracting for the 'Internet of Things': looking into the Nest. European Journal of Law and Technology. 2016. 7(2).

There are many factors behind the IoT trend, such as advances in nano technology, artificial intelligence (AI), cloud computing, smart devices and connectivity (e.g. Wi-Fi and Bluetooth). It is proving a two-way relationship as IoT has also fuelled change in these areas; for example, the enormous volumes of data it generates helped drive the need for cloud computing.[15]

For researchers and health professionals, the IoT network offers opportunities to improve the quantity and quality of data and it has already been used to great effect in some disciplines.

- It has a wide range of applications in health care where, for example, smart devices monitor conditions like diabetes or asthma in outpatients and transfer the collected data to a physician's smartphone. It is also used widely in hospitals to monitor equipment performance and patient welfare.[16]
- At Harvard University in the US, there are five freezers and refrigerators stocked with irreplaceable marine samples that cost millions of dollars to collect. Using technology offered by TetraScience, users can now access data on those freezers through a web browser, set temperature thresholds and alarm options, and monitor each sensor's performance so problems can be identified at an early stage.[17]
- In geology, drones are proving a valuable tool, particularly in hard-to-reach or dangerous places. They are used for aerial surveys, field mapping, and monitoring, with scientists able to access the data in real time.[18]
- In labs, "[in] addition to collecting data about equipment performance and laboratory conditions, scientists ...can use the IoT to deposit vast amounts of experimental data into the cloud directly from instruments and to control experiments remotely".[19]

Some would like to see the integration of IoT taken a step further. Silicon Valley start-ups are already working to automate basic experiments, offering a glimpse into a possible future; but, to date, take-up remains low. There are also companies focused on building fully smart laboratories, but the price of equipment is likely to limit adoption rates in the short term.[20]

A number of industry watchers believe that the IoT, along with many of the other technologies explored in this essay, could contribute toward a solution for the reproducibility problem currently facing research, particularly in the life sciences (see "Open science and research integrity: a match made in heaven?" in the Pathways to open science essay). The interconnectivity of lab devices means researchers can track and record data in real time, so that they can check experiments and adjust them, if needed. For example, there are now internet-connected pipettes that send data about liquid quantities and the number of pipetting steps to a tablet via Bluetooth. This can then we shared with an electronic lab notebook (ELN).[19] And the storage of the information in those electronic notebooks in the cloud "provides a permanent, transparent home for data that can be easily accessible to all lab members and collaborators".[21]

Back in 2011, Cisco's Internet Business Solutions Group (IBSG) predicted that there will be 50 billion devices

15 Eastwood, G. How AI is transforming cloud computing. NetworkWorld. 3 January 2017. https://www.networkworld.com/article/3154363/cloud-computing/how-ai-is-transforming-cloud-computing.html

16 Matthews, K. 6 Exciting IoT Use Cases in Healthcare. IOT for all. 3 May 2018. https://www.iotforall.com/exciting-iot-use-cases-in-healthcare/

17 Perkel, J. M. The Internet of Things comes to the lab. Nature. 30 January 2017. https://www.nature.com/news/the-internet-of-things-comes-to-the-lab-1.21383

18 Jordan, B. R. A bird's-eye view of geology: The use of micro drones/UAVs in geologic fieldwork and education. GSA TODAY. July 2015. 25(7) 42-43.

19 Olena, A. Bringing the Internet of Things into the Lab. The Scientist. 1 June 2018. https://www.the-scientist.com/bio-business/bringing-the-internet-of-things-into-the-lab-64265

20 Elias, B. Science and the Internet of Things. cglife. https://cglife.com/blog/science-and-internet-things/

21 De Jouvencel, T. Connecting the Lab Bench: IoT's Role in Addressing the Reproducibility Crisis. RDMag. 26 September 2018. https://www.rdmag.com/article/2018/09/connecting-lab-bench-iots-role-addressing-reproducibility-crisis

connected to the internet by 2020.[22] In contrast, in 2016, *Business Insider* forecast that the number of internet-connected devices installed globally will reach 24 billion by 2020 – just over four devices for every human on earth.[23] Whichever figure proves to be true, it is generally agreed that the future potential for the Internet of Things is huge.

But the progression of IoT will depend on the cost of the technology and data involved (although these could be offset by the savings that IoT may bring). And there are other factors to consider: a 2017 survey of IoT developers found that nearly half – 47 percent – have concerns about its security, with just over 20 percent concerned about interoperability and connectivity.[24] In addition, some see "connecting" the data as only the first step, with "the Analytics of Things", or AoT, required to make that data useful.[25] Others believe that the time is ripe to introduce standards for the IoT data and its analysis. In 2018, Franks noted: "The longer standardization is put off, and the more processes built as one-offs, the more painful it will be to implement and retrofit standards later."[26]

Another hurdle is one that faces many of the technologies we explore in this essay – the availability of people with the skills required to drive it. IoT developers will be in high demand in the decade ahead.

Embracing a new kind of intelligence

Artificial intelligence (AI), machine learning, deep learning… these are just some of the buzzwords on everyone's lips whenever talk turns to the future.

Their impact on our society is already immense in both visible and less noticeable ways. Just as with big data, they have the potential to revolutionize the way that researchers work and think – according to some, they may even replace researchers. However, others feel it's still too early to judge the full extent of the change ahead.

> *"Making predictions on the impact of AI on research is like trying to determine the outcome of a soccer game after the first minute."*
>
> **Joseph Esposito, Senior Partner, Clarke & Esposito, US, interviewee**

So what exactly are these disruptive technologies that are poised to transform our societies?

According to Professor John McCarthy, who coined the term artificial intelligence (AI), it is "the science and engineering of making intelligent machines, especially intelligent computer programs. It is related to the similar task of using computers to understand human intelligence, but AI does not have to confine itself to methods that are biologically observable".[27]

AI was founded as an academic discipline in 1956 and relies on a truly interdisciplinary approach, drawing on the fields of computer science, mathematics, psychology, linguistics, philosophy, neuroscience, artificial psychology

Understanding the terms

Algorithm: The set of rules, or instructions that a machine (particularly a computer) follows to achieve a goal.

Machine learning: Computer programs that can access data and use it to learn for themselves.

Deep learning: An artificial neural network that attempts to mimic human thinking.

22 Evans, D. The Internet of Things: How the next evolution of the internet is changing everything. April 2011. https://www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf

23 There will be 24 billion IoT devices installed on Earth by 2020. Business Insider Intelligence. 9 June 2016. https://www.businessinsider.com/there-will-be-34-billion-iot-devices-installed-on-earth-by-2020-2016-5?international=true&r=US&IR=T

24 Skerret, I. IOT Developer Trends 2017 Edition. April 2017. https://ianskerrett.wordpress.com/2017/04/19/iot-developer-trends-2017-edition/

25 Davenport, T. The Analytics of Things. Deloitte Insights. 17 December 2014. https://www2.deloitte.com/insights/us/en/focus/internet-of-things/connected-analytics-of-things.html

26 Franks, B. Why Analytics of Things Standards are Needed. International Institute for Analytics. 12 April 2018. https://www.iianalytics.com/blog/2018/4/12/why-analytics-of-things-standards-are-needed

27 McCarthy, J. What is AI? / Basic Questions. Stanford University website. http://jmc.stanford.edu/artificial-intelligence/what-is-ai/index.html

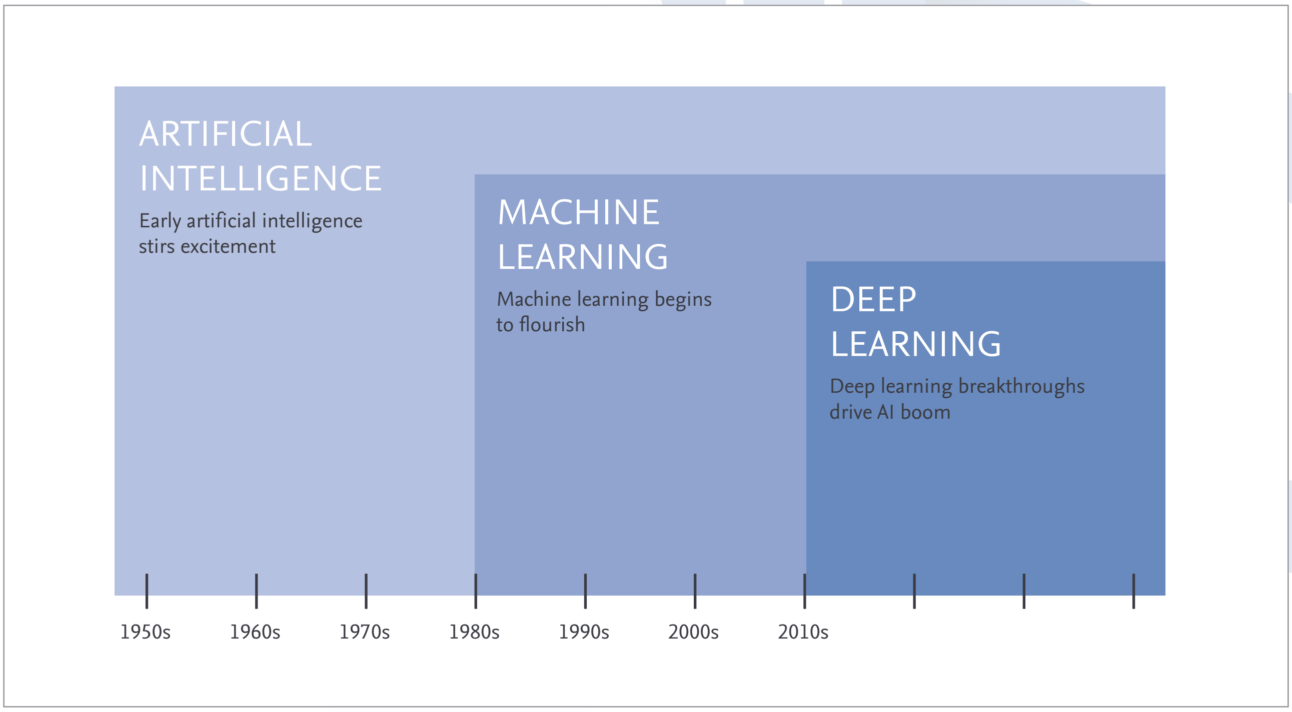


Figure 4.2: Since AI emerged in the 1950s, smaller subsets – first machine learning, then deep learning – have been creating ever larger disruptions.

and many others. Since 1956, it has "experienced several waves of optimism, followed by disappointment and the loss of funding (known as an "AI winter")".[28] But this century has seen AI become (probably) the most rapidly growing technology thanks to advances in computer power, our ability to create sophisticated algorithms to help those computers learn, and large amounts of data.[29] Over the past five years, the volume of published literature on AI has accelerated, growing at an annual rate of 13 percent, compared to the much lower annual rate of 5.3 percent if we look at the last 10 years as a whole.[30]

AI imitates the constant processes occurring in human brains and nervous systems. Instead of taking in information through senses, as we do, it absorbs it through data. And just as we use that information to learn, so does AI via algorithms, or machine learning. AI systems never sleep and the input they receive is enormous, so programs can be continuously adjusted and improved, speeding up the learning process.[31]

"Relatively straightforward tasks that require man power and time could be easily adapted for machines/AI."

Biological scientist, UK, aged 26-35, respondent to researcher survey

We are currently in the era of deep learning, which takes AI and machine learning a step further. Deep learning uses artificial neural networks built like the human brain to carry out the process of machine learning.[32] But, unlike machine learning, deep learning doesn't require the data it receives to be structured or labelled. And, with the rising volume of data available to feed deep

28 Chandrayan, P. Artificial Intelligence Fundamentals: Making Machine Intelligent. Towards Data Science. 10 September 2017. https://towardsdatascience.com/artificial-intelligence-fundamentals-making-machine-intelligent-d3f28f236c7

29 Settle, J. Preparing for the future: artificial intelligence and us. University of Cambridge website. 2 February 2018. https://www.cam.ac.uk/research/discussion/preparing-for-the-future-artificial-intelligence-and-us

30 AI Resource Center. Elsevier. https://www.elsevier.com/connect/resource-center/artificial-intelligence

31 Nymand, K. The Current State of Artificial Intelligence, and How it Evolves in the Palm of Your Hand. Forecast. https://blog.forecast.it/the-current-state-of-artificial-intelligence-and-how-it-evolves-in-the-palm-of-your-hand

32 Frankenfield, D. Deep Learning. Investopedia. 9 March 2018. https://www.investopedia.com/terms/d/deep-learning.asp

learning and calculation power increasing, the stage is set for accelerated progress; although, in the near term at least, it will still work hand in hand with more traditional AI techniques to carry out scientific reasoning and hypothesis-formation tasks.

In a 2017 blog post for semiconductor company Graphcore, Andrew Briggs, Professor of Nanomaterials at University of Oxford, wrote: "I predict that by 2025, AI will be as ubiquitous for running experiments as computers are today for controlling instrumentation and logging data. The paradigm shift will be from AI used for analysing the data which has already been obtained, to AI deciding what to measure next."[33]

The role of AI is perceived to be so important that nations are vying to be in pole position. As noted in Elsevier's 2018 report, *Artificial Intelligence: How knowledge is created, transferred, and used*, China aspires to lead globally in AI, which appears to be supported by its ambitious policies and rapid growth (see "Regional shifts: the China effect" in the Funding the future essay). A recent "brain gain" of AI researchers in China suggests it is also proving an increasingly attractive environment for researchers.[30]

And it's not only nation states and academia that want to drive forward development. Google's DeepMind, which is on a "scientific mission to push the boundaries of AI",[34] is assisting physicians during surgery and can identify the early stages of blindness.[35] The first applications of AI in health and medicine are already making waves, particularly in personalized medicine; for example, tailoring combination therapy to suit individual cancer patients.[36] Other disciplines are also witnessing dramatic results: in astrophysics, complex analyses that typically take weeks to months to complete, require the input of experts and are computationally demanding, can be done by brain-mimicking "neural networks" within a fraction of a second.[37]

Expectations are high in many fields, for example, a recent review in the chemical sciences found that "the number of applications [of machine learning] is growing at an extraordinary rate. This new generation of computational science, supported by a platform of open-source tools and data sharing, has the potential to revolutionize molecular and materials discovery".[31]

"Technological advances are crucial for novel discoveries. The more you can observe, measure and the more you can specifically influence processes, the more information you can get."

Researcher in immunology and microbiology, the Netherlands, aged 36-45, respondent to researcher survey

Natural language recognition – technology that can understand what you say – is another area experiencing growth. We are only a step away from realizing the Universal Translator sci-fi authors have been writing about since the 1940s; we will soon be able to talk in our native languages while computers in our ears live translate the conversation.[31] There are already early products on the market.[38]

There seems no doubt that the coming decades will see the involvement of AI in science continue to escalate at a rapid pace. In fact, many see AI as one of the most promising avenues for battling the key issues affecting society and illuminating some of our greatest mysteries. Writing for the Smithsonian Institute in 2018, Talty suggested: "AI 'scientists' will solve the puzzle of dark matter; AI-enabled spacecraft will reach the asteroid

30 AI Resource Center. Elsevier. https://www.elsevier.com/connect/resource-center/artificial-intelligence

31 Nymand, K. The Current State of Artificial Intelligence, and How it Evolves in the Palm of Your Hand. Forecast. https://blog.forecast.it/the-current-state-of-artificial-intelligence-and-how-it-evolves-in-the-palm-of-your-hand

33 Briggs, A. Why Artificial Intelligence will enable new scientific discoveries. Graphcore. 2018. https://www.graphcore.ai/posts/why-artificial-intelligence-will-allow-us-to-make-new-scientific-discoveries

34 DeepMind – About page. https://deepmind.com/about/

35 Millar, A. Using AI to personalise drug combination therapy. Pharma Technology Focus. October 2018. https://pharma.nridigital.com/pharma_special_oct18/using_ai_to_personalise_drug_combination_therapy

36 Artificial Intelligence analyzes gravitational lenses 10 million times faster. Science & Technology Research News. 4 September 2017. https://www.scienceandtechnologyresearchnews.com/artificial-intelligence-analyzes-gravitational-lenses-10-million-times-faster/

37 Butler, K.T. et al. Machines learning for molecular and materials science. Nature. 26 July 2018. 559 547-555. doi:10.1038/s41586-018-0337-2

38 Kendall, N. Google's translation headphones are here, and they're going to start a war. The Guardian. 6 October 2017. https://www.theguardian.com/commentisfree/2017/oct/06/google-translation-headphones-war-douglas-adams-hitchhikers-guide

belts, while on Earth the technology will tame climate change, perhaps by sending massive swarms of drones to reflect sunlight away from the oceans. Last year, Microsoft committed $50 million to its "AI for Earth" program to fight climate change."[39]

AI could be another of the technologies that contributes to solving the reproducibility crisis, checking big data for issues around "veracity" and "variability". And it already plays a key role in identifying ethics issues in the texts of academic papers, particularly plagiarism. Work is underway to develop similar algorithms to identify manipulated images. Others see AI as a way to reduce human bias in experiments and results, but point out that AI tools will only ever be as strong as the data behind them.

"We don't yet know the full consequences of GDPR [European data protection regulation]. We are going to have to ask permission for personalized data, even anonymized data… We will need to get better at explaining why we need it so that people will consent, or it will create data biases within the algorithms."

Nicola Millard, Head of Customer Insight & Futures, BT, UK, interviewee

Just as with the Internet of Things, AI is driving collaboration; in many cases, between industry and science (we take a closer look at the dynamics of these relationships in our Funding the future essay). For example, in July 2018, the University of Cambridge announced a new DeepMind Chair of Machine Learning, in association with the British artificial intelligence company DeepMind Technologies. Cambridge Vice Chancellor, Stephen Toope, has stated that "this gift will not only enhance Cambridge's strengths in the field of AI research, but will benefit the UK more broadly, as AI has such transformative potential in so many aspects of our lives".[40]

As we've seen, many time-consuming activities such as aggregating, preparing and analyzing data can, and will be increasingly executed by computers. AI will also help authors write and communicate about their research. Some believe it also has the potential to move beyond the "support role".

"There will also be tools that can act on their own. These tools will be able to do analysis and write papers themselves. This is already being done with weather and news articles – machines as co-authors. AI won't take over from researchers within the next 10 years, but it will aid them."

Josh Nicholson, co-founder and CEO, scite.ai, US, interviewee

On the research impact front, companies like Meta have emerged, "a platform that uses artificial intelligence to help scientists read, analyze, prioritize, and draw insights across millions of scientific papers".[41] In 2017, it was acquired by the Chan Zuckerberg Initiative (CZI), with plans to invest heavily in its development. Meta's AI "recognizes authors and citations between papers so it can surface the most important research instead of just what has the best SEO".[42] It is currently being trialled with journal editors, helping them identify manuscripts with strong impact potential.

In our essay How researchers work: change ahead, we explore the role that AI will play in finding and recommending relevant content to researchers, as well as helping them highlight their own work in the ever-rising sea of published literature. We also touch on the potential impact of technology on one of the core elements of the publishing process – peer review.

