Research futures

Drivers and scenarios for the next decade

Summary report

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Ipsos MORI

A study by Elsevier and Ipsos MORI

Published February 2019

Contents

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 in the full version of this report (available to download from Elsevier.com). 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 (which appear in the full report only), 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

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 31

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 in the full version of this report, which is available to download from Elsevier.com[1]

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 in the full version of the report.

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

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

Together, the drivers, essays and scenarios form the key findings of this study. (Essays are included in the full version of the report.)

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

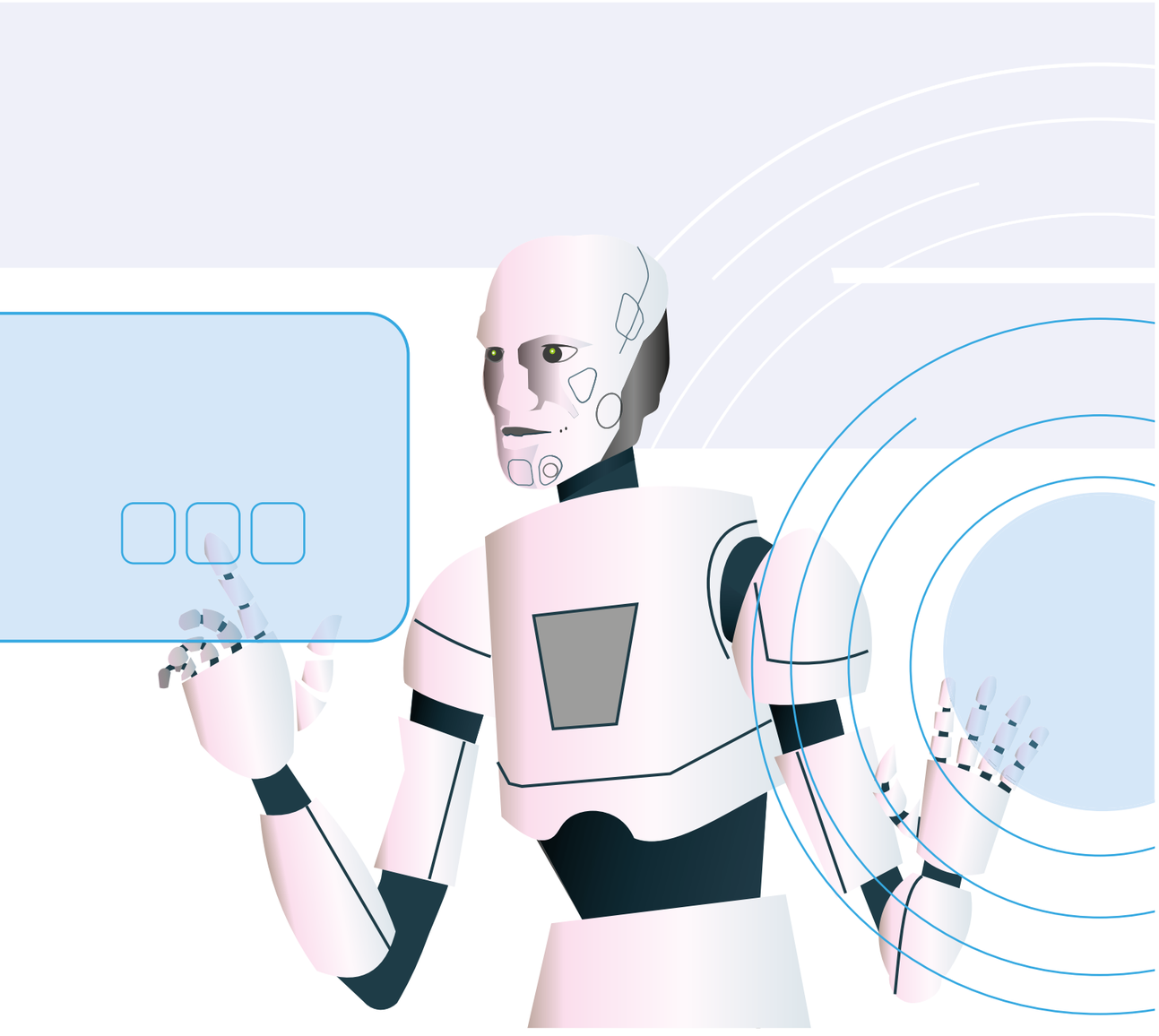
State and philanthropic funders align in their goals, approaches and principles, resulting in open science taking off, aided by artificial intelligence-enabled technologies.