39 Talty, S. What will our society look like when artificial intelligence is everywhere? Smithsonian.com. April 2018. https://www.smithsonianmag.com/innovation/artificial-intelligence-future-scenarios-180968403/

40 Collins, S. Cambridge to appoint DeepMind Chair of Machine Learning. University of Cambridge website. https://www.cam.ac.uk/research/news/cambridge-to-appoint-deepmind-chair-of-machine-learning

41 Vander Ark, T. Chan Zuckerberg backs personalized learning R&D agenda. Getting Smart. 17 November 2017. https://www.gettingsmart.com/2017/11/chan-zuckerberg-backs-personalized-learning-rd-agenda/

42 Constine, J. Chan Zuckerberg Initiative acquires and will free up science search engine Meta. 2017. https://techcrunch.com/2017/01/23/chan-zuckerberg-initiative-meta/?guccounter=1

Securing the future: striking the right balance

There is much speculation that, unlike previous technological revolutions, AI and robotics (which we explore later in this essay) could result in job losses, including in academia. As Vutha noted in 2018: "The implications of machine intelligence, for the process of doing science and for the philosophy of science, could be immense… For example, in the face of increasingly flawless predictions, albeit obtained by methods that no human can understand, can we continue to deny that machines have better knowledge? ...unless we can articulate why science is about more than the ability to make good predictions, scientists might also soon find that a "trained AI could do their job"."[43]

Many predict that it is the routine jobs or tasks that will disappear, as the actions and decisions required are easy to replicate.[44] Some are hopeful that this will leave the way open for people to learn new skills. According to Ekkehard Ernst, chief of the macro-economic policies and job unit at the UN International Labour Organization, jobs in service sectors such as construction, health care, and business are most likely to be impacted, and it's not that they will necessarily be lost. Instead, "employees…. will add new tasks to their profile while being supported by computers and robots in others".[45] This is broadly endorsed by a 2018 World Economic Forum report, which found that while machines and algorithms will do more tasks than humans by 2025, they will still create 58 million net new jobs in the next five years.[46] For Ernst, a willingness to learn will be key to creating the skills required for those new roles with people getting used to "engaging with digital technology" and using machines as a "normal tool, as someone uses a car or an axe".[47]

While it's generally agreed that changes to the job market are coming, the scale of that change is debated. For example, some believe that it is not only the simple or routine tasks that will be automated, but potentially intellectual and creative roles too – and that it's already happening. According to a 2017 United Nations news post: "The astonishing progress in such areas as artificial intelligence (AI), robotics, 3D printing and genetics has enabled computers to perform the tasks of architects, medical doctors, music composers and even a 16th century Dutch master of painting."[48]

This raises philosophical arguments about the nature of the mind and the ethics of creating artificial beings endowed with human-like intelligence; issues which have been explored by myth, fiction and philosophy since antiquity. Some people consider the whole area of artificial intelligence could even be a danger to humanity if it progresses unchecked. In a blog post for the Smithsonian Institute, David Chalmers, a Professor of Philosophy at New York University, commented: "I do worry about a scenario where the future is AI and humans are left out of it. If the world is taken over by unconscious robots, that would be about as disastrous and bleak a scenario as one could imagine." The same post points out that Chalmers isn't alone: "Bill Gates and Elon Musk have warned about AIs either destroying the planet in a frenzied pursuit of their own goals or doing away with humans by accident—or not by accident."[39]

But some point out that while expectations may currently be high about AI's rate of development, if it follows the typical hype cycle for emergent technologies, it will

39 Talty, S. What will our society look like when artificial intelligence is everywhere? Smithsonian.com. April 2018. https://www.smithsonianmag.com/innovation/artificial-intelligence-future-scenarios-180968403/

43 Vutha, A. Could machine learning mean the end of understanding in science? The Conversation. 2 August 2018. https://theconversation.com/could-machine-learning-mean-the-end-of-understanding-in-science-98995

44 Ford, M. & Colvin, G. Will robots create more jobs than they destroy? The Guardian. 6 September 2015. https://www.theguardian.com/technology/2015/sep/06/will-robots-create-destroy-jobs

45 McCourtie, S.D. With AI, jobs are changing but no mass unemployment expected – UN labour experts. UN News. 4 September 2018. https://news.un.org/en/story/2018/09/1018292

46 Zahidi, S. Here are 5 ways for workers to win in the robot age. World Economic Forum. 17 September 2018. https://www.weforum.org/agenda/2018/09/ways-to-win-as-a-worker-in-the-robot-age/

47 Jobs changing with AI but no mass unemployment expected: UN labour experts. Outlook. 5 September 2018. https://www.outlookindia.com/newsscroll/jobs-changing-with-ai-but-no-mass-unemployment-expected-un-labour-experts/1376612

48 Will robots and AI cause mass unemployment? Not necessarily, but they do bring other threats. United Nations news. 13 September 2017. https://www.un.org/development/desa/en/news/policy/will-robots-and-ai-cause-mass-unemployment-not-necessarily-but-they-do-bring-other-threats.html

inevitably plateau in terms of productivity.[49] Others feel that AI has developed an "image problem" which is being fed by fears over job losses. In an interview with *Stanford Business*, computer scientist and Coursera co-founder, Andrew Ng, commented: "No, [AI] will not someday control the human race. I think that there is no clear path to how AI can become sentient… Worrying about evil AI killer robots today is a little bit like worrying about overpopulation on the planet Mars." He claims the "evil AI hype" is being used as a cover up for job displacement. "AI software will be in direct competition with a lot of people for jobs… That's something Silicon Valley needs to own up to."[50]

The evolution of AI is a topic that our interviewees for this study were keen to discuss. For many, machines will never be able to truly replace people, or build the same kind of trust that is established through personal contact. For others, it is crucial that humans continue to pull the strings.

"If the human is not accountable for what the system does, then that's a dystopian future. I would like to see a world where we have a clear understanding of where computing systems play a role and where humans play a role; but will government policy and culture draw lines in the sand and say we won't let computers do this?"
Technology expert, US interviewee

He, and others, believe that if those lines aren't drawn, there is a danger that academia could lose its appeal for future generations.

"One incentive for scientists to be scientists is the joy of finding the signal in the noise; scientists like doing that, irrespective of the field. They may be less interested if the system can find it for them!"
Technology expert, US interviewee

Securing the future: sourcing the right skills

There are two strands to the "skills shortage" story. The first focuses on the know-how that individuals must develop to fill the new roles arising from the ashes of jobs lost to automation.

We don't yet know what these new roles will look like. But, as we've seen, many are confident they will come. As Ford and Colvin recall in a blog post in *The Guardian*: "…after the worldwide web first made the internet accessible to everyone, no one predicted jobs for search engine optimisers, mobile app developers, social media managers and countless other jobs of today."[51]

For some, the answer lies in focusing on our "humanity" and fostering our ability to connect with others. A review of secondary education in the UK by British educators and CEOs concluded that "empathy and other interpersonal skills are as important as proficiency in English and mathematics in ensuring young people's employment prospects…everyone will need these skills".[51]

The job of managing this change will inevitably fall on the shoulders of governments and education institutions.[50] In our essay The academy and beyond, we explore how education is evolving to produce graduates with "employable skills", and examine the growing need for lifelong or renewable learning. While in How researchers work: change ahead, we look at the pressure on academics to learn new skills to remain relevant in an increasingly AI-led world.

The other skills shortage that society will need to tackle if AI is to reach its full potential, is the scarcity of people with the right technical skills to help it grow. According to a 2018 World Economic Forum report, which looked at the job landscape in 2022, the top 10 emerging jobs are all focused on technology, with data analysts and scientists, and AI and machine learning specialists taking first and second place.[52]

49 Gartner Hype Cycle definition. Gartner website. https://www.gartner.com/en/research/methodologies/gartner-hype-cycle

50 Lynch, S. Andrew Ng: Why AI is the new electricity. Stanford Business. 11 March 2017. https://www.gsb.stanford.edu/insights/andrew-ng-why-ai-new-electricity

51 Ford, M. & Colvin, G. Will robots create more jobs than they destroy? The Guardian. 6 September 2015. https://www.theguardian.com/technology/2015/sep/06/will-robots-create-destroy-jobs

52 Zahidi, S. Here are 5 ways for workers to win in the robot age. World Economic Forum website. 17 September 2018. https://www.weforum.org/agenda/2018/09/ways-to-win-as-a-worker-in-the-robot-age/

Governments are already laying their ground plans. In the past couple of years, Canada, China, Denmark, the EU Commission, Finland, France, India, Italy, Japan, Mexico, the Nordic-Baltic region, Singapore, South Korea, Sweden, Taiwan, the UAE, and the UK "have all released strategies to promote the use and development of AI. No two strategies are alike, with each focusing on different aspects of AI policy".[53]

Companies are currently involved in a "talent war" for the existing data scientists. Having them onboard is crucial to a company's success because AI typically needs to be tailored to business needs – there's not a one-size fits all solution.[50] However, experts estimate the number of skilled workers globally at between 90,000 and 200,000 to 300,000.[54] This battle isn't just taking place in the corporate world – there are also tussles between academia and industry for data scientists, with some claiming researchers are being "lured away" by big pay packets.[55]

With a skills shortage and big business seeking out the experts and developers, it is likely academia will struggle to attract or retain the data scientists it needs to progress. This may lead to research institutions partnering with industry for AI-led projects.

Other developments reshaping the future

Blockchain – auditing science

Blockchain is an upcoming technology that some believe has the potential to transform many industries, including scholarly research. For others, it is a case of hype and it will be many years before blockchain has a practical application beyond its current use in supporting cryptocurrencies, such as Bitcoin.

Understanding the terms

Blockchain: "Transactions made with bitcoins are verified in bundles by 'miners' – members of the general public using their computers to help validate and timestamp transactions. These validated transactions are then added as "blocks" to the end of a chain of similar blocks at regular intervals (approximately every 10 minutes) and shared on the network.

Cryptography is used to ensure that all previous transactions cannot be altered. Through this, a permanent record of transactions is created and kept on every participating node, ensuring that there is no single point of failure nor a single entity controlling the data.

Miners receive financial rewards for their work in the form of bitcoins – the right to create a new block depends on who manages to solve a mathematical problem incorporated in the process. This process is designed such that no single miner can be guaranteed to write the next block to the chain, which greatly reduces the opportunity to manipulate the system…

A ledger of all transactions is created that is shared (although information like people's identities are hidden using cryptography), verified and permanent, without the need of a central authority."[57]

Quantum computers: Not yet in existence, these will draw on quantum mechanical phenomena to solve complex problems we are unable to tackle today.

50 Lynch, S. Andrew Ng: Why AI is the new electricity. Stanford Business. 11 March 2017. https://www.gsb.stanford.edu/insights/andrew-ng-why-ai-new-electricity

53 Dutton, T. An overview of national AI strategies. Medium.com. 28 June 2018. https://medium.com/politics-ai/an-overview-of-national-ai-strategies-2a70ec6edfd

54 Kahn, J. Just how shallow is the artificial intelligence talent pool? Bloomberg. 7 February 2018. https://www.bloomberg.com/news/articles/2018-02-07/just-how-shallow-is-the-artificial-intelligence-talent-pool

55 Sample, I. 'We can't compete': why universities are losing their best AI scientists. The Guardian. 1 November 2017. https://www.theguardian.com/science/2017/nov/01/cant-compete-universities-losing-best-ai-scientists

57 van Rossum, J. Blockchain for Research. Digital Science Report. November 2017. https://figshare.com/articles/_/5607778

In fact, it was the desire for a public transaction ledger for Bitcoin that led to the invention of blockchain in 2008[56] – in the process, it created a new method to manage and organize data: in a blockchain, it is open, permanent, verified and shared, eliminating the need for a central authority.[57]

Blockchain has continued to evolve with new versions becoming available every few years, and if investment and interest in blockchain continues to grow at its current rate, those iterations are likely to increase in pace.

Already, we see new tools emerging to serve the budding trend, including MultiChain, which helps companies and institutions build their own blockchains. On the research front, interest in blockchain is high in some quarters. In Berlin, the think tank Blockchain for Science has been established, a "voluntary and loose association of individuals and groups" with a mission to "Open up Science and knowledge creation by means of the blockchain (r)evolution".[58]

In November 2018, IBM filed a patent application with the US Patent and Trademark Office for a "Blockchain for Open Scientific Research". According to the application, IBM feels that there is a lack of platforms showing transparent data collection and analysis steps and those that do exist offer "few options for ensuring that data will be resistant to modification".[59]

"Cloud computing and artificial intelligence are the tech that is important in the next two years. The next wave that we are investing in – around four to five years from now – is blockchain and quantum computing."

Kerry Purcell, VP, IBM Japan, Japan, interviewee

Already, there are early adopters of blockchain for research. Initiatives include:

- **Scienceroot**, a scientific ecosystem that plans to use the Waves blockchain platform to build and issue its own cryptocurrency, the "science token". In addition, it will provide "a decentralized open access collaboration platform" and "a Blockchain-based 'Scienceroot Journal' where all the scientific results, regardless of the outcome, might be published and rewarded".[60]
- **Pluto**, "a decentralized scholarly communication platform" that is powered by the Ethereum blockchain. Its aims include providing transparency around actions and transactions, compensating all activities on the platform, and empowering participants to make all major decisions.[61]
- **ARTiFACTS:** The platform allows researchers to "record a permanent, valid, and immutable chain of records in real-time, from the earliest stages of research for all scientific and scholarly artifacts, including citing/attribution transactions".[62]
- **Matryx**, a decentralized platform built on blockchain "that lets anyone contribute research, get the credit they deserve, and ultimately solve problems faster".[63]
- **Iris.ai**: Project Aiur aims to "use the blockchain to support a transparent AI peer review and publishing service with its own online economy".[64]

There are also discipline-specific examples in fields such as genomics and medicine.

56 Marr, B. A very brief history of blockchain technology everyone should read. Forbes. 16 February 2018. https://www.forbes.com/sites/bernardmarr/2018/02/16/a-very-brief-history-of-blockchain-technology-everyone-should-read/#e8c98d67bc47

57 van Rossum, J. Blockchain for Research. Digital Science Report. November 2017. https://figshare.com/articles/_/5607778

58 Blockchain for Science – Mission Statement. https://www.blockchainforscience.com/2017/04/25/mission-statement/

59 Suberg, W. IBM targets scientific research in latest blockchain patent. Cointelegraph. 12 November 2018. https://cointelegraph.com/news/ibm-targets-scientific-research-in-latest-blockchain-patent

60 Filippova, E. Blockchain solutions for scientific publishing. Medium.com. 19 June 2018. https://medium.com/crypto3conomics/blockchain-solutions-for-scientific-publishing-ef4b4e79ae2

61 Pluto – FAQ page. https://pluto.network/faq

62 ARTiFACTS – About page. https://artifacts.ai/

63 Matryx – About page. https://nanome.ai/matryx/

64 Knowles, K. Blockchain for scientists takes on Elsevier, the business the internet couldn't kill. Forbes. 13 June 2018. https://www.forbes.com/sites/kittyknowles/2018/06/13/blockchain-science-iris-ai-project-aiur-elsevier-academic-journal-london-tech-week-cogx/#34c5f30a1e0a

A 2017 report by technology company Digital Science outlined a number of ideas for applying blockchain to the research process, from providing a notarization function – allowing scientists to post a text or file with ideas, results or simply data – to pre-registration of studies and support for various forms of peer review. It also explored the introduction of a "Bitcoin for research" which could be used to provide financial rewards for research activities, such as writing, peer review, statistical support, exchange of lab equipment, outsourcing specific research, or the hosting of data.[65]

Some believe that the notarization aspect, in particular, has promise for academia, particularly given the growing influence of AI.

"When we get 10 years down the line and you've got AIs giving you real predictive insights, that is going to create a lot of debate around how you determine what was done by a person and what was done by a machine. Blockchain will give complete traceability and reproducibility of the experiment."

Andrew Till, VP – Technology & Marketing, HARMAN Connected Services, US, interviewee

But while expectations are high for blockchain's future potential in some quarters, there are also many that question its value.

"It's a hype right now – most of the stuff is quite gimmicky …It's a solution looking for an answer. That doesn't mean it will not have some utility in the market."

Josh Nicholson, co-founder and CEO, scite.ai, US, interviewee

Widespread adoption, not just by the academic community but by society at large, is still some way off due to a number of factors. These range from scalability – each chain or network involves a large number of users – to the environmental cost; it's been estimated that the average amount of electricity used to mine Bitcoin in 2017 outstripped the annual energy usage of around 159 individual countries.[66]

Another difficulty centers on the complexity of the current blockchain process. This appears to be supported by figures uncovered by consulting firm Deloitte, which found that while the number of blockchain-related projects on GitHub is growing significantly – in 2016 alone, there were almost 27,000 new projects – around 90 percent become idle.[67]

Some believe that the cryptocurrency model, (the one with the highest level of adoption to date), is unlikely to work for research.

"The idea that you can do endless iterations is fascinating. However, the question is whether it won't get too messy for research purposes. Personally, I think AI has a bigger and more obvious potential."

Gregory J. Gordon, Managing Director, SSRN, an Elsevier company, US, interviewee

In a *Nature* blog post, Gideon Greenspan, founder of Coin Sciences, commented: "Currency-style blockchains are unsuitable as scientific archives, because recording each transaction incurs a financial cost, which can easily add up."[68] In the same post, Claudia Pagliari, who researches digital health-tracking technologies at the University of Edinburgh, touched on the ethics issues involved: "What happens if a patient withdraws consent for a trial that is immutably recorded on a blockchain? And unscrupulous researchers could still add fake data to a blockchain, even if the process is so open that everyone can see who adds it."[68]

65 van Rossum, J. Blockchain for Research. Digital Science Report. November 2017. https://figshare.com/articles/_/5607778

66 Galeon, D. Mining Bitcoin costs more energy than what 159 countries consume in a year. Futurism.com. 27 November 2017. https://futurism.com/mining-bitcoin-costs-more-energy-159-countries-consume-year/

67 Trujillo, J. L., Fromhart, S., & Srinivas V. Evolution of blockchain technology. Deloitte Insights. 6 November 2017. https://www2.deloitte.com/insights/us/en/industry/financial-services/evolution-of-blockchain-github-platform.html

68 Extance, A. Could Bitcoin technology help science? Nature. 18 December 2017. 552, 301-302. doi:10.1038/d41586-017-058859-4

Enhancing learning with VR and AR

There are two additional technologies experiencing tremendous growth that could prove game-changers in how society learns, communicates and collaborates – virtual reality and augmented reality. People often use the terms interchangeably, but there are distinct differences between the two (see sidebar "Understanding the terms").

Virtual reality (VR) is frequently used to enhance computer game playing or watching movies but, equally importantly, it can be used to improve training options, allowing people to learn and practice in a simulated environment. This has huge implications for many fields, particularly health.

"That's one of the next big things, what virtual reality can do to not only help you understand that reference material someone is pointing to, but experience it."

Andrew Till, VP – Technology & Marketing, HARMAN Connected Services, US, interviewee

Augmented reality (AR) is entering the mainstream faster than VR, possibly because some elements can be enjoyed without special equipment, which reduces the costs. For example, AR apps already deliver pop-out 3D emails, photos or text messages on mobile devices. And, in the tech industry, AR is being used to create holograms and motion-activated commands.[69]

Both technologies have enormous potential in education and training. Their key strength is that they can bring knowledge to life by making it visual and applicable. Many existing examples of their use in teaching can be found in the health and medical sciences. For example, a study exploring the effects of AR in science laboratories found that the technology enhanced the development of the university students' lab skills.[71] And several studies have shown improvements in surgical residents trained on VR simulators – they "were almost 30 percent faster in surgical dissections and made 1/6 of the errors of their non-simulator trained counterparts".[72]

In fact, virtual reality in the health care market is expected to be worth $3.8bn by 2020, and $5.1bn by 2025.[72] And a 2016 study found that 18 percent of US physicians have already used VR for professional purposes; three in five are interested in using VR for medical training and CME (continuing medical education); and more than half are interested in using it to learn about new treatments and conditions.[73] VR also has practical applications in other fields.

"We're experimenting with augmented reality headsets with our trainee and newly-trained engineers to overlay plans in front of their eyes. We can also get experienced remote engineers to use the camera on the headset to effectively look through their eyes and talk them through complex jobs."

Nicola Millard, Head of Customer Insight & Futures, BT, UK, interviewee

Understanding the terms

Virtual reality is a computer-generated recreation of a real-life environment or situation. Users are "immersed" in these virtual worlds, usually by donning a special headset that stimulates hearing and vision.[69]

Augmented reality overlays virtual information on top of your existing natural environment, with the two harmoniously coexisting. Virtual information is often used as a tool to provide assistance in everyday activities.[70]

69 Virtual reality vs. augmented reality. Augment. https://www.augment.com/blog/virtual-reality-vs-augmented-reality/

70 The ultimate guide to understanding augmented reality (AR) technology. Reality. https://www.realitytechnologies.com/augmented-reality/

71 Akçayıra, M. et al. Augmented reality in science laboratories: The effects of augmented reality on university students' laboratory skills and attitudes toward science laboratories. Computers in Human Behavior. April 2016. 57, 334-342. doi:10.1016/j.chb.2015.12.054

72 Cobos, S. AR/VR innovations in surgery and healthcare. Premo Grupo. 14 August 2017. https://3dcoil.grupopremo.com/blog/arvr-innovations-surgery-healthcare/

73 Arnold, M. Gauging VR's promise for pharma. Decision Resources Group. 21 April 2016. https://decisionresourcesgroup.com/

Virtual reality makes remote surgeries a future possibility.[72] And it is already being used to treat and heal psychological conditions such as post-traumatic stress disorder (PTSD).[69] Scientists from Tomsk Polytechnic University and Siberian State Medical University in Russia have used VR to develop an early diagnosis system for neurodegenerative disorders. It will work by immersing the patient in a virtual environment to carry out some functional tests. Researchers will vary the parameters of the virtual environment and record changes in the person's movements.[74]

In the case of AR, it enables us to experience scientific experiments, such as chemical reactions, that we cannot easily experience in the real world.[75] By displaying virtual elements over real objects, it also makes it possible to visualize concepts, such as airflow or magnetic fields, or events.[76, 77] For some, AR in particular could be a key ingredient in helping researchers achieve the desired increase in public engagement.

"It might be helpful to close the cognitive gap between science and society. Visualization will become more important and this will enable that."

Josh Nicholson, co-founder and CEO, scite.ai, US, interviewee

But the costs of AR and VR devices remain high and that has held back wide adoption rates to date. In addition, both require high-performance supporting technology. If these obstacles can be overcome, we could see their use become more widespread. Eventually, a scenario could arise where human trainers are no longer required. The question is how long it might take us to reach that stage.

"Will we have a world that looks like Ready Player One [sci-fi thriller]? And when will that happen? When does it become something that in some sectors you can't work without?"

Technology expert, US, interviewee

The rise of robotics

Robots are another example of machines or tools that have the power to aid researchers and streamline workflows. But, just as with AI, some fear that their increased use could signal job losses in academia and beyond. Writing for the *Huffington Post*, Harvey stated: "The future of manual labour inevitably lies in the clutches of robots and many menial tasks requiring less cognitive thinking will be transitioned into a machine based labour force."[78]

They already play an active role in manufacturing and have done so for many years now. Many are also used in dangerous environments (including bomb detection and de-activation), or where humans would be unable to survive. Robotics – the interdisciplinary science behind robots – is increasingly used as a teaching aid.[79]

Understanding the terms

Robot: There are many definitions, but most agree that robots are programmable machines that can carry out tasks independently, or semi-independently.

Robotics: The interdisciplinary branch of engineering and science that looks at the design, construction, operation and application of robots.

69 Virtual reality vs. augmented reality. Augment. https://www.augment.com/blog/virtual-reality-vs-augmented-reality/

72 Cobos, S. AR/VR innovations in surgery and healthcare. Premo Grupo. 14 August 2017. https://3dcoil.grupopremo.com/blog/arvr-innovations-surgery-healthcare/

74 Virtually reality simplifies early diagnosis of multiple sclerosis and Parkinson's disease. ScienceDaily. 2 September 2016. https://www.sciencedaily.com/releases/2016/09/160902082650.htm

75 Klopfer, E. & Squire, K. Environmental Detectives—the development of an augmented reality platform for environmental simulations. Educational Technology Research and Development. April 2008. 56, 2, 203-228

76 Dunleavy, M., Dede, C., & Mitchell, R. Affordances and Limitations of Immersive Participatory Augmented Reality Simulations for Teaching and Learning. Journal of Science Education and Technology. 2009. 18, 7-22. doi:10.1007/s10956-008-9119-1

77 Wu, H-K. et al. Current status, opportunities and challenges of augmented reality in education. Computers & Education. March 2013. 62, 41-49. doi:10.1016/j.compedu.2012.10.024

78 Harvey, C.T.S. The knowledge economy is real – we just might not like it. Huffington Post. 27 July 2017. https://www.huffingtonpost.co.uk/christopher-ts-harvey/knowledge-economy_b_17597610.html

79 The use of robotics and simulators in the education environment. Purdue University website. https://online.purdue.edu/ldt/learning-design-technology/resources/robotics-simulators-education-environment

In the short term, robots are expected to continue easing the burden on humans by taking on more of these kinds of tasks. The use of robotics in surgery has been growing steadily since the turn of the century and companies are working to create smaller, faster models. These are currently largely controlled by human doctors but, in a blog post in *The Guardian*, Luke Hares, Technology Director at CMR Surgical, commented: "We'll see the man/machine barrier changing…Eventually you'll get to the point where the surgeon can say 'put a stitch in here please'. But we're right at the beginning of that journey."[80]

We already see them assisting researchers with standard jobs – for example, at Radboud UMC, an academic hospital in Nijmegen, the Netherlands, digital assistants do the first scans of tissue samples for pathologists. According to the pathologists, the robots are better and faster at detecting very early stages of cancer and they work 24/7. The pathologists need only check the conclusions the robots have drawn.[81]

But robots are mostly non-AI at present and if artificial intelligence is introduced, that opens the door to new possibilities. Some industries are already combining the two, including a UK agritech start-up which is developing an arable farming system that will draw on both technologies to increase precision in planting, gain better yields and reduce pollution and waste.[82] As The American Society of Mechanical Engineers notes: "More advanced generations of collaborative robots are on the way: smart, mobile, collaborative, and more adaptable. Humans are not strictly necessary, as robots can collaborate effectively with other robots."[83]

In the world of research, robots and the other technologies we've explored in this essay are being used to create the labs of the future, which give researchers more time to think while machines run and gather data on experiments; "faster, more reproducible research that leads to newer, more effective therapies developed in less time".[84]

Some believe we'll see robots play a role in teaching, particularly as degree courses change form and are increasingly delivered online (see The academy and beyond essay).

"It's a positive change to use human beings where they are better than robots, and to use robots where they are better than human beings. But there is a bigger question about how we'll deal with robots in the next 10+ years; for example, if they do a job like a human then fiscally they might have to be treated like human beings and pay their taxes…"

Rolf Tarrach, President of the European University Association, Belgium, interviewee

The power of 3D printing

The last technology we explore in this essay is the 3D printer. While it has been in existence for nearly three decades now, and has already created items as diverse as car and body parts, clothes and medication, it is gaining in popularity in many industries as the costs continue to decrease.

Understanding the terms

3D printing: Material is joined or solidified under computer control to create a three-dimensional (3D) object. These objects can be almost any shape or size and are typically produced using digital model data from a 3D model or other electronic data source, such as an additive manufacturing (AM) file.

80 Devlin, H. The robots helping NHS surgeons perform better, faster – and for longer. The Guardian. 4 July 2018. https://www.theguardian.com/society/2018/jul/04/robots-nhs-surgeons-keyhole-surgery-versius

81 Bejnordi, B.E. Diagnostic assessment of deep learning algorithms for detection of lymph node metastases in women with breast cancer. JAMA. 2017, 318(22), 2199-2210. doi:10.1011/jama.2017.14585

82 Robotics and AI combine for precision future farming platform. The Engineer. 2 November 2018. https://www.theengineer.co.uk/future-farming-platform/

83 Crawford, M. Top 5 robot jobs in manufacturing. March 2017. ASME. https://www.asme.org/engineering-topics/articles/robotics/top-5-robot-jobs-manufacturing

84 Smith, S. & Forbes Technology Council. In the lab of the future, robots run experiments while scientists sleep. Forbes. 21 December 2017. https://www.forbes.com/sites/forbestechcouncil/2017/12/21/in-the-lab-of-the-future-robots-run-experiments-while-scientists-sleep/#2de96c1d1b3e

For researchers, it can be a user-friendly tool for experimentation, for example, the production of protypes "used to cost thousands of pounds at each stage of development". With a 3D printer, protypes can be printed at each stage of the process at a fraction of the usual cost.[85] 3D printing also supports collaboration and sharing – information or data can be sent to colleagues for printing anywhere in the world.

In the near future, researchers and "DIY scientists" could be setting up their own science labs using 3D printed materials. "Scientists are now creating innovative designs for lab equipment that can be sold online and printed out affordably."[85]

In the biology and medical science fields, it is possible to use 3D bioprinting to print scaffolds on which living cells can be seeded. These then grow into an approximation of human tissue. Miniature organs have already been created for drug testing; some predict that technology to print complete, workable organs is likely to be available within the next 10 years.[85] Its potential uses in all areas of science, technology, engineering and medicine are continually growing and researchers have been quick to embrace the opportunities on offer. A team of scientists from Australia and the US have developed a way to print brain structures in 3D so that they can grow nerve cells to mimic a real brain.[86] And, in the future, it might be possible to make your own medicines at home – the same technology could see chemistry become digitized, allowing users to synthesize almost any compound, whatever their location.[87]

"I think 3D printing will have a tremendous impact because it will enable complete new branches of science to be developed."

Andrew Till, VP – Technology & Marketing, HARMAN Connected Services, US, interviewee

Easing the burden on reviewers and editors

The technologies we've explored in this essay have enormous potential to reshape core researcher activities, including the validation process of peer review, which many consider the cornerstone of the research communication process. The peer review system is under pressure: a small proportion of researchers are taking on a disproportionately large share of the peer review burden.

New models of peer review have been trialled in recent years and open peer review has some support (see Pathways to open science essay), but, overall, there has been no fundamental change in the process. There is much speculation that AI and machine learning could prove the catalyst for change. A Digital Science report looking at the future of peer review lists several ways early AI technology is being used to support the process and related activities. These include identifying new peer reviewers; fighting plagiarism; identifying bad reporting and bad statistics; and detecting data fabrication.[88] And a new product has entered the marketplace, StatReviewer, which aims to provide "an automated review of statistical and reporting integrity for scientific manuscripts".[89]

Some industry watchers believe that machines could help solve a problem that journal editors face daily – locating the right referees for a manuscript – as they can assess the suitability of researchers much faster and more efficiently than humans can. Others believe that introducing automation would likely speed up the peer review process – a real benefit to scientific progress. In addition, human bias could be removed.[88] As we've seen, depending on how blockchain develops, it could also prove beneficial to peer review.[90]

While our interviewees and survey respondents generally agree that technology could make an important

85 The future is now: 3D printing in science laboratories. InterFocus. 26 January 2018. https://www.mynewlab.com/blog/the-future-is-now-3d-printing-in-science-laboratories/

86 Lozano, R. et al. 3D printing of layered brain-like structures using peptide modified gellan gum substrates. Biomaterials. October 2015. 67, 264-273. doi:10.1016/j.biomaterials.2015.07.022

87 Service, R. You could soon be manufacturing your own drugs—thanks to 3D printing. Science. 18 January 2018. doi:10.1126/science.aat0484

88 What might peer review look like in 2030? BioMed Central & Digital Science. April 2017. http://events.biomedcentral.com/wp-content/uploads/2017/04/SpotOn_Report_PeerReview-1.pdf

89 StatReviewer website. http://www.statreviewer.com/

90 Blockchain powered peer-reviewed journal. ThoughtWorks. https://www.thoughtworks.com/talks/blockchain-powered-peer-reviewed-journal

contribution to the evaluation of papers, many remain unsure just how far that involvement should extend. It is feasible that, in the future, rather than augment peer review, AI could replace it with a form of evaluation that excludes human intervention. Some believe that automating something that has so much influence on scientific progress and researcher careers is risky; for example, computers could introduce errors, or the systems could be hacked. And some believe that computer algorithms that learn are inherently biased by the programmer or have the potential to be fooled – as a result, we could see AI shaping how researchers draft their submissions.

"It will… drive researchers to write more in the line of earlier work rather than doing something new and creative. This will trigger more "incremental" research rather than real innovative research."

Researcher in engineering and technology, Belgium, aged 26-35, respondent to researcher survey

Others question whether algorithms can truly replace human input; for example, the vision someone might contribute to shape a field. In particular, there are concerns that novel papers might be lost.

"I am just wondering if it would lead to confirmation bias by the AI machine: only selecting those articles that were considered qualitatively good in the past. Can it consider revolutionary papers?"

Psychologist, Belgium, aged 26-35, respondent to researcher survey

But, according to some interviewees, we still have plenty of time to iron out these issues.

"AI peer reviewed papers without human involvement at all is unlikely within our lifetime or our children's lifetimes."

Saul Tendler, Acting Vice-Chancellor, York University, UK, interviewee

Pain or gain? What researchers think about the new tech

In the researcher survey element of this study, we asked respondents what impact they think technology might have on their work in the decade ahead. Here's what they had to say…

59 percent expect that scientific progress will be dependent on technological advances in 10 years' time, a slightly lower number (50 percent) believe their own research will be dependent on it, while even fewer (46 percent) believe it is desirable.

When we break down those statistics by age group, we see that researchers aged 56 and over are less likely to expect research will be dependent on technological advances in the future.

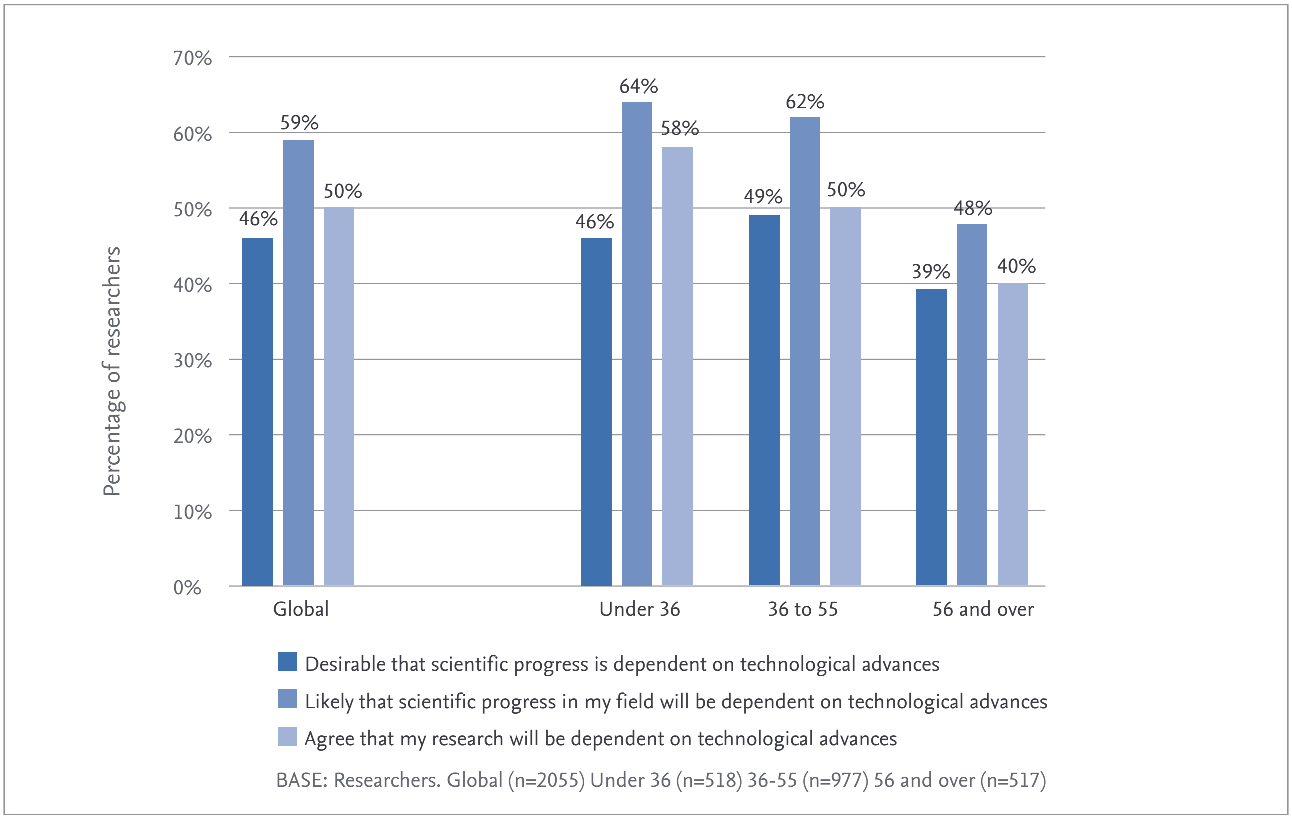


Figure 4.3: Researchers' views on the impact of AI and other technologies on scholarly research 10 years from now. Source: Researcher survey for this study.

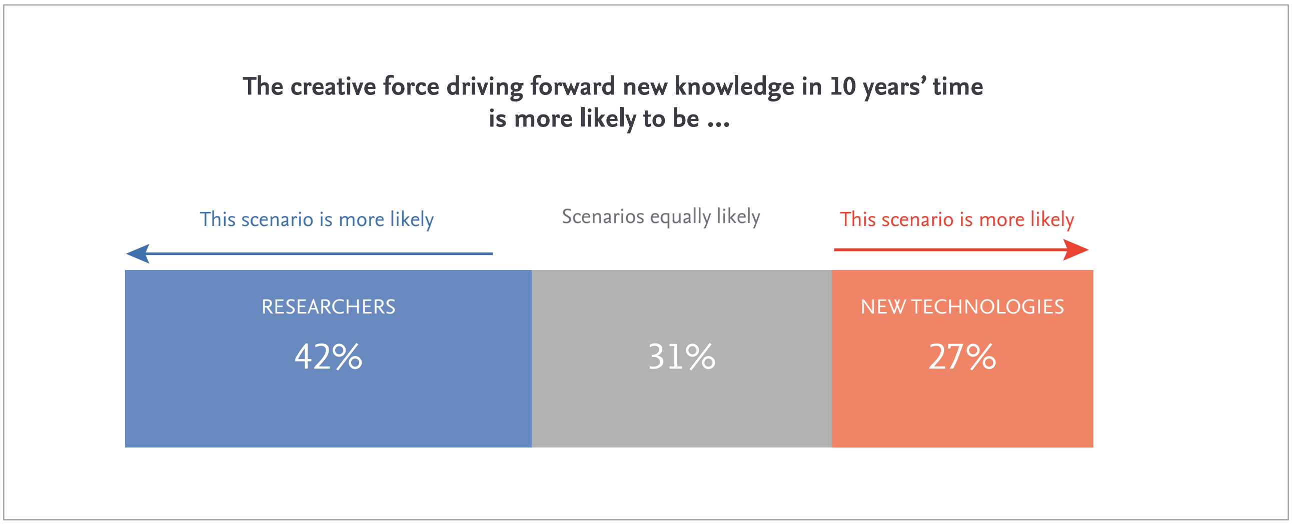


Figure 4.4: What researchers believe will drive knowledge forward a decade from now. Source: Researcher survey for this study. n=2055

When asked whether AI should be used to determine the publication of articles in the future, only a quarter (25 percent) agree it is desirable, but nearly two fifths (39 percent) expect that it will be used. There appears to be a greater appetite among those under the age of 36 years for AI to play a key role in peer review; almost a third (32 percent) desire it.