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

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.

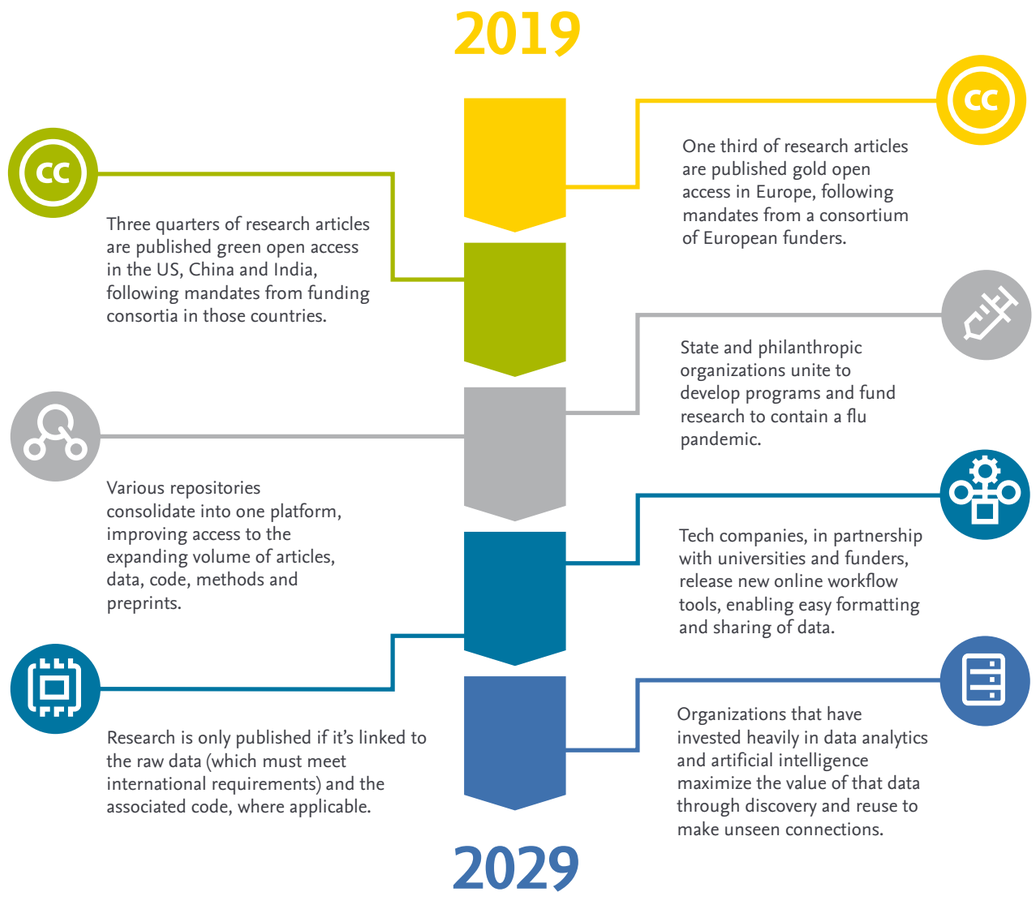
Dr. Hoffman: Another funding requirement is that we explain our findings in a way that makes them accessible to everyone. Writing for a non-scientific audience isn't easy and soaks up a lot of my time.