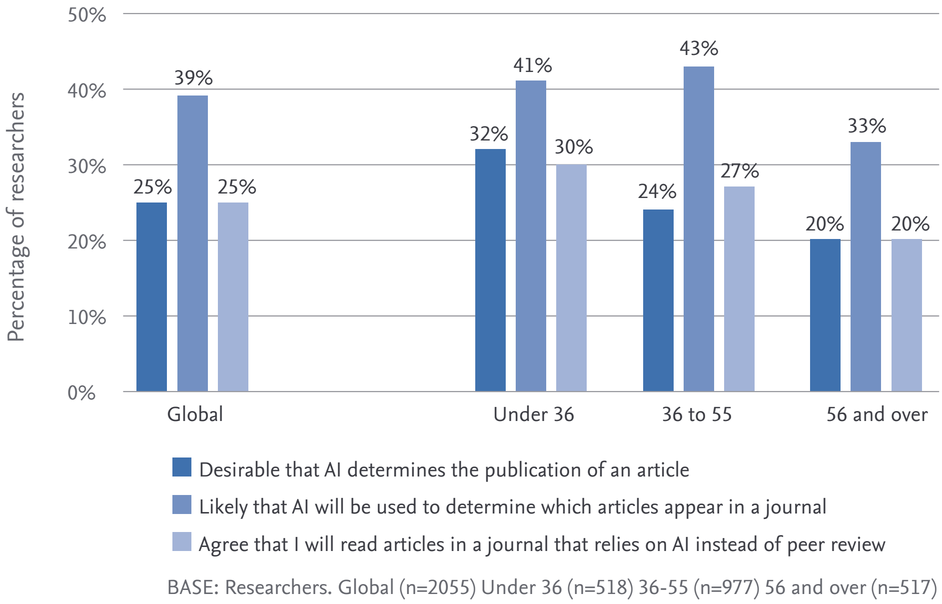


Figure 4.5: Researchers' views on AI's involvement in peer review. Source: Researcher survey for this study.

What's next?

There is no doubting the impact of technology, and AI in particular.

"Imagine a graph that goes from data in the bottom left through information, context, knowledge and finally to wisdom in the top right. I think that we are currently at the knowledge part of the graph and AI will take us to wisdom."

Gregory J. Gordon, Managing Director, SSRN, an Elsevier company, US, interviewee

The technological advances we will see over the next decade will undeniably have an impact of research, both in how it is done and the way it is communicated. Much of that impact will be positive: processes will speed up, menial tasks will be done by machines, researchers will be able to analyze vast data sets in novel ways, delivering new insights. Importantly, it will free up researchers' time so that they can think about the big issues, develop new hypotheses and communicate findings. However, there are other factors that we need to consider: technology is a double-edged sword; it has a habit of enabling more work, with the result that society expects more for less. It also has an unparalleled capacity for disruption.

The big question is probably just how far, and how quickly, AI will develop. The ultimate goal of many developers is general artificial intelligence; in other words, a system that can teach itself. The arrival of such intelligence threatens jobs, not only in industry, but in medicine and research too. Talty notes: "Some scientists believe it's 30 years away; others talk about centuries. This AI "takeoff," also known as the singularity, will likely see AI pull even with human intelligence and then blow past it in a matter of days. Or hours."[39]

At the moment, the general consensus seems to be that until we agree a definition of consciousness for people, helping a machine achieve that state remains an impossibility. Yann LeCun, Head of Facebook's AI research facility FAIR, confirms: "We're very far from having machines that can learn the most basic things about the world in the way humans and animals can do… in particular areas machines have superhuman performance, but in terms of general intelligence we're not even close to a rat. This makes a lot of questions people are asking themselves premature."[91]

39 Talty, S. What will our society look like when artificial intelligence is everywhere? Smithsonian.com. April 2018. https://www.smithsonianmag.com/innovation/artificial-intelligence-future-scenarios-180968403/

91 Vincent, J. Facebook's head of AI wants us to stop using the Terminator to talk about AI. The Verge. 26 October 2017. https://www.theverge.com/2017/10/26/16552056/a-intelligence-terminator-facebook-yann-lecun-interview

Building the future research information system

Setting the scene...

Traditional publishers, content aggregators, new entrants to the market such as information analytics players; all will be affected by the drivers of change we discuss in this essay. So too will researchers, funders, and higher education institutions. Each of them must navigate their way through an increasingly complex research workflow. And each party has the potential to reshape the future of scholarly research with their choices – content providers by adapting the formats and channels used to communicate research findings, funders and research producers through policy decisions and behaviors. Their decisions will determine the speed of change and the impact of trends such as open science, shrinking library budgets, the desire for transparency and reproducibility, and the need to evaluate and showcase research. With the help of our researcher and industry colleagues, we consider how the roles of these companies, and scholarly communication itself, might evolve in the coming 10 years.

What will be the key drivers and changes?

1. The role of the journal is transforming to meet modern needs

- In the future, the journal, or any new entities that emerge, will apply the **same level of attention to the data** and supplementary material as to the article. Most research articles will not be static, but will be updated by the author post-publication.
- As interdisciplinary collaboration, speed of publication and volume of content increases, **how research outputs are curated, grouped, stored, structured and disseminated** is being challenged. There may be an increased emphasis on the article over the journal, with the result that articles are published as standalone outputs and non-innovative journals close.
- One large information solution provider could **shift its value proposition** by fully embracing disintermediation and radically restructuring its products and services; this has the potential to **alter the entire marketplace**.

2. The article structure is evolving and new forms will become the norm

- Technology is enabling change and will continue to fuel it:
  - With access to a network of research outputs, the interconnectivity of articles will increase. They will become more **interactive and multi-layered**.
  - Articles are structured to enable discovery and analysis. The rising focus on the publication of **code and data**, combined with NLP (natural language processing) advances, will allow deeper **interrogation**.
- Many expect articles to become further **atomized**, breaking into standalone elements.

3. The measurement system will become even more critical

- The entire community is facing mounting pressure to **demonstrate the impact of research**, particularly on society, as the demand for accountability and transparency increases.
- In response, tools and metrics to help researchers, higher education institutions and funders will **transform how research is assessed, showcased and evaluated**, enabling evidence-based decision making and strategic planning.

Research communication: the essentials

Kent Anderson, CEO of Redlink & Redlink Network, regularly publishes updates to his 2012 Scholarly Kitchen blog post, highlighting the "things publishers do". While the number of items on his list now stands at 102,[1] four elements are generally recognized as cornerstone publishing activities:

- **Registration:** A timestamp officially recording who submitted scientific results first.
- **Validation:** Adding value to the research article and ensuring the validity and integrity of its results through peer review.
- **Dissemination:** Providing a medium for discoveries and findings to be shared.
- **Archiving:** Preserving the minutes of science for posterity.

But advances in technology are creating an environment in which traditional publishing-related activities are evolving, and there is growing pressure to respond to the changing needs of the community that publishers serve. In 2015, Michael Mabe, ex-publisher and CEO of the International Association of STM Publishers, was already forecasting that "the game is changing, and future revenue growth will [be] more innovation-led". He went on to add: "Publishers will have to come to terms with a faster rate of change, more frequent development and release cycles, and more external innovation."[2]

In the same year, Dominic Byatt, Publisher & Senior Commissioning Editor, Politics, at Oxford University Press, noted: "It will no longer be enough to offer content you can read to aid your research, publishers will need to offer content you *have* to read. If they don't do that, they won't survive. And the quantity of essential content is limited – which has challenging consequences for the number of scholarly publishers."[3]

For some, the arrival of platforms that illicitly bypass publisher subscription models, such as Sci-Hub, has created a ripple effect that will continue to make its presence felt in the publishing industry for some years to come.

"…making the papers available is creating a Napster moment, which brought in sharing and changed the business model of the music industry – this is having similar effects. Now there is a source to see any paper, so that's raising the pressure on publishers."

Jane X. Wang, Senior Research Scientist, DeepMind, UK, interviewee

And while universities have historically made their publishing arms independent commercial entities, more recently, it has been mooted that libraries and university departments could take control of the publishing reins. This concept of "taking back publishing"[4] has been a discussion point circulating for many years but has yet to gain the momentum and support required to spark real change.

In response to these factors, publishers have taken a long and critical look at their services and introduced innovations designed to help researchers. These include offering support to comply with funder requirements, disseminate research data and find an appropriate journal for publication. Publishers are also transferring rejected manuscripts to potentially suitable journals on the authors' behalf. At the same time, other, more traditional activities are becoming decoupled from publishers, moving to external services and companies.

Beyond the four publishing pillars

The four key elements, or pillars of publishing listed above have served the research community well to date, but how fixed are they, and to what extent are they likely to be impacted by these shifts in research communication?

1 Anderson, K. Focusing on Value — 102 Things Journal Publishers Do (2018 Update). Scholarly Kitchen. 6 February 2018. https://scholarlykitchen.sspnet.org/2018/02/06/focusing-value-102-things-journal-publishers-2018-update/

2 Ware, M. & Mabe, M. The STM Report: An overview of scientific and scholarly journal publishing. STM Association. March 2015. http://www.stm-assoc.org/2015_02_20_STM_Report_2015.pdf

3 Goldsworthy, S. The future of scholarly publishing. OUP blog. 10 November 2015. https://blog.oup.com/2015/11/future-scholarly-publishing/

4 Björk, B-C. Publishing speed and acceptance rates of open access megajournals. Online Information Review. 2018. https://doi.org/10.1108/OIR-04-2018-0151

In the case of registering research, for many years, publishers have fulfilled this role by publishing articles in a journal with a date stamp showing when the article was received and accepted. Each article also receives a DOI (digital object identifier), a unique alphanumeric string that creates a persistent link to the content's location on the internet. The published articles are either made available on publishers' customized content platforms, or third-party platforms.

While these content platforms are widely used to access articles, over the past few years, we've seen a rise in the popularity of preprint servers such as arXiv, bioRxiv and SSRN, which offer an early method of registering results publicly (and quickly). One of our interviewees for this study, Gregory J. Gordon, MD of Elsevier company SSRN, believes the secret to their growth is that they help "people fail faster" by sharing ideas at an earlier stage of the process and testing what works and what doesn't.

"Every single hurdle in the process of scientific discovery is a delay in our ability to cure diseases, tackle climate change and antibiotic resistance – all these challenges are slowed down by the fact that we can't have a faster turnaround in the publication and consumption of results …can we accelerate the amount of content and improve the management of growth along with better filters?"
Social computing researcher, US, interviewee

Many preprint servers are independent or are backed by foundations/funders (bioRxiv, for example, is funded by the Chan Zuckerberg Initiative). In addition, we've seen researchers themselves stepping into the marketplace with the launch of ASAPbio, a "scientist-driven initiative to promote transparency and innovation in life sciences communication".[5] As several major funders have policies that support the dissemination of results through preprint servers, the signs are strong that their star will continue to rise. However, one potential cloud on the horizon could be a reluctance among some researchers to share their information so openly.

"Getting information out faster (i.e. speed to publication) is the way forward and preprints should be accepted as a legitimate form of publication. However, we are still in a Principal Investigator (PI)-centric world, with secrecy, and where citation metrics rule."
Melissa Rethlefsen, Associate Dean, George A. Smathers Libraries, US, interviewee

Despite the opportunities offered by technology, attempts to revitalize the evaluation process of peer review have yet to gain traction.

"… journals offer the unique opportunity to have peer experts review and critique articles… This peer review process is critical for maintaining confidence in scientific study results."
Researcher in earth and planetary sciences, US, aged 26-35, respondent to researcher survey

Peer review lies at the very heart of scholarly communication and the 20th century saw its widespread adoption. Yet many feel that it is the phase in the research communication process most ripe for development, either by changing how it is done or by challenging the very need for it.

In recent years, software and platform developments have offered opportunities to trial alternate methods for conducting peer review, particularly "open" forms of peer review. Though these have enjoyed some success, and double blind peer review (in which the reviewer and author information is closed to all but the editor) is repeatedly noted as the most desirable form, single blind peer review remains by far the most common model.[6]

The arrival of megajournals more than 10 years ago (explored later in this essay), signaled a new approach to peer review – evaluation is minimal and is focused on determining the validity of the research. The article's merit is established following publication, typically via the posting of reader comments. The megajournal model was pioneered by *PLOS ONE*, which has been remarkably successful since its launch in 2006, holding

5 ASAPbio website – About us page. http://asapbio.org/about-us.

6 Elsevier. What is Peer Review? https://www.elsevier.com/reviewers/what-is-peer-review

true to its founding principle of publishing research that is "sound" rather than novel. However, in the intervening years, the journal's peer review times have slowed down,[4] likely as a result of peer review becoming more involved or difficulties in finding willing and motivated reviewers.

Securing reviewers is possibly the biggest single challenge for journal editors. In recent years, platforms like Publons and Elsevier's Reviewer Recognition Platform have been established. These not only support editors in sourcing new referees, but help reviewers demonstrate their contribution to scholarly communication. They also offer indicators around the quantity and quality of peer review and are perfectly placed to incorporate peer review metrics. But despite efforts by the community to develop a new peer review measure, the hunt continues. And, if one is found, its success will depend upon the willingness of the research community and institutions to adopt it.

Recent technology developments have created an environment in which peer review could become detached from journals and ultimately publishers.

"Peer review might become more self-organized in online communities – without the intermediary of the publisher."

Jane X. Wang, Senior Research Scientist, DeepMind, UK, interviewee

Early attempts along these lines have yet to gain a foothold, probably because, for many, peer review is strongly linked to the brand of the journal, a "...signifier of quality in an era where filtering the sheer volume of content online can prove overwhelming".[3] But it is likely that over the next 10 years, as the role of the journal diminishes (see "The article tries on new jackets for size" in this essay), we will see further attempts to turn peer review into an independent activity, dissociated from journals and mediated through third-party software platforms. Peer review is also likely to be significantly impacted by advances in artificial intelligence and, potentially, blockchain technology (see Technology: revolution or evolution essay).

Although peer-reviewed journals are the main channel for research dissemination, when it comes to getting their work seen – pre- or post-publication – authors currently have a range of options; for example, they can post it on the preprint servers we discussed earlier in this essay, or they can share it via social media, personal homepages and repositories.

Scholarly collaboration networks such as ResearchGate and Mendeley also serve as repositories and continue to gain traction, although the rules around content sharing are sometimes infringed. There are also illicit sharing sites such as Sci-Hub, as well as new, legitimate players in the market, including "access brokers" such as Unpaywall and Kopernio, which provide one-click access to legal versions of research articles.

Although a 2010 global study conducted on behalf of the Publishing Research Consortium (PRC) found that 93 percent of researchers have "easy / fairly easy access" to journal articles,[7] Unpaywall and the like move beyond access – they offer convenience. They provide researchers with a seamless journey across a range of providers without the need to recall logins or be on campus. Existing providers understand these platforms can bolster their own tools. This has prompted new product launches and acquisitions, for example Clarivate recently acquired Kopernio.

Archiving or preservation remains the least visible (and so, perhaps, the least valued) element of a publisher's traditional functions. Despite the rise of online "archives" in repositories and preprint services, the need for records to be both complete and permanent means this is likely

3 Goldsworthy, S. The future of scholarly publishing. OUP blog. 10 November 2015. https://blog.oup.com/2015/11/future-scholarly-publishing/

4 Björk, B-C. Publishing speed and acceptance rates of open access megajournals. Online Information Review. 2018. https://doi.org/10.1108/OIR-04-2018-0151

7 Access vs. Importance A global study assessing the importance of and ease of access to professional and academic information Phase I Results. This global study extends a UK study by Mark Ware Consulting Ltd for the PRC (Publishing Research Consortium). Fieldwork, technical support and analysis was provided by Elsevier's research team for the PRC. October 2010. http://publishingresearchconsortium.com/index.php/prc-documents/prc-research-projects/19-prc-access-vs-importance/file

to remain a role for established publishers, in association with deposit libraries and newer online archives such as LOCKSS and Portico. Blockchain technology may also have a part to play: in the UK, The National Archives (TNA), in partnership with the University of Surrey and the Open Data Institute, began a project in 2018 to prototype a blockchain technology capable of archiving and checking the authenticity of its documents.[8] If successful, it is possible that the technology could be adapted to archive research articles.

As the four publishing pillars and the role of the publisher continue to evolve in the decade ahead, what might be the consequences – good and bad – for the research ecosystem? In the sections below, we consider the potential of these factors to shape how researchers work, how they – and the wider community – are assessed, how the articles published might change, and what (if any) role journals will play as the future unfolds.

New era, new tools: the researcher workflow

Companies previously focused on publishing have been expanding the scope of their solutions for the researcher, institution and funder for several years now (see How researchers work: change ahead essay). Moreover, we have also seen new players enter the market; a trend that is expected to continue. Researchers themselves are among the new entrants: several successful platform and product launches have stemmed from researchers building a solution to meet a workflow need, often harnessing technologies such as natural language processing (NLP) and machine learning. All these products are aimed at simplifying and increasing the efficiency of the researcher workflow, as we explore below:

Finding and managing literature

Researchers have long been able to search for scholarly literature through a host of databases, including Scopus, Web of Science and PubMed. They can also manage (collect, store and share) references through platforms such as Mendeley, ReadCube, PubMed and EndNote. More recently, these tools have evolved to include web and PDF annotation options. Some are increasingly taking a holistic approach, offering collaboration and networking opportunities so researchers can stay up to date with developments in their field, find each other and share knowledge.

Identifying funding opportunities

Tools such as Instrumentl and Grantome help researchers locate and apply for funding, while Dimensions offers tracking of funding by field of research.

Engaging with peers and beyond

Researchers are also making use of tools designed to serve the wider public; for example, social media. Twitter in particular is used for communicating about conferences, finding collaborators, public engagement, and sharing information with peers. And YouTube videos can help explain complex concepts.

Conducting research

Many tools have been designed to help researchers conduct research, a number of which are discipline-specific, or very niche, designed to tackle a very specific task, e.g. genome analysis or image-processing software. More broadly, there are tools built for the automation of various tasks, for example, statistical analysis, text mining and sharing of protocols.

Traditionally, laboratory work includes many repetitive, often simple tasks, which eat up valuable researcher time. Laboratory information systems (LIMs) and electronic laboratory notebooks (ELNs) have emerged to help automate some of these. They also support remote control of activities, early warning alerts about problem equipment, the capture of data or results, and they are increasingly providing much-needed connections between machines and outputs.

8 Blockchain: checking and archiving the documents of The National Archives in complete security. Orange: Hello Future. 12 March 2018. https://hellofuture.orange.com/en/blockchain-checking-archiving-documents-national-archives-complete-security/

Finding and sharing data

Sites like Figshare and Mendeley Data provide researchers with locations to find data sets and related research outputs and enable them to openly host their own data.

Writing articles

While digital writing tools have existed for many years, more recently there has been a focus on supporting collaborative writing with the launch and development of platforms such as Authorea, Overleaf, F1000Workspace, StackEdit, and ShareLaTeX. Some aspects of the authoring process can be outsourced to expert editors via sites such as BioEdit and Peerwith. Authorea is a clear example of researchers building solutions for researchers: the platform was developed because the founders "were frustrated that other writing tools didn't fully understand the needs of researchers – especially researchers in a web-first world".[9]

Choosing a journal

Services already exist to help a researcher identify journals that might be a suitable match for their manuscript. In addition to advice from libraries and research offices, researchers can now call on services such as Sherpa/RoMEO to identify which journals meet their funder's open access policy requirements – often a point of confusion for researchers.