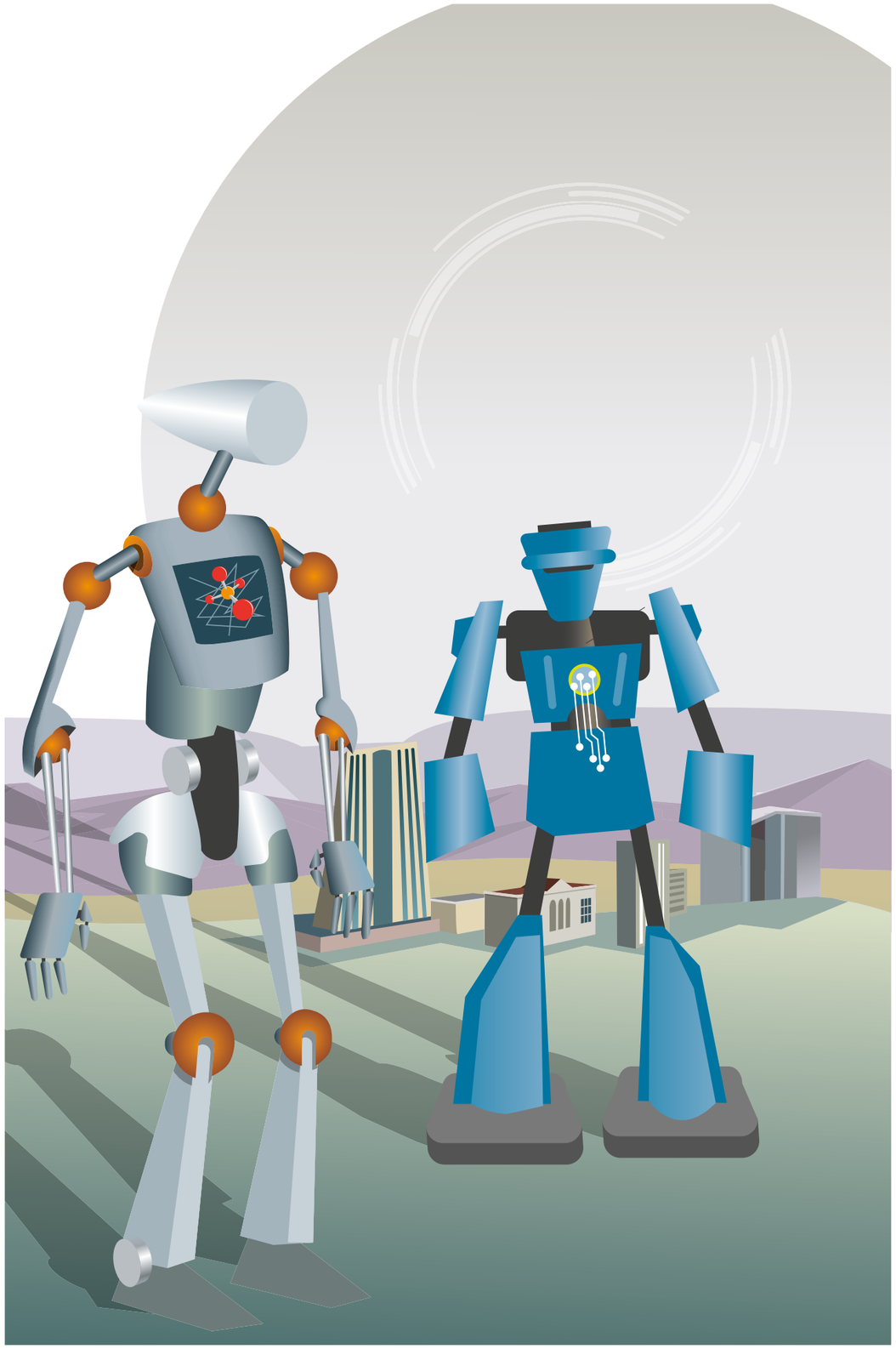
Danielle: So, you need a tool that will help you convert your findings into a digestible format. I have some natural language processing colleagues that are exploring this – I'll flag your issue with them. Thank you for your time today, your feedback will be critical to the development of our tools. 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.





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!

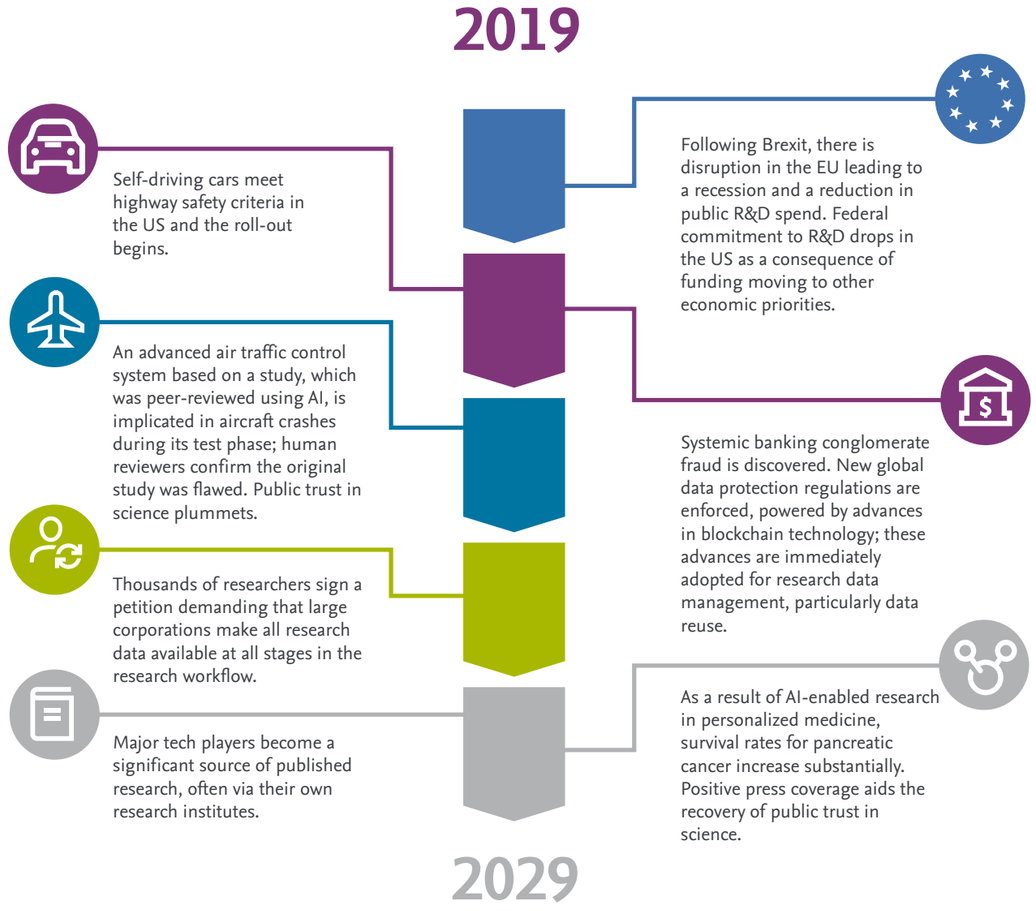
Of course, just as with any job, there are downsides. You and I are used to openly sharing our findings. That isn't always the case here. I mean, one of the reasons they are pumping money into research is because they hope to make a big return on it at some stage, so there's a lot of pressure. But, on 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.



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?

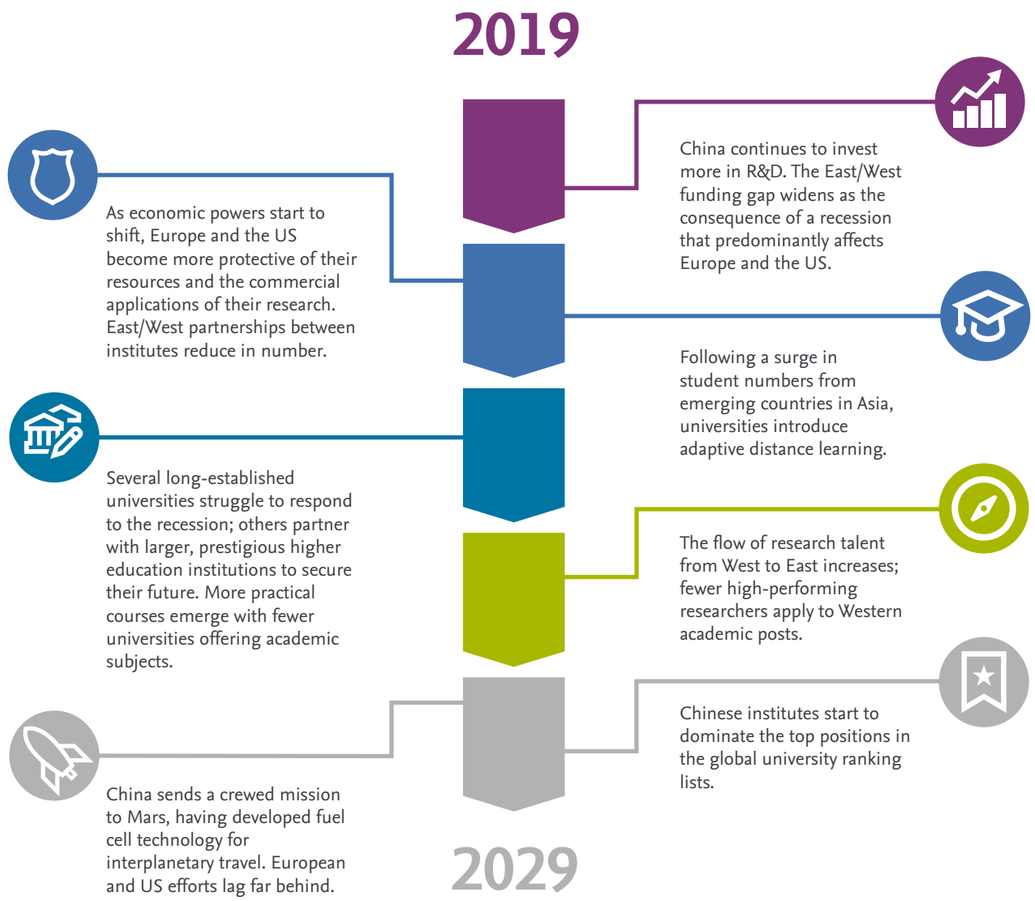
Marie: If I do decide to go, I will try to learn some Chinese, but most academics speak English, the Chinese researchers too. And I don't expect isolation to be a problem – while there are a few social media tools the authorities block, there are still lots of conferences and other networking opportunities.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