Demonstrating impact

Showcasing research is also a key part of the researcher workflow experiencing change. Established and new platforms are being developed to help researchers satisfy these needs. Kudos is a prime example, providing researchers with an online toolkit to help explain and share their work, as well as track and show their impact. Kudos, like other platforms – including those built to serve other aspects of the researcher workflow – provides a range of indicators looking at usage, scholarly impact and wider engagement.

Over the coming decade, it is inevitable that we will see more new tools and platforms launch in response to newly-emerging researcher needs. We can also expect to see existing workflow solutions become increasingly intuitive, broadening their services as machine learning grows more sophisticated, and interconnected (see Technology: revolution or evolution essay).

How institutions are showcasing and evaluating research

Researchers aren't the only group under pressure to demonstrate impact. With many economies facing restricted budgets and tough spending choices, research institutions and funders are being asked to show that the projects they are linked to further knowledge and deliver true benefits, particularly to society. This, in turn, is increasing the pressure on researchers to share findings and explain how their work adds value (see "Making science accessible – and accountable" in the Funding the future essay).

Performance-based research funding systems (PRFSs) have been introduced in some countries to measure and benchmark the impact of research institutions, including their wider societal impact. The results of these PRFSs determine, among other things, the allocation of state-level research funding. While PRFSs vary in their details, they are typically large undertakings. New research analytics tools such as SciVal, Dimensions, Pure and Symplectic are helping institutions and funders track, analyze and report on some of the activities vital to these rankings. These platforms are also starting to incorporate new research outputs, specifically patents and policy documents, to improve the measurement of societal impact. It's expected that the existing partnership between the research community and information analytics providers will continue to grow, with new metrics focusing on societal impact being developed.

There has also been a rise in the number of ranking services to help students – and funders – understand and compare institutes, either regionally or globally. These include the various Times Higher Education World University Rankings, which evaluate teaching, research, international outlook, reputation and more. Other examples include the Financial Times (FT) MBA Rankings, Quacquarelli Symonds (QS), Shanghai China national university rankings, and the Maclean's University Rankings Canada. These ranking systems reinforce a culture of measurement, which, in turn, is impacting

9 Authorea website – About page. https://www.authorea.com/aboutus

the way governments perceive performance and how institutes think about themselves. The increasingly competitive landscape, combined with the continued need for accountability, means that the dependency on services to rank, categorize and order universities will only increase over the next decade.

The article tries on new jackets for size

The death of the journal has been discussed and questioned for many years[10] and yet its overall form has remained largely unchanged.

Despite the fact that the journal wrapper tends to be less visible in this digital age (when readers use keywords to search for content), industry watchers point to three key factors for its survival:

- The inertia in the attitudes and practices of academia, meaning that change is slow.
- The requirement, by most funders and institutions, that researchers publish in (preferably) high-impact journals.
- The fact that many readers still use journals to determine the quality of a paper. Or as interviewee Saul Tendler, Acting Vice-Chancellor, York University, UK, puts it: “I would still look to see where it’s published as a mark of its importance.”

In a 2015 STM report, Ware and Mabe noted: “The core motivations of authors do indeed appear to remain remarkably fixed, in terms (of) need for attribution and recognition, for quality control including peer review, for visibility and the widest reach for their idea.”[2]

In addition, many researchers consider journals to be central to their community’s identity, not only shaping it, but representing it, and acceptance into the community often depends on publishing in a journal that is closely connected to it.

There are signs that journals will continue to thrive: ”The number of articles published each year and the number of journals have both grown steadily for over two centuries, by about 3% and 3.5% per year respectively.”[11] Underlying drivers for growth in published journal articles also remain positive. These include investment by governments and higher education in research and development (see Funding the future essay), an increase in researcher numbers, and the continuing pressure on academic researchers to publish, and publish well. However, change is in the air.

In 2017, the European Commission called for a shift “… from the standard practices of publishing research results in scientific publications towards sharing and using all available knowledge at an earlier stage in the research process”.[12] One step toward this goal is the EU’s plan to establish the European Open Science Cloud, to which it has committed €2 billion of the overall €6.7 billion cost. This will host and process research data and will be free at point of use, but “currently, the commission’s dream is so big and shapeless that many involved can’t see a path to achieving it”.[13] In response to, or even anticipating these market demands, new journal formats and other article “jackets” have been gradually emerging.

Since the launch of *PLOS ONE* as the first megajournal, a host of similar titles have followed in its footsteps. Megajournals, which are often gold open access, already challenge the norm: they are designed to be much

2 Ware, M. & Mabe, M. The STM Report: An overview of scientific and scholarly journal publishing. STM Association. March 2015. http://www.stm-assoc.org/2015_02_20_STM_Report_2015.pdf

10 Weiner, G. The Academic Journal: Has it a Future. Education Policy Analysis Archives, 9(9). 2001. http://dx.doi.org/10.14507/epaa.v9n9.2001

11 Johnson, R., Watkinson, A., & Mabe, M. The STM Report An overview of scientific and scholarly publishing. Fifth Edition. STM Association. October 2018. https://www.stm-assoc.org/2018_10_04_STM_Report_2018.pdf

12 European Commission. Open Innovation Open Science Open to the World. 2016. doi:10.2777/061652. http://www.openaccess.gr/sites/openaccess.gr/files/Openinnovation.pdf

13 Don’t let Europe’s open-science dream drift. Nature. 20 June 2017. 546, 451. doi:10.1038/546451a. https://www.nature.com/news/don-t-let-europe-s-open-science-dream-drift-1.22179

larger than a traditional journal, often covering an entire discipline, or even all scientific disciplines. As we've seen earlier in this essay, while many traditional journals only publish novel articles, for megajournals, the requirement is frequently that papers simply contain sound science and are original. "An essential component in the pattern is somewhat low non-acceptance rates....handling peer review for manuscripts that are eventually declined is maintained to a minimum. Papers are evaluated in regard to their scientific trustworthiness only."[14] This also makes them an ideal home for negative results and a useful tool in combating reproducibility issues.

Though still one of the largest journals, the publication output of *PLOS ONE* is falling year on year and has been since its peak in 2013.[15] Launching and maintaining a megajournal isn't easy: "...a business model that ostensibly relies on a relatively rapid scaling of operations brings with it a host of challenges... These challenges manifest themselves in a number of ways: technically, operationally, and culturally."[16]

Is this an indication that these titles will struggle to hold their own in the years ahead? Not according to some industry experts. In 2017, the Association of Learned and Professional Society Publishers interviewed senior publishers and editors about open access megajournals for their journal, *Learned Publishing*: "A small number of interviewees suggested that it might be possible for the scholarly communications ecosystem to evolve into one driven by 'fifty to a hundred' megajournals responsible for the totality of scholarly output... However, the vast majority of participants felt a mixed-economy would be the most likely outcome." The interviewees considered it highly unlikely that open access megajournals would ever completely replace selective titles. [16]

There have also been new titles launched devoted to single article types – not the traditional research article but shorter papers looking at methods, protocols, software or data only. Typically, these titles are gold open access. In 2013, F1000 launched a platform, F1000Research, offering rapid publication (within seven days of submission) and immediate, open access to content; a channel where life scientists can publish all their "findings including null results, data notes and more".[17] Peer review takes place post-publication and is published online. Two major funding bodies (the Bill & Melinda Gates Foundation and Wellcome Trust) have partnered with F1000 to launch their own platforms for findings funded by their grants. The model has also been adopted by institutions including UCL Great Ormond Street Institute of Child Health and Montreal Neurological Institute and Hospital.

"There will be alternative open platforms that become credible competitors; based on network effects."

Researcher in economics, econometrics and finance, UAE, aged 56-65, respondent to researcher survey

In part, these new formats aim to solve a problem dogging today's scientific world: the reproducibility and transparency of research. As a result, a major focus of many of these new channels is the sharing of data, either directly within the article or via links to data repositories. And the speed of publication that many offer answers the need for rapid sharing of results, while still offering the reassurance of a registration "timestamp".

For some of our interviewees, the long-term future of the journal remains unclear, especially as open science, speedier publication, and preprint servers gather pace.

"This whole notion of academic journals policing the access to and release of information is debatable. We now have new ways of reaching an audience."

Anand Desai, Professor, John Glenn College of Public Affairs, Ohio State University, US, interviewee

14 Lazaroiu, G. Do mega-journals constitute the future of scholarly communication? Educational Philosophy and Theory. 1 March 2017. 49(11), 1047-1050. doi:10.1080/00131857.2017.1300022

15 Davis, P. PLOS ONE Output Drops Again in 2016. Scholarly Kitchen. 5 January 2017. https://scholarlykitchen.sspnet.org/2017/01/05/plos-one-output-drops-again-in-2016/

16 Wakeling, S. et al. Open access megajournals: The publisher perspective (Part 2: Operational realities). Learned Publishing. September 2017. 30(4), 313-322. doi:10.1002/leap.1118

17 F1000Research website. https://f1000research.com/

"The book and journal are archaic, artificial constructs, from the printing press (age). Now we are used to them but someday that won't be the case."

Postdoc in computational neuroscience, UK, interviewee

Some industry watchers believe the future holds a two-step process that allows researchers to swiftly publish initial findings before later sharing a polished and refined version. For others, the key to the journal's survival is finding a way to remove the "noise" so that content can be easily found. Most agree the form will continue to evolve, with artificial intelligence powering increased virtual linking of papers.

"…publication in scientific journals is a tedious and time-consuming work, and new technologies and communicating tools will offer (opportunities) to communicate the results more readily."

Medicine and allied health professional, Spain, aged 36-55, respondent to researcher survey

There is broad agreement that the most prestigious journals will survive, with researchers, attracted by their strong reputations and trusted positions, choosing them for "critical" submissions. However, some predict the number of prestigious titles will reduce as researchers start to make do with other channels for the bulk of their work.

It seems clear that, in the future, the article will continue to need some kind of outer wrapper, or container, to give the content some context. The question is how that container will differ from the journals we read today. It could well be broader in terms of content type, and broader too in terms of the novelty of the papers it accepts. Or, more likely still, we'll see the size of the container increase in line with the megajournal format we've explored above.

How do researchers expect to share their findings in the future?

80 percent of the researchers who responded to our survey think it is likely that the article will still be the key output of research in 10 years' time. In contrast, 65 percent of respondents think this is desirable. Views vary depending on discipline and location: researchers in mathematics and Western Europe are less likely to think journal articles will remain the primary communication channel.

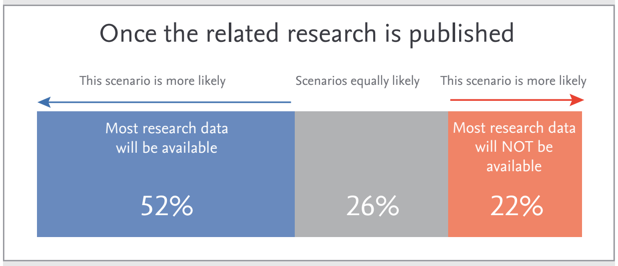


Figure 5.1: Researchers' views on the future of the article. Source: Researcher survey for this study. n=2055

Only half the respondents feel that most research data related to published research will be made available in 10 years' time. This could create a potential conflict with the growing data sharing mandates. And if industry funds more research going forward (which is likely to be the case – see the Funding the future essay), that tension will only rise.

Scholarly articles: a fresh look

For many centuries, the dominant channel for delivering research results has been the research article – a multi-page, text-based report of a full research study published in a scholarly journal. However, for a number of years now, many have questioned whether there is a better way to communicate findings.

This has prompted two key developments. The first, as we've seen in the section above, is centered around the conventional article being deconstructed, or "atomized", with new, shorter publications emerging. The second development centers on the sharing of new types of research outputs alongside the core article; for example, data, code and images, satisfying the general move toward more open practice of research (see Pathways to open science essay).

These developments to the research article enable the reproduction of experiments and potentially save other researchers time, and funders money, by allowing existing knowledge to be reused. Some industry watchers believe that readers will soon be able to search for, and access, each component of the traditional research article individually, potentially replacing the need to publish findings in full.

"People like a narrative, but it will get smaller with elements like protocols and methods published separately – there's something called Matters that simply publishes individual figures."

Robert Kiley, Head of Open Research, Wellcome Trust, UK, interviewee

Alongside the new journals that focus on a single research component, e.g. data or software, a growing number of traditional journals are allowing or encouraging the publication of microarticles. These publications share common features: they are often only a couple of pages long; they capture a single stage or finding of an experiment (or even negative results); and they are usually published in addition to the main research article. For authors, they offer the opportunity to receive recognition for separate steps in the research process and share findings earlier than might otherwise be possible.

Other types of channels are also emerging to support these innovations, for example, Code Ocean, a cloud-based computational reproducibility platform focused on the sharing of code.

"In my research field, software and data sets are key. These should be discussed in a more open form than an article."

Respondent working in computer sciences/IT, Germany, aged 26-35, respondent to researcher survey

In particular, the intrinsic value of data is being recognized globally, not only in academia, but across all industries with companies investing heavily in data resources. But the challenge is to understand how it is best used and all industries are wrestling with the same issue when it comes to data sets: how to balance privacy with producing results.

There have been moves by funders, research institutions and government bodies to encourage, and even mandate the open sharing of research data (see "Open data: to share or not to share" in the Pathways to open science essay). And many publishers and sites like Mendeley Data and Figshare now provide DOIs (unique identifying numbers) for published data, so that it can be easily linked to the author and cited by other researchers. "As the call for greater sharing of research data and code grows louder, researchers are citing data sets more often and scholars are starting to get credit for publishing high quality data."[18]

Data is also being visualized online through 3D viewers and even video articles. We've also seen the launch of dedicated video journals such as the *Journal of Visualized Experiments* (*JoVE*) and *VideoGIE*.

"I do expect that in the future everything published will contain the figures and the data and you will be able to run the code on the fly in your browser to easily validate the findings. Sure, people like PDFs to read offline, but the online version will become less static."

Robert Kiley, Head of Open Research, Wellcome Trust, UK, interviewee

18 Swoger, B. Does the scientific journal have a future? Scientific American. 18 June 2014. https://blogs.scientificamerican.com/information-culture/does-the-scientific-journal-have-a-future/?print=true

While there are solutions being put in place to cater for the registration and dissemination of the article in its new formats, challenges remain; for example, there is no established, effective and consistent way to peer review these new and non-traditional outputs.

Another challenge is to ensure effective linking between the various elements. This has led, in part, to the current drive to enhance the connectedness of information. In 2014, a number of university professors joined forces to write the online post, "The "Paper" of the Future", in which they argue that there should be "seamless linkages amongst data, pictures, and language, where "language" includes both prose and mathematics". They go on to explain: "When an individual attempts to understand each of these kinds of information, different cognitive functions are utilized: communication is inefficient if the channel is restricted primarily to language, without easy interconnection to data and pictures…"[19]

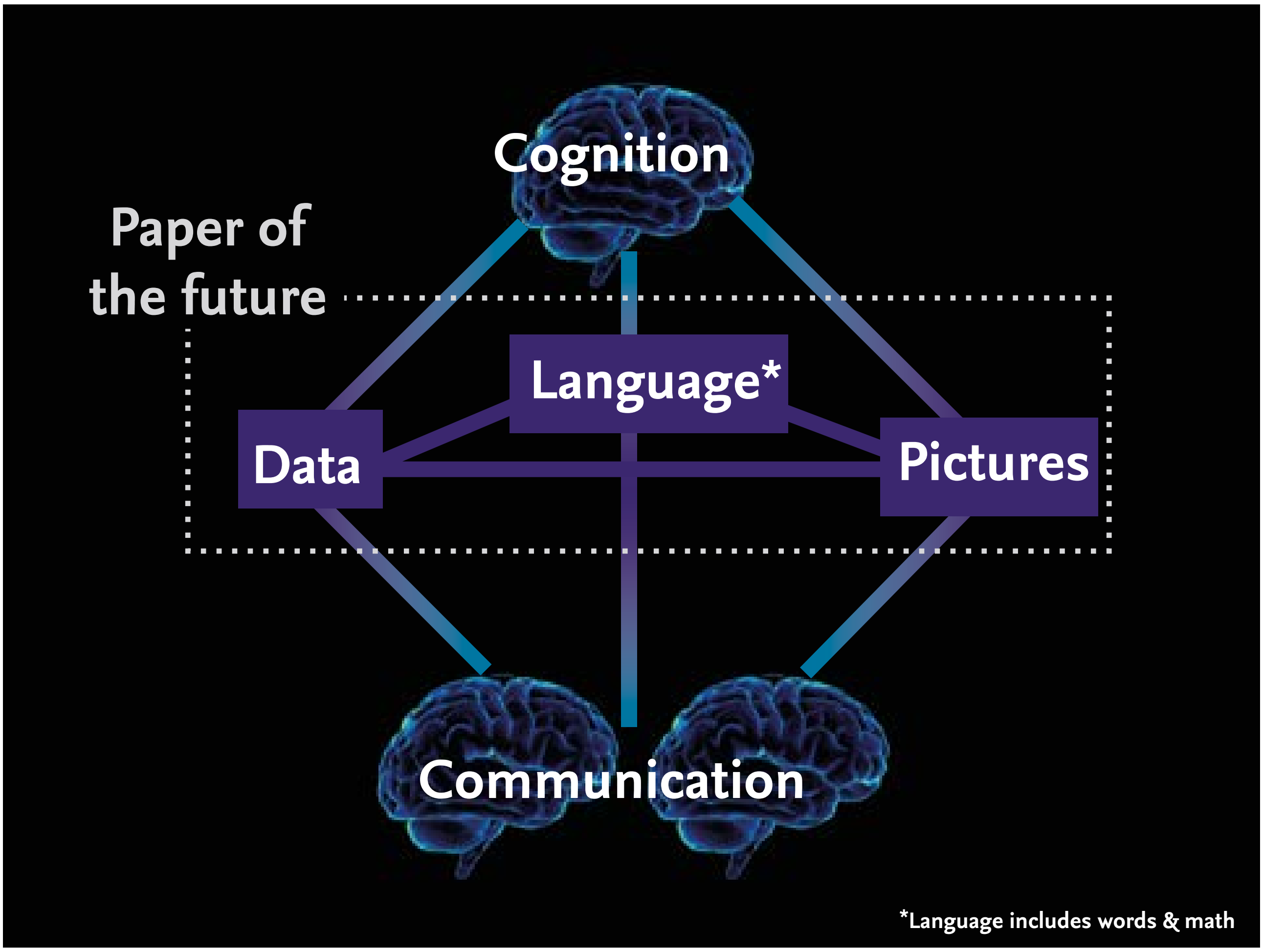


Figure 5.2: Image taken from "The "Paper" of the Future" post.[19]

19 Goodman, A. et al. The "Paper" of the Future. Authorea. https://www.authorea.com/users/23/articles/8762-the-paper-of-the-future

In recent years, publishers, including Elsevier, Wiley and eLife, have developed new formats based on how articles are "used", which have made it possible for researchers to not only link to their own research data, but to a range of third-party data repositories such as gene and protein databases.

But while the interactivity of articles is likely to continue evolving as artificial intelligence and other technology developments create new opportunities (see Technology: revolution or evolution essay), further change will rely on the willingness of researchers to supply the extra material required.

Many of our interviewees for this study also feel that there is a need to focus on making content more machine-learning friendly to cater for the artificial intelligence tools that increasingly scan and mine articles alongside researchers.

"We should think more about the scientific information system rather than articles or journals. In particular, we need more links with protocols and data."

Odile Hologne, Delegate for Scientific Information, INRA, France, interviewee

For some in the industry, the first step toward enabling this mining – and, indeed, the true atomization of the research article – is to address how researchers work.

"We still follow the pattern of: do an experiment – study – write a report – publish a paper. This doesn't lend itself to finding and sharing the information. If I currently search for content, I find the "container", i.e., the paper. In reality, what I want is atomization of the insight or the method in a way that is easy for the machine to consume and find and share and replicate."

Product development specialist, US, interviewee

What's next?

The process of research will continue to change across the entire workflow: from how funding is allocated and researchers locate literature, to how they collaborate, execute research, store data, and showcase their work. As with all the developments we've discussed in this report, whether these changes will play out in the way our study suggests, depends on a number of factors. One will be the willingness of researchers themselves to adopt these new tools or support new journal and article formats. Another will be the ability of traditional publishing companies to adapt. As we've seen, many are leveraging new developments to refashion their activities and develop new areas of expertise in analytics and data (we explore these points further in "Technology to the rescue" in the How researchers work: change ahead essay). And for some industry watchers, there are other new opportunities to be embraced.

"I think the benefit of publishers is that they are a bit like the United Nations, the independent player in this game. So, they are the optimal ones to try and build up the facilitation, be the facilitator between all the different stakeholders as artificial intelligence continues to develop."

Kerry Purcell, VP, IBM Japan, Japan, interviewee

The academy and beyond

Setting the scene...

Universities are the beating heart of the research ecosystem – they train future generations of researchers and health professionals. At the same time, many perform their own research projects, delivering discoveries that have shaped modern society. And they feed industry with suitably-trained employees, stoking the fires of economic progress.... Or do they?

Many are questioning the role of the university in this rapidly-evolving digital age. Some worry that there is too much focus on producing employees for industry, rather than intellectually curious researchers who will advance human knowledge. Others are concerned that graduates are emerging without the skills the job market requires, forcing industry to increasingly take on the role of education provider. Advances in technology mean the location and delivery mechanism of education will change, while shifts such as an ageing population and globalization mean we'll need access to formalized learning throughout our lives. As a result, demands on higher education institutions to prove they provide value for money are growing. With the help of the research community, we explore how these issues and drivers could transform academic institutions.

What will be the key drivers and changes?

1. Courses will diversify from a lecture-focused model

- There will be a move toward more **flexible learning**, e.g. a shift in focus from "early life" education toward "lifelong learning" and fast-track undergraduate degrees.
- As the pressure to compete with new market entrants mounts, **universities will experiment with teaching styles**. Education will increasingly take the form of "flipped" classrooms, with students watching video lectures at home and class time devoted to discussions and interactive problem solving.

2. Higher education institutions are changing structure

- Higher education institutions are being asked to **demonstrate their impact** and as the pressure to show a return on investment increases, they will further align their courses with governments' industrial strategies.
- Universities will re-engineer their offerings to **show they are providing the skills required** for an increasingly competitive job market.
- **Industry will likely play a much greater role** in education over the next decade. While some large corporations will choose to set up alone, many will form partnerships with existing higher education institutions.
- **Universities will change at different rates**; it is likely that teaching-led institutions will be under more pressure to adapt than those that are research-led.

3. EdTech will become a serious higher education contender

- Adoption of EdTech is taking place slowly and unevenly. A few governments already broadly support it and it is likely more governments will in the future, enabling a **new generation of EdTech institutions** to emerge.
- MOOCs have NOT disrupted the education space to the extent predicted a decade ago; it takes more than just online access to benefit from online resources. However, the concept has not disappeared and universities are likely to **continue offering online and remote education**.

Changing course: a focus on real world skills

Each year, graduates across the globe emerge from universities and other higher education courses, often loaded with debt, to search for work in an increasingly competitive employment market. And, if current predictions are correct, that pressure will only grow in the years ahead as factors such as advances in technology (see Technology: revolution or evolution essay) and an ageing population remodel the job market.

As we explore in the essay How researchers work: change ahead, graduates in STEM (science, technology, engineering and medicine) are not immune to the current competition and are among those struggling to find work. On the plus side, with societal changes increasingly driven by the kind of innovation that STEM degrees offer, they have been enjoying higher employment rates than their counterparts in other disciplines. That's not the case in all areas of STEM though: natural sciences, mathematics and statistics graduates experience similar employment rates to arts and humanities graduates – for engineering and ICT graduates the rates are higher.[1]

When it comes to securing tenure, in the UK, only about 3-4 percent of PhD students will go on to get a permanent job at a university and the numbers in the US are only a little higher.[2] For many, temporary contracts will be standard. This has led to younger researchers seeking jobs outside academia, often in the private sector.

In the researcher survey element of this study, respondents made it clear that they expect little to change in the years ahead – 43 percent say they think it's likely nearly all researchers at institutes will be on temporary contracts 10 years from now and only 25 percent believe the majority of staff members will be permanent.

"My field is getting more and more competitive, especially for faculty positions, so as the competition is increased, more will be expected from us."

Researcher working in engineering and technology, US, aged 26-35, respondent to researcher survey

In light of these rising pressures, higher education institutions are reaching a fork in the road. There is increasing discussion around what their role should be in society – is the purpose of education to create graduates equipped with the thirst for discovery that has led to some of the great advances of our age? Or should students be given the kind of practical skills that will help them find work in today's competitive job market? In India, for example, there are reports that engineer graduates are largely unprepared for the roles for which they have been educated: of the 6 million+ graduates each year, "only 1.4% can write functionally correct and efficient code".[3]

"What is a university for? Should it be producing people who can be employed instantly or think creative or abstract thoughts?"

Nicola Millard, Head of Customer Insight & Futures, BT, UK, interviewee

Universities are facing calls to adopt new and flexible forms of teaching that will equip students – whatever their age and end-goal – with market-ready skills. "Scientists of the future will operate and maintain incredibly complicated machines. They will play a bigger role in public engagement. They will run science-based businesses. And all that means universities will have to train students to be more than just cerebral. To survive, they'll have to be entrepreneurial, creative, adaptable and good with their hands."[4] A 2018 Studyportals report on the future of global higher education indicated that "the continued shift in the demographic, technological, and economic contexts will encourage institutions to experiment and innovate with new models of blended, online or lifelong learning".[5]

1 OECD. Education at a Glance 2017. Paris: OECD Publishing. 2017. doi:10.1787/eag-2017-en

2 Many junior scientists need to take a hard look at their job prospects. Nature. 2017. 550, 429. doi:10.1038/550429a

3 Aspiring Minds. Report on programming skills of Indian engineers. https://www.aspiringminds.com/automata-national-programming-report

4 Renault, M. Technology helps science advance, but the U.S. could struggle. The Columbus Dispatch. 2017. http://gatehouseprojects.com/cbusnext/the-future-of-research/site/dispatch.com/

5 Choudaha, R. & Van Rest, E. Envisioning pathways to 2030: Megatrends shaping the future of global higher education and international student mobility. Studyportals. January 2018. Bit.ly/Megatrends2030.

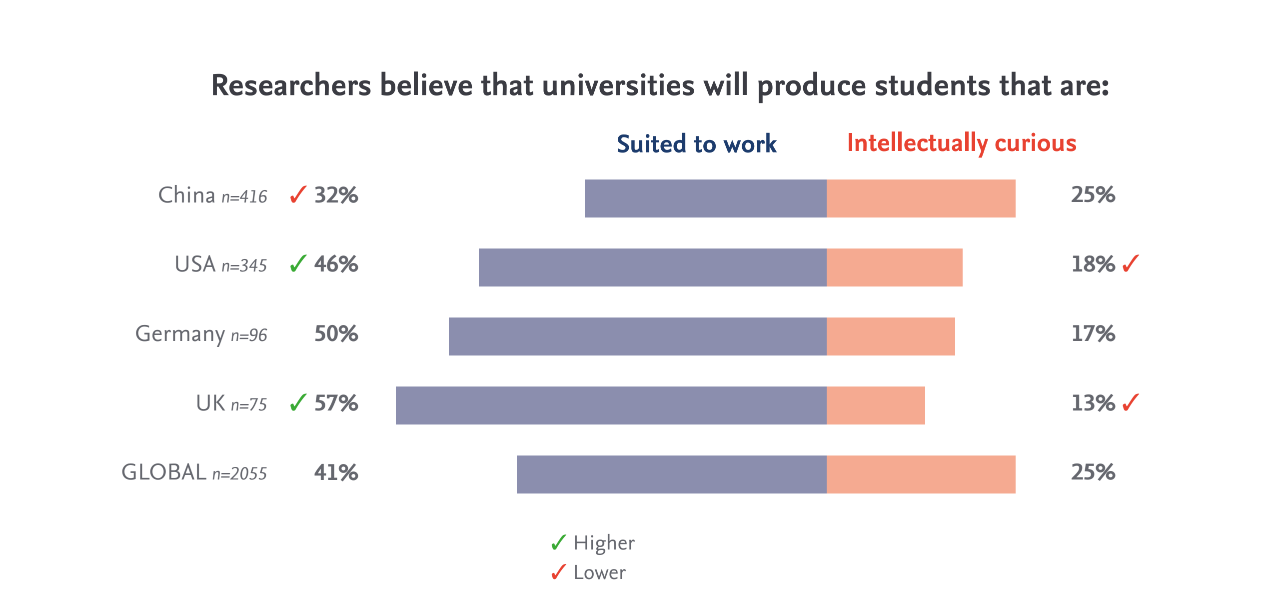


Figure 6.1 shows which of two scenarios researchers think is most likely 10 years from now. Ticks indicate significant difference ($p<0.05$) to the global population. Source: Researcher survey for this study. n=2055

Many of the industry experts we interviewed for this study agree that we have reached a critical point where universities must adapt if the private sector is to continue to thrive.

"It's imperative we find a way to help universities tailor courses that will give us graduates who have the right skill sets for us."
Nicola Millard, Head of Customer Insight & Futures, BT, UK, interviewee

We asked the researchers we surveyed which route they think universities will have prioritized 10 years from now. 41 percent believe universities will be producing graduates that are well suited for work. In contrast, only 25 percent think universities will focus on training students to be intellectually curious. These percentages vary by country (see figure 6.1).

But some are concerned that if practical skills become the priority, it will be at the expense of the "blue-sky thinking" that has fuelled major discoveries of our age – from penicillin to electricity – and is crucial to help us meet future challenges.[6,7,8] And this comes at a time when many feel blue-sky thinking and basic science are already under threat due to stretched research and development (R&D) budgets and increasing collaborations between industry and academia (see Funding the future essay). In addition, with the rise of artificial intelligence (AI), people are currently being urged to nurture skills that distinguish them from computers – curiosity included.[9]

6 Roberts, J. Curiosity is most important trait in scientists – Matas Navickas, EUCYS prize winner. Horizon, the EU Research & Innovation Magazine. 5 November 2014. https://horizon-magazine.eu/article/curiosity-most-important-trait-scientists-matas-navickas-eucys-prize-winner.html

7 Bourguignon, J-P. Why curiosity is the secret to scientific breakthroughs. World Economic Forum. 17 August 2015. https://www.weforum.org/agenda/2015/08/why-curiosity-is-the-secret-to-scientific-breakthroughs/

8 Oppong, T. The Curious Brain (Why Curiosity is as Important as Intelligence). Thrive Global. 17 March 2017. https://medium.com/thrive-global/the-curious-brain-why-curiosity-is-as-important-as-intelligence-d41799cae42d

9 Why curiosity and collaboration are the critical skills of the future. Ethical Corporation. 26 July 2017. http://www.ethicalcorp.com/why-curiosity-and-collaboration-are-critical-skills-future

"Some research must be done out of focus, out of immediate applications. For example, going to the moon helped in the development of satellites and other applications years later."

Fabio Figueiras, postdoc researcher, CICECO, Universidad de Aveiro, Portugal, interviewee

If universities do choose the "practical skills" route, we may see more institutions specializing in certain disciplines – even devoting themselves to one field, attracting students keen to progress in that area.[5] This kind of specialization would likely arise in response to requests from areas of the market with identified skills shortages (for example, data scientists and artificial intelligence and blockchain developers – see Technology: revolution or evolution essay). Meanwhile, other institutes may take the opposite path, focusing on the "student experience, flexible learning and career advancement".[5] We could also see deeper partnerships between universities and industry develop.

"I would worry if a university became too attached to a specific area. There's a risk of creating a 'football management' environment, where you know absolutely what you're going to do with no contingency or opportunity to explore new options."

Saul Tendler, Acting Vice-Chancellor, York University, UK, interviewee

However, there are concerns around how universities would reconcile the conflict between specialization and the increasing push from funders to take an interdisciplinary approach to research: an approach which many see as the most promising route to tackling some of our key societal challenges (see "Crossing the discipline borders" in our How researchers work: change ahead essay).

"I'm just absolutely convinced that we need to do research in a much more collegial, and community-based, and collaborative way. Most research is now interdisciplinary. In some cases, it's a collaboration and in other cases it's just pure blue-sky research. You've got to have a balance between these, but the pendulum has swung too far in the other direction now: everything seems pushed towards purely applied research."

David Gavaghan, Professor of Computational Biology, University of Oxford, UK, interviewee

New structures for new times

Higher education institutions aren't just under pressure to change the format and focus of their courses; increasingly they are being asked to look critically at their entire structure. While this is driven, in part, by the changes we've just explored, reduced funding and discontent over the pay of senior staff also have a role to play.[10]

In 2017, research into the education system was conducted by the Organisation for Economic Co-operation and Development (OECD), a forum of 34 industrialized countries. It found that while "expenditure [on education] has been increasing at a much higher rate than student enrolments at all levels, particularly tertiary", there was a decrease of 2 percent in public expenditure on educational institutions as a percentage of GDP over the same period. It noted: "Similarly, in half of OECD countries, the share of public spending on primary to tertiary education in total government spending declined between 2010 and 2014."[1]

This has created a higher education market ripe for change; a change that some believe is long overdue. In an interview for *Quartz* website, Larry Summers, economist and previous President at Harvard University in the US, commented: "General Electric looks nothing like it looked in 1975. Harvard, Yale, Princeton, or Stanford look a lot like they looked in 1975."[11]

1 OECD. Education at a Glance 2017. Paris: OECD Publishing. 2017. doi:10.1787/eag-2017-en

5 Choudaha, R. & Van Rest, E. Envisioning pathways to 2030: Megatrends shaping the future of global higher education and international student mobility. Studyportals. January 2018. Bit.ly/Megatrends2030.

10 Wright, R. Bath resignation shines light on university governance. Financial Times. November, 2017. https://www.ft.com/content/b0f2aadc-d520-11e7-8c9a-d9c0a5c8d5c9

11 Schrager, A. & Wang, A. It's the end of the university as we know it. Quartz. 27 September 2017. https://qz.com/1070119/the-future-of-the-university-is-in-the-air-and-in-the-cloud/

"I'm skeptical of academic speed and resourcing levels. You'd think universities should look different today, but they're way, way behind in terms of core functions in research and education."
Technology expert, US, interviewee

According to a 2016 blog post in *The Guardian*, we have a situation where the majority of new jobs no longer even require degree-level qualifications: "In the US in 2010, 20% of jobs required a bachelor's degree, 43% required a high-school education, and 26% did not even require that. Meanwhile, 40% of young people study for degrees."[12]

So with a decline in the demand for skilled workers and the supply of those with degrees continuing to grow, "high-skilled workers have moved down the occupational ladder and have begun to perform jobs traditionally performed by lower-skilled workers".[13] Some feel that this is because traditional colleges are a mismatch for what future consumers will want.[14]

One (perhaps extreme) view is that universities will be redundant within 15 years as developments in robotics and artificial intelligence will mean there are "no jobs needing proof of academic ability".[15] Others predict that more than 50 percent of colleges will collapse by 2030.[14] This reflects a wider trend: after a long period of steady-as-she-goes, higher education institutions are, like so many other industries, now being pushed to change and to become more responsive to the needs of their customers.

And the various types of universities are feeling slightly different pressures. For example, these are particularly testing times for low-tier state and small private universities in the US where enrolment numbers are declining.[16] However, top-tier higher education institutions, where the focus is on research, are managing to maintain or grow their enrolments. In this increasingly competitive landscape, struggling institutions need to offer new majors in areas of high demand, e.g. data analytics; make changes to attract more students from overseas; and streamline the links between school and college to make for an easier transition.[17]

However, some of the factors required to drive that modernization may well be out of the universities' hands. Changes in government administrations have the potential to slow down the transformation required.

"Short-term thinking prompted by short election cycles means it is a problem… the politicians start immediately worrying about being re-elected which is very bad for society and universities. If politicians were more worried about the long-term future, the pressure on universities to commercialize in a quick way would disappear."
Rolf Tarrach, President of the European University Association, Belgium, interviewee

And there is no global consistency in how education is delivered and managed. Australia, China, Korea, Sweden and the UK, for example, have some form of national, or at least top-down curriculum. However, in the US and Canada, each state or province and territory determines the curriculum (although, in the US, with guidance from the Department of Education). Similarly, schools receive funding in different ways. The result? Uneven and location-dependent developments to the higher education system.

12 Spicer, A. The knowledge economy is a myth. We don't need more universities to feed it. The Guardian. 18 May 2016. https://www.theguardian.com/commentisfree/2016/may/18/knowledge-economy-myth-more-universities-degree

13 Beaudry, P., Green, D. A., & Sand, B. The great reversal in the demand for skill and cognitive tasks. NBER Working Paper No. 18901. March 2013. https://www.nber.org/papers/w18901

14 Frey, T. By 2030 over 50% of Colleges will Collapse. Futurist Speaker. 5 July 2013. http://www.futuristspeaker.com/business-trends/by-2030-over-50-of-colleges-will-collapse/

15 Cooke, E. Future perfect: what will universities look like in 2030? Times Higher Education. December 2015. https://www.timeshighereducation.com/features/what-will-universities-look-like-in-2030-future-perfect

16 Vedder, R. Why Enrollment Is Shrinking At Many American Colleges. Forbes. 5 July 2018. https://www.forbes.com/sites/richardvedder/2018/07/05/academic-deserted-villages/#21d498d85121

17 Marcus, J. College enrollment has plummeted, and private universities are scrambling. Business Insider. 29 June 2017. https://www.businessinsider.com/private-colleges-worried-over-plummeting-college-enrollment-2017-6?international=true&r=US&IR=T

Enabling the workforce of the future

One important way in which universities can provide the skills the job market is seeking, is by opening up courses to students of every age and level of experience. Lifelong or "renewable" learning has been a hot topic in education for some time now. Supporters believe it has the potential to help us solve some of the key challenges facing society today. For example, learning new languages or competencies in response to globalization; retraining to meet the rise in increasingly sophisticated (tech) jobs; and regularly refreshing existing knowledge or gaining new skills to see us through our longer work lives. "Economic security will not come from having a job for life but from having the ability to maintain and renew the right skills through lifelong learning."[18]

Employees themselves are aware that if they want to get ahead, they must keep learning. A US report into the state of American jobs[19] found that:

- "More than half (54 percent) of adults in the labor force say it will be essential for them to get training and develop new skills throughout their work life to keep up with changes in the workplace."
- "35 percent of workers, including about three-in-ten (27 percent) adults with at least a bachelor's degree, say they don't have the education and training they need to get ahead at work."
- "Roughly seven-in-ten (72 percent) say 'a lot' of responsibility falls on individuals to make sure that they have the right skills and education to be successful in today's economy."

And it seems employees aren't afraid to dip into their own pockets to fund their training, according to Peter Cappelli, Director of the Wharton Center for Human Resources in the US: "One development we have seen in executive education is individuals coming to our longest and most expensive development program and paying their own way to do so. This never happened before. Attendees were always sponsored and paid for by their employer."[20]

Globally, governments are recognizing that suitably-skilled employees are key to securing a country's financial future. For example, in 2016, Singapore's government established the Committee for the Future Economy (CFE) to "develop strategies for supporting long-term economic growth" in the country. In 2017, the committee reported that "workforce development" should be a priority.[21] And, in the UK, HEFCE (Higher Education Funding Council for England) awarded £6.1 million to universities and colleges to support projects aligned with the Government's Industrial Strategy's Grand Challenges. Sam Gyimah, UK Universities Minister in 2018, responded: "These projects will see providers working with employers across the country to develop higher level skills… vital to help build a Britain that is fit for the future."[22]

Another development has been the introduction of accelerated learning, with institutions in the UK, US and Australia already offering fast-track undergraduate degrees. The model varies, however: for example, in 2017, the UK government agreed universities can charge students £2,000 more in fees to complete a degree over two years rather than three. While, Hartwick College in Oneonta, New York, offers a three-year degree "in three-quarters the time and at three-quarters the cost".[23] Other countries are also offering these condensed courses and more are expected to follow.

18 Government Office for Science (UK). Future of Skills & Lifelong Learning. 2017. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/727776/Foresight-future-of-skills-lifelong-learning_V8.pdf

19 Pew Research Center. The State of American Jobs. 6 October 2016. http://www.pewsocialtrends.org/2016/10/06/the-state-of-american-jobs/

20 Boyde, E. The future of lifelong learning. Financial Times. 12 May 2013. https://www.ft.com/content/a79cdf26-ae87-11e2-8316-00144feabdc0

21 Kamei, R. How Singapore Encourages Lifelong Learning and Workforce Resilience. The Diplomat. 12 October 2017. https://thediplomat.com/2017/10/how-singapore-encourages-lifelong-learning-and-workforce-resilience/

22 Higher Education Funding Council for England. Universities and colleges receive £6.1 million to develop courses to teach the skills of the future. 23 January 2018. http://www.hefce.ac.uk/news/newsarchive/2018/Name,116468,en.html

23 Bridgestock, L. Fast-Track Degree Programs. QS Top Universities. 6 March 2012. https://www.topuniversities.com/student-info/choosing-university/fast-track-degree-programs

Uptake of accelerated learning is currently quite low. In the UK, there are "frustrations inside government that only about 2,500 students – just a fifth of 1 percent – are studying accelerated degrees, despite hopes that they would encourage more mature students into higher education, as well as those who do not want to commit to three years on campus".[24] But if the UK's goal is to increase the number of mature students, the government may face a challenge: a 2017 report found that "participation in formal learning declines with age. Adult learning is in overall decline and is disproportionately taken up by wealthier, more highly skilled individuals".[18]

Higher education: globalization or internationalization?

Generally, student numbers are continuing to grow (see figure 6.2). In emerging Asian economies (largely driven by China and India) numbers are particularly strong and rising. Countries in South America are also showing growth, while the counts for the EU are steady. The US shows a slight decline in the year-on-year student headcounts.

Students are also adopting a more international approach – the number choosing to study outside their own country is growing rapidly, for example:

- In 2014, Canada launched a strategy to attract 450,000 international researchers and students by 2022; it had exceeded that number by 2017.
- South Korea reported a record growth of 18.8 percent in overseas student numbers in 2017.
- The US saw international student numbers grow by 104 percent between 2008 and 2016.

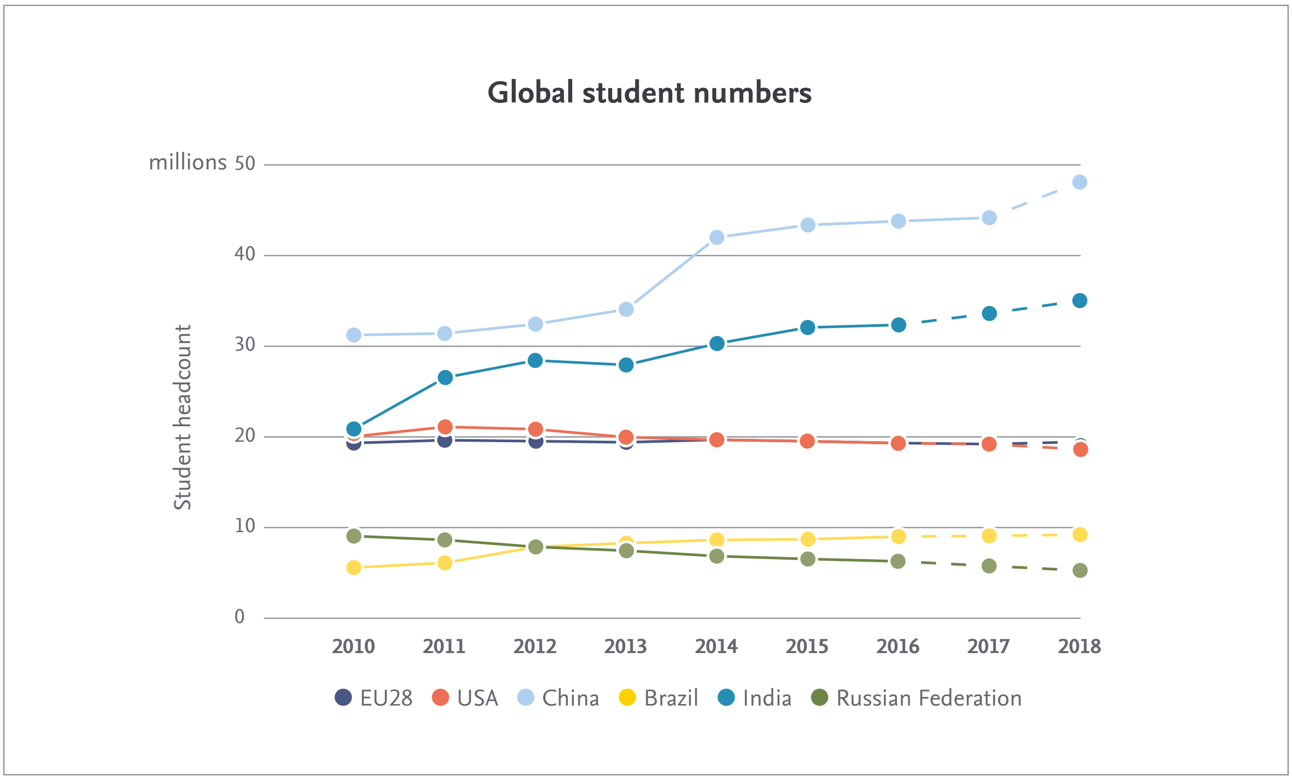


Figure 6.2: Global student numbers. Forecast data (symbolized by dashed lines on chart) are calculated based on linear extrapolation of data. Source: UNESCO.

18 Government Office for Science (UK). Future of Skills & Lifelong Learning. 2017. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/727776/Foresight-future-of-skills-lifelong-learning_V8.pdf

24 Savage, M. Universities win permission to charge £2,000 premium for two-year degrees. The Guardian. 10 December 2017. https://www.theguardian.com/education/2017/dec/10/universities-can-charge-two-thousand-pounds-more-for-fast-track-degrees

- The UK has seen a significant rise in its numbers "especially due to Chinese student enrolments. More countries and their governments have started to understand the increased value that foreign expertise brings them, especially regarding their economic future".[25]

At this moment in time, the largest movement of students is from Asia to the US and the second largest is from Asia to Europe.[26] Although recent tensions between the US and China mean that the influx into the US has slowed, with the length of visas for Chinese graduate students working in certain fields reduced to one year. This step "is intended to protect advanced U.S. technology from Chinese appropriation…".[27] We explore the growth of the Chinese economy and what it might mean for researchers in "The China effect" in our Funding the future essay.

Some critics believe that universities, and indeed governments, are too focused on "internationalization"; in other words, competing for international students and creating international campuses and partnerships. Instead, the focus should be on "globalization"; the integration of education systems and institutions. As van Rooijen notes: "It is impossible to make higher education immune to the globalisation processes. One can only try to delay the inevitable through regulation or inertia, but that is a risky strategy. Like in every aspect of our modern society, we will create losers and winners, not just in regard to individual universities but even to entire national systems."[28] These critics see multinational universities and unversity groups as an inevitability. Whether they are correct, only time will tell, but change is on its way. And with China's focus on attracting international students and improving its own higher education system, it is a key force on the current education stage.

"There is a tradition in China that education is the only way to get a respectable position and high salary; more parents will want their children to get educated outside China in the global prestige universities; and within China, investment to the most prestigious universities will increase (funding the winners)."

Jing Ping Liu, Founding Director, Centre of Evidenced-Based Chinese Medicine, Beijing University of Chinese Medicine, China, interviewee

The past decades have already seen "a dramatic growth in higher education internationalisation, student mobility in and out of China and the cross-border presence of foreign universities in China, all contributing to the establishment of world-class universities and a significant rise of Chinese universities in the rankings".[29]

And the Chinese Ministry of Education is aiming to increase those international student numbers with a multi-pronged plan. Moves include establishing seven "Sino-foreign joint venture universities", for example, Duke Kunshan University – a partnership between Duke University in the US and Wuhan university in China. The China Scholarship Council has also provided scholarship money that makes the cost of tuition "extremely attractive" to international students. In addition, Chinese universities are investing in changes that will make international students feel more at home, for example, hiring English-speaking faculty, teaching courses in English and adapting halls of residences. As a result, some predict that China will be teaching at least 500,000 international students by 2020.[30]

25 Dandes, D. International students on the rise in 2018. Studyportals. 2018. https://www.studyportals.com/blog/international-students-growth-2018/26 van der Wende, M. How do globalisation forces affect higher education systems? University World News. 23 June 2017. http://www.universityworldnews.com/article.php?story=20170620114312877

26 van der Wende, M. How do globalisation forces affect higher education systems? University World News. 23 June 2017. http://www.universityworldnews.com/article.php?story=20170620114312877

27 Farley, R. The Consequences of Curbing Chinese STEM Graduate Student US Visas. The Diplomat. 15 June 2018. https://thediplomat.com/2018/06/the-consequences-of-curbing-chinese-stem-graduate-student-us-visas/

28 Van Rooijen, M. What does globalisation really mean for higher education? European Association for International Education. 31 October 2013. https://www.eaie.org/blog/what-does-globalisation-really-mean-for-higher-education.html

29 Altbach, P.G. & de Wit, H. The closing of China will affect universities worldwide. University World News. 9 March 2018. https://www.universityworldnews.com/post.php?story=20180308085109268

30 Bhardwa, S. Why more students are choosing to study in China. THE World University Rankings. 7 February 2018. https://www.timeshighereducation.com/student/blogs/why-more-students-are-choosing-study-china

"More and more universities are opening branches in Asia and sending staff there. This will also influence our way of doing science, but I'm not sure how…"

Rolf Tarrach, President of the European University Association, Belgium, interviewee

China's investment in education goes beyond improving its existing facilities — in 2016, it was building the equivalent of almost one university per week.[31] And, as we've seen earlier in this essay, the number of students is rising rapidly. Writing for the BBC, Schleicher reports: "Even modest predictions see the number of 25 to 34-year-old graduates in China rising by … 300% by 2030, compared with an increase of around 30% expected in Europe and the United States... Students in China and India are much more likely to study mathematics, sciences, computing and engineering – the subjects most relevant to innovation and technological advance." [31]

Some believe that China's increased focus on education could "have profound implications in a globalized economy in which a growing share of goods and services is traded across international borders… the boom in higher education in China is starting to put pressure on employment opportunities for college graduates elsewhere — including in the United States".[32]

While China's investment in education may have proved fruitful to date, there are developments that could impact the future mobility of students.

For example, several Chinese universities now have centers dedicated to deepening "the research and interpretation of Xi Jinping Thought", the socialist philosophy of China's President. In 2016, Xi pledged to turn university campuses into "strongholds of the Party's leadership" and, in 2017, the Chinese Ministry of Education published a guide for universities stating that ideological performance will be the most important factor in determining the career prospects of university faculty. Additionally, the government will increase its supervision of universities in order to enforce compliance.[33]

And not all Sino-foreign joint ventures have proved successful: the University of Groningen in the Netherlands shelved plans to establish a branch campus in China, a joint venture with China Agricultural University, Beijing, "after concerns were raised over academic freedom".[34]

In addition, China's involvement in foreign affairs, including higher education, has prompted some debate. "Chinese authorities are increasingly attempting to interfere overseas – and…there is growing pushback by Western academics and institutions." [29]

To date, China's research capacity has benefitted from returning Chinese researchers who've been educated or employed overseas, but some believe this trend is unlikely to continue if the Chinese higher education system continues on its current course. A *University World News* article notes: "A restrictive academic environment will make it more difficult to attract talented foreign faculty to work in China and it is likely that international students, especially at the graduate level, will be reluctant to study in China… efforts to convince Chinese students who have studied abroad to return, particularly those at the masters and doctoral levels, will have less success as many question what is happening to academic life in China." [29]

29 Altbach, P.G. & de Wit, H. The closing of China will affect universities worldwide. University World News. 9 March 2018. https://www.universityworldnews.com/post.php?story=20180308085109268

31 Schleicher, A. China opens a new university every week. BBC News. 16 March 2016. https://www.bbc.com/news/business-35776555

32 Bradsher, K. Next Made-in-China Boom: College Graduates. The New York Times. 16 January 2013. https://www.nytimes.com/2013/01/17/business/chinas-ambitious-goal-for-boom-in-college-graduates.html

33 Taber, N. How Xi Jinping is Shaping China's Universities. The Diplomat. 10 August 2018. https://thediplomat.com/2018/08/how-xi-jinping-is-shaping-chinas-universities/

34 Sharma, Y. Dutch branch campus shelved over academic freedom fears. University World News. 30 January 2018. http://www.universityworldnews.com/article.php?story=20180130135833257

The changing face of education – going digital

Internationalization, globalization and the other growing trends we've explored in this essay have all been aided – and disrupted – by EdTech, or education technology. This term "encompasses everything from the simple use of computers to teach maths and reading to children in elementary schools… to the submission of homework online, entire online degree platforms, informal mobile learning applications, gamification or virtual reality techniques".[35]

Over the past few years, new content, new methods of teaching and even new education providers have been arriving on the scene and it is widely agreed that technology, including developments in artificial intelligence (AI), will prove the biggest disruptive force in education as we embark on the decade ahead. In our essay Technology: revolution or evolution, we explore how developments such as virtual reality and augmented reality are already reshaping training, particularly in the health and medical fields.

"A 3D object you can walk around or look underneath is highly valuable in an education setting. For example, in medicine, what if doctors-in-training didn't have to cut up a cadaver to see a human heart? It also has a role in vocational training too – who knows how much we will need to repair in the future, but a mixed reality system could help you learn how to fix a car or an elevator."

Technology expert, US, interviewee

Already, universities are using AI algorithms to offer more personalized learning options. This is likely to continue and expand beyond students – a smart "classroom connected to the Internet of Things… can adapt to the personalised settings to prepare the classroom for different faculty members. Monitoring attendance and invigilating exams will also be automated and made much more robust".[36]

Many of our interviewees for this study identified personalized education as a key development for the decade ahead, with courses tailored to students' knowledge, interests, and the speed with which they want to learn.

"The development of four-year college in 10 years' time will be increasingly "boutique" or specialized to promote experiential learning or multi-institutional exchanges so you can have different experiences."

Sarah Pritchard, Dean of Libraries, Northwestern University, US, interviewee

A 2017 report on current EdTech trends in higher education also identified personalized learning as an area we will see grow in the short term, alongside mobile learning, which will offer greater accessibility to course materials.[37] But these are likely to be only the first steps on a long road to change. John Hennessy, board member of Google and Cisco, believes that the future of education will take the form of a "flipped classroom model, in which students [will be] watching video lectures at home and class time is devoted to discussions and interactive problem-solving – provided that class sizes are 'small to moderate'". Hennessy believes this could cut the costs of running classes by ~15 percent.[38]

35 Vedrenne-Cloquet, B. What is EdTech and why is it such a big opportunity? Hot Topics. https://www.hottopics.ht/14731/what-is-edtech-and-why-is-it-important/

36 Alam, N. & Kendall, G. Five ways artificial intelligence will shape the future of universities. The Conversation. 18 April 2018. http://theconversation.com/five-ways-artificial-intelligence-will-shape-the-future-of-universities-94706

37 NMC. Horizon Report: 2017 Higher Education Edition.2017. doi:http://cdn.nmc.org/media/2017-nmc-horizon-report-he-EN.pdf

38 Bothwell, E. Moocs can transform education - but not yet. Times Higher Education. July 2016. https://www.timeshighereducation.com/features/massive-open-online-courses-moocs-can-transform-education-but-not-yet

Others predict that online-only degrees will increase in availability and uptake – and already we're seeing small signs of this.[39] In 2017, Coventry University in the UK, in partnership with FutureLearn, announced that it would be providing 50 entirely online postgraduate degrees over the next five years.[40] This is a step beyond the massive open online courses (or MOOCs – see the next section in this essay) that many universities are now offering, often for free. As a result, some believe that traditional institutions like the University of Oxford could face a troubled future unless they are willing to embrace online learning.[41]

"Online courses will become more prevalent. Small-scale learning – a few weeks or hours every week instead of three years' full time. It's more flexible and you can focus on one small thing you would like to master."

Jane X. Wang, Senior Research Scientist, DeepMind, UK, interviewee

Some believe a split between onsite and online is the most likely scenario.

"Most students think 'presence' is still interesting and compelling but not everything needs to be delivered in the physical location."

Nicola Millard, Head of Customer Insight & Futures, BT, UK, interviewee

For at least one of our interviewees, an interesting by-product of online training is that students can choose who their lecturer is and we could see local professors competing with "academic superstars" located on the other side of the world.

The researchers we surveyed for this study are fairly evenly split in their opinions about the delivery of education 10 years from now. More than a third of respondents (36 percent) think students will be educated on campus, while 27 percent think education will largely take place remotely. Life and social scientists are more likely to think remote education will be prevalent - 40 percent and 32 percent, respectively.

Anticipated changes in education and a fall in book circulation[42] have seen some US institution libraries already re-evaluate their role and purpose. They are changing shape – quite literally. In Texas, campus libraries are adding study rooms, booths and exercise machines;[43] University of Wisconsin-Madison plans to close 22 libraries and replace them with six "hubs", in a consolidation move;[44] the remodelled library at University of California, Berkeley, features modern meeting spaces and nap pods and food and drink are welcome;[45] and the newly-remodelled and expanded library at Virginia Commonwealth University features a media studio with 3D printers, scanners, laser cutters and robotics.[46]

39 Yale. Non-Degree Offerings. https://www.yale.edu/academics/non-degree-offerings

40 Coventry University. Coventry makes "massive" move into online degree market with FutureLearn 50 degrees to roll out online over five years. 28 June 2017. http://www.coventry.ac.uk/primary-news/coventry-makes-massive-move-into-online-degree-market-with-futurelearn-50-degrees-to-roll-out-online-over-five-years/

41 Adams, R. Online degrees could make universities redundant, historian warns. The Guardian. 17 April 2016. https://www.theguardian.com/education/2016/apr/17/oxford-university-online-degree-historian-laurence-brockliss

42 Anderson, R. Less Than Meets the Eye: Print Book Use Is Falling Faster in Research Libraries. Scholarly Kitchen. 21 August 2017. https://scholarlykitchen.sspnet.org/2017/08/21/less-meets-eye-print-book-use-falling-faster-research-libraries/

43 Ellis, L. Like in Texas, college libraries around the U.S. rethink their future. Chron. December 2017. https://www.chron.com/local/education/campus-chronicles/article/Like-in-Texas-college-libraries-around-the-U-S-12457836.php

44 Aadland, C. UW-Madison library plan would create six 'hubs,' close 22 libraries and reduce collection space. Wisconsin State Journal. December 2017. http://host.madison.com/wsj/news/local/education/university/uw-madison-library-plan-would-create-six-hubs-close-libraries/article_0822c3ed-9288-5ef1-bc82-40facfc203df.html?utm_medium=social&utm_source=twitter&utm_campaign=user-share

45 Watanabe, T. Universities redesign libraries for the 21st century: fewer books, more space. Los Angeles Times. 19 April 2017. http://beta.latimes.com/local/lanow/la-me-college-libraries-20170419-story.html

46 McNeill, B. $50.8 million expansion, renovation of VCU's main library is now open. VCU. 2 November 2015. https://news.vcu.edu/article/508_million_expansion_renovation_of_VCUs_main_library_is_now

According to Daniel Korski, deputy head of the No 10 Policy Unit under former UK Prime Minister, David Cameron, the arrival of EdTech offers universities the opportunity to provide what computers cannot – the delivery of knowledge through human contact. Writing for The Telegraph in 2017, he said: "Adelaide University in Australia, for example, is already offering considerably fewer live lectures and much more small-group teaching… Doing so requires a greater attention to the quality of the classroom experience than is usual for universities." [47] It's a view shared by our interviewees for this study.

"…in the next 10 years, much teaching can be offered online, by robots, likely at the same or higher level of quality… but I think it will be substituted by much more teaching with small groups (like Oxford/Cambridge model, seminars)… the lectures to 100 students at a time will likely disappear."

Rolf Tarrach, President of the European University Association, Belgium, interviewee

For Korski, "the whole sector should be much more open to new providers," and with the passing of the UK Higher Education and Research Bill in 2017, it is now "easier for high-quality newcomers – perhaps companies such as Google DeepMind – to enter the sector and award degrees, giving students more choice, driving innovation and boosting competition".[47]

Those newcomers are already arriving. Institutions are facing increasing competition from the private sector and non-traditional education providers. Big players include Lynda.com, which announced investments of $186 million in 2015, the "largest single investment in an education-technology company since at least 2010".[48] Later that year, LinkedIn bought Lynda.com for $1.5 billion.[49] Changingedu.com – a platform that enables students to find tutors – received $100 million in 2015, led by Sequoia Capital China. Other big players in the EdTech field include Udacity, Age of Learning, iTutorGroup and Pluralsight.[50]

Established tech giants like Google and Apple have also stepped in to offer training in areas such as computer and data science, either alone or in partnership with institutions.

Apple has announced that it will "accelerate its efforts across the US in support of coding education as well as programs focused on Science, Technology, Engineering, Arts and Math (STEAM)…". It has also developed a new coding language, Swift™, accompanied by an app and curriculum, which aims "to address the coding skills gap and help prepare more people for jobs in software development". And it plans to add new programs to support teachers and teacher training.[51]

The Chan Zuckerberg Initiative (CZI) and University of Massachusetts Amherst have partnered in a project called Computable Knowledge. The goal is "to create an intelligent and navigable map of scientific knowledge using a branch of artificial intelligence known as knowledge representation and reasoning".[52] The end product will be accessible through CZI's free Meta platform.

In October 2017, Alibaba, a Chinese multinational conglomerate specializing in e-commerce, retail, internet, artificial intelligence (AI) and technology, announced that

47 Korski, D. Britain's universities must change to survive. Higher education reform is the way forward. The Telegraph. 23 January 2017. http://www.telegraph.co.uk/education/2017/01/23/britains-universities-must-change-survive-higher-education-reform/

48 Newcomer, E. Lynda.com Raises $186 Million in Funding Led by TPG Capital. Bloomberg Technology. 14 January 2015. https://www.bloomberg.com/news/articles/2015-01-14/lynda-com-raises-186-million-in-funding-led-by-tpg-capital

49 Kosoff, M. LinkedIn just bought online learning company Lynda for $1.5 billion. Business Insider UK. 9 April 2015. https://www.businessinsider.com/linkedin-buys-lyndacom-for-15-billion-2015-4?international=true&r=US&IR=T

50 Tom, M. The 12 highest value edtech companies. PitchBook. 20 May 2016. https://pitchbook.com/news/articles/the-12-highest-valued-edtech-companies

51 Apple. Apple accelerates US investment and job creation. 17 January 2018. https://www.apple.com/newsroom/2018/01/apple-accelerates-us-investment-and-job-creation/

52 Blaguszewski, E. UMass Center for Data Science Partners with Chan Zuckerberg Initiative to Accelerate Science and Medicine. University of Massachusetts Amherst. 16 January 2018. https://www.umass.edu/newsoffice/article/umass-center-data-science-partners-chan

it will launch the Alibaba DAMO (Discover, Adventure, Momentum, and Outlook) Academy. This program will see seven research and development labs set up worldwide with a focus on "foundational and disruptive technology research" in areas such as data intelligence, natural language processing, quantum computing, and machine learning. The labs will publish papers and develop technology that can be used by both Alibaba and third parties. Funding for the academy comes as part of a larger $15 billion push into R&D that Alibaba has planned for the next three years.[53]

Perhaps unsurprisingly, EdTech is also proving an attractive proposition for super-wealthy philanthropists like the Bill & Melinda Gates Foundation. In 2016, global investment in learning technology companies reached an all-time high of more than $7.33 billion, up 12 percent on 2015 figures.[54]

MOOCS – what does the future hold?

Just a few years ago, MOOCs, or massive open online courses, were being seen as the answer to bringing education to the masses as they require only an internet connection. In fact, in 2013, the increase in the availability and uptake of MOOCs caused Professor Clayton Christensen at Harvard Business School to predict that over half of the US' universities would go bankrupt within 15 years.[55] However, MOOCs have yet to fully deliver on their early promise. John Hennessy, board member of Google and Cisco, states that (certainly in the case of the US), the MOOC is "not the kind of revolutionary thing I think people were hoping for. It's not a disrupter".[38]

India has been notably active in engaging with the courses and has the second highest enrolment numbers across the available platforms (after the US). In a country that has problems with the quality of its education[56] and an economy expected to be the second largest in the world by 2050,[57] MOOCs are providing a solution. Huang notes: "One of the biggest challenges faced by the Indian education system is the mismatch between higher education curriculums and employer demands… Fortunately, [the] MOOC presents itself as a remedy for these situations. Many popular MOOC offerings are closely tied to industries in demand, such as IT, machine learning, mobile development, and self-driving cars."[58] Meanwhile, China is the country with the most online courses. The majority (around 70 percent) come from the top universities and these are set to grow; the Chinese Ministry of Education has plans for "3,000 elaborate online courses [to] start in 2020".[59]

Although MOOCs have seen phenomenal growth since their star really started to ascend in 2012, more recently the global user base has declined; in 2018, 20 million new learners signed up for at least one MOOC, down 3 million on 2017 figures.[60] One of the challenges MOOCs face are completion rates – the average is just

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15 percent.[61] This could be a sign that the courses are not providing students with what they need. Or it could reflect the accessibility issues users are experiencing. Shah reports: "Researchers have found that it takes more than just access to an internet connection to benefit from online resources: It also takes basic technology skills, the ability to draw on social networks for help and guidance when needed, and a willingness to look to the internet for information and resources..." 33 percent of Americans are described as "reluctant" internet users and this considerable proportion of the population are "very unfamiliar with educational resources online and where to find them".[62]

In response, MOOCs are slowly changing, they are "gradually being transformed from virtual classrooms to a Netflix-like experience".[63] They've generally become shorter, often achieved by simply splitting up existing courses. In addition, more are now self-paced and have soft deadlines. The greater flexibility around start dates mean the cohorts of students attending a course have decreased in size; however, this also means that forum activity has fallen.

Another big development is the monetization of the model. Initially, everything was (largely) free: registration, certification, etc. Now paywalls exist with some sites putting subscription fees in place and others introducing fees for certification. "...lifelong learners are no longer the primary target... the real money lies in professional development courses." [63]

In 2018, Coursera and Google announced a collaboration to train IT support professionals. The course is written by Google and will be available globally. It has "64 hours of coursework... and students are expected to complete it [in] eight to 12 months, at a cost of $49/month". This is similar to typical Coursera pricing, but Google is subsidizing the program and is offering financial aid.[64]

MOOCs could potentially play a role in future education policy. This is already happening in India, where the Ministry of Human Resource Development (MHRD) has announced it will include distance/open learning (DOL) and MOOCs under a special category in its new National Education Policy. "Meanwhile, the Indian government also announced an official partnership with Microsoft to launch the nation's first, proprietary MOOC platform – SWAYAM. All residents in India will have the option to enrol in courses and earn eligible credit on the platform, making university education a truly flexible and digital experience for many."[58]

With a global workforce that needs more highly-skilled workers and more than half of the world's population living in either India, China or Africa by 2100,[65] improvements to accessibility, pricing and the standard of MOOCs will only increase in importance.

Ensuring students (and society) get their money's worth

With many students facing uncertain job prospects and a hefty student loan or overdraft following graduation, due diligence when choosing a university has never been more vital. Higher education institutions are increasingly being asked to demonstrate they provide not only innovative learning opportunities and impact, but value for money.

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"I see universities in the US competing for undergraduates… How do you compete when the costs are going up, when you're getting less money from the state legislature and when it's harder to find undergraduates? That's the environment they're in."

Jean-Gabriel Bankier, Managing Director, bepress, an Elsevier company, US, interviewee

This has led to an increasing role for institution ranking systems, including the various Times Higher Education World University Rankings, the Financial Times (FT) MBA Rankings, Quacquarelli Symonds (QS), Shanghai China national university rankings, and the Maclean's University Rankings Canada. These all use data to assess and rate institution performance at a country- or global-level across core activities, such as teaching and research. Importantly, they provide students and funders with a way to understand and compare institutions.

Among OECD countries, the highest tuition fees for tertiary students can be found in Australia, the UK and the US, though a large share of students (75 percent) receive some form of public loan or scholarship/grant.[1]

However, there are measures being put in place to democratize higher education and make it more inclusive. In the US, in April 2017, Bernie Sanders introduced the College for All Act to make "public colleges and universities tuition-free for working families and to significantly reduce student debt".[66] Meanwhile, in the UK, 2017 saw the arrival of the Higher Education and Research Act,[67] which created two new bodies to regulate and fund higher education providers: the Office for Students and UK Research and Innovation. The Act, the first of its kind and scale since 1992, is designed to increase competition and student choice and ensure universities deliver better value for money to students.

Just as with researchers and funding bodies, higher education institutions are facing increasing calls to demonstrate the impact of their research at a societal level. In several countries (at least 14),[68] performance-based research funding schemes (PRFSs) have been introduced. These aim to understand the wider societal impact of research in a climate of growing pressure on public funding and a desire for greater accountability and transparency. They are gradually spreading to more countries as familiar pressures on funding grow.[69]

In the UK, the Research Assessment Exercise – one example of a PRFS – was launched in 1986 (replaced by the Research Excellence Framework (REF) in 2014). The REF is unusual for combining performance-based institutional funding and research evaluation; most European countries do both, but separately.

But the UK's PRFS, along with Australia's, often come under criticism and have been described as not fit for purpose. [70] The systems for measuring research impact are continuing to evolve and in the UK HEFCE has acknowledged that definitions of impact need to be aligned with the research councils as part of the REF exercise.[71]

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What’s next?

Universities have long carried a dual responsibility – to create new knowledge and educate the next generation. Generally, they strive to achieve a healthy balance between the two. However, in an era in which education is increasingly the foundation for individual prosperity, and the swift delivery of knowledge to the market place is the cornerstone of economic growth, this balance will likely shift.

Over the coming decade we can expect to see academic institutions adapt their infrastructure to become more student-centric by leveraging digital advances in EdTech; providing courses that enable lifelong learning; adapting their funding model by enabling distance learning for global students; and shifting their focus to practical courses that guarantee viable employment.

Academic institutes will also likely strengthen their bonds with industry and the number of partnerships between the two will increase. We will see a greater focus on the application of research and greater alignment of academia to government industrial strategies.

Methodology

As highlighted in the visual overview, this study followed several key stages, with each step informing the next. This allowed us to develop a comprehensive view of the current landscape: specifically, the trends, drivers, attitudes and behaviors that will shape the future. From the very start of the project, we worked closely with Ipsos MORI, who are experts in future thinking and scenario building.

This section outlines the approach we adopted, the steps we took and why. In total, there were four key stages.

Stage 1: literature review

We started with a review of the literature in early 2018, which was actually a comprehensive search across recently published articles and books, declarations on government websites, policy statements, guidelines from funders, and blog sites of futurists and technologists. We also used internationally-respected data sources such as the OECD and IMF for economic data. Throughout the essays in this report, we have cited all our sources – you will find them at the foot of each page. We have been as neutral and objective as possible to reflect a balance of opinion.

Stage 2: expert interviews

Who we spoke to

We know that published literature may not reflect the latest thinking, so, to capture a broad view of the research landscape, we interviewed 56 experts from around the world in spring 2018. Their backgrounds are very varied and range from funding agencies and established technology companies to start-ups. We also spoke with individuals based at academic institutions, including representatives from the senior leadership team, the research office and the library, as well as researchers at every career stage. And we spoke to futurists and publishers. We interviewed as diverse a group of individuals as possible to ensure a wide range of perspectives.

You can see the names of the individuals we interviewed in the Acknowledgements section of this report. Please bear in mind that not everyone we spoke with is listed there – interviewees were offered the opportunity to contribute anonymously and some took us up on that offer.

How we did the interviewing and analysis

The interview phase of the research was led by Ipsos MORI; they recruited and undertook the majority of the interviewing, supported by Elsevier employees. The literature review informed the scripts that were used and questions were deliberately broad to ensure we covered a range of topics about the current research ecosystem, how it might evolve over the coming decade, and why. Each interview lasted an hour, was open-ended, and interviewees were welcome to focus on topics they felt strongly about.

Most interviews were conducted in English; where appropriate, some were conducted in the local language. Each interview was recorded and transcribed by the interviewer. The transcripts were summarized before being brought together in a framework, which was structured according to the themes that had emerged during the interviews. This framework was analyzed by the core team of project researchers to provide an overview of the key learnings. This phase of the research identified 19 drivers, which were organized into six themes – these themes are the essays that make up this report. The results were then used to inform the quantitative phase of the study; a survey of researchers.

Stage 3: measurement phase – researcher survey

The focus of the research instrument

The survey instrument was based upon the themes that emerged from the literature review and expert interviews. It was important that it tested the constructs and forces that would enable the futures suggested during those phases.

To achieve this, we asked researchers to think about the same topic from three different perspectives, and to indicate whether they *expected* something to happen, *wanted* it to happen, and whether they will *do* something to enable, or make it happen. This approach allowed us to triangulate the results to help identify tensions in the system. We also asked researchers to consider several possible opposed futures and indicate which they thought would occur.

Who we surveyed

Sample source: To ensure a robust view of the research community, we approached 146,679 individuals. These were randomly selected from the Scopus database, which contains more than 3.6 million active researchers, including those who have published in serials or books. We had 2,055 respondents from a range of disciplines and geographies.

Survey tool: It was an online survey available in English only via the Confirmit platform. The survey took 20 minutes to complete (median average). Fieldwork took place during April 2018.

Results: During fieldwork, we closely monitored respondents by country and adjusted the sample to ensure results were as representative of the research community as possible. Responses have been weighted to be representative of the global researcher population by country (UNESCO 2014 data). Base sizes shown in the report are weighted, unless otherwise stated.

Statistical testing: Maximum error margin for 2,055 responses is ± 1.8 percent at 90 percent confidence levels. When comparing the main group and sub-groups we have used a Z-test of proportion to identify differences between the overall average and the sub-group (90 percent confidence levels).

Stage 4: scenario building

Two scenario workshops were held in late spring 2018 – one in Amsterdam and one in London. They were attended by 53 people in total, both Elsevier employees and external experts. Each person was given a pre-read package the week before, which contained a summary of the prior research. They were then divided into eight teams tasked with developing scenarios for the future, with guidance from expert facilitators from Ipsos MORI. Three dimensions of "uncertainty" were used to help teams think about the futures. These were:

Open vs. controlled: This axis reflects future uncertainty around how data (in particular) will be handled.

- **Open:** The principles of open science and open access have become fully realized in the culture of scholarly research and communication. Data is accessible to all. However, different types of data (from content to code) might be freed up in different ways.
- **Controlled:** The process and outputs of research are more tightly controlled, with soft barriers around content (e.g. some, but not all, elements of research and data are put into the public domain while others are retained privately). The overall culture is one of control, rather than free access.

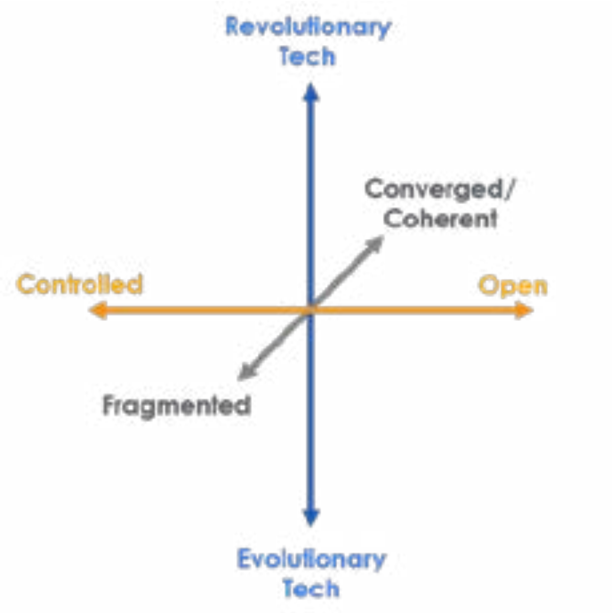
Fragmented vs. converged: This axis describes the level of cohesion in the research ecosystem.

- **Fragmented:** Elements of funding, workflow systems and metrics are fragmented in terms of ownership, uptake and coordination/ collaboration and diversity. There is little cooperation between funders (including nation states) with competing research priorities. Total amounts of research funding may be disproportionately and unevenly distributed across the world. The sources of funding may also be diverse. Workflow systems are not interoperable; there is no global agreement on how science can best measure and determine quality.
- **Converged/coherent:** Funders are aligned on global priorities. Workflow systems are interoperable and there is more collaboration among the various stakeholders, including researchers, than today. There is agreement on standardized metrics for measuring quality.

Revolutionary vs. evolutionary tech: This axis describes different speeds in the development of technology.

- **Revolutionary tech:** Technology has radically changed the shape of research and scholarly communication. The advancement of artificial intelligence (AI) has dramatically accelerated the volume of research, driven hypothesis generation and all but replaced traditional peer review.

- **Evolutionary tech:** Technology has continued to evolve at the steady pace we see today, but has not radically altered science and scholarly communication. AI plays a supporting role in the researcher workflow and in the publishing of research content.



The workshop teams considered the relationship between different high-level trends, the forces at play and the likely behaviors and interactions of different actors. They were encouraged to brainstorm and test hypotheses, and identify opportunities and challenges. Importantly, they were asked to ensure that the scenarios they developed were rooted in the realities of today. Their work was reviewed by the Ipsos MORI and Elsevier research teams and distilled down to three plausible scenarios, which are included in this report.

Monitoring the future

Once the scenarios had been confirmed, we developed a monitoring framework; key metrics we intend to track on Elsevier.com[1] that will allow everyone to identify whether a scenario, or aspects of any scenario, are unfolding. This has been made publicly available in the hope it will prove useful to all of us working in the research ecosystem as we plan for the future.

1 https://www.elsevier.com/connect/elsevier-research-futures-report

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