Conclusion – what we learned and Elsevier's plans

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

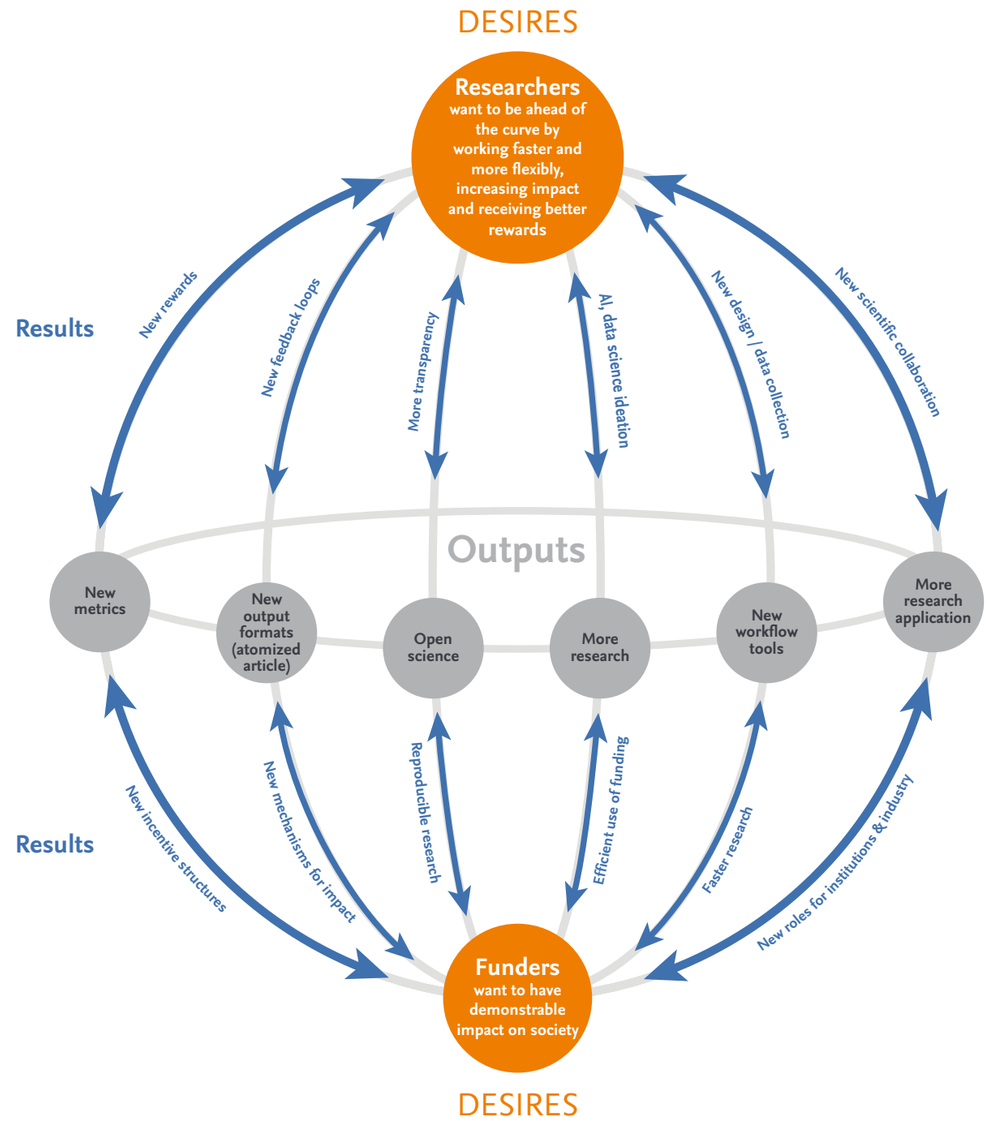
As this study has made clear, we have reached a tipping point. How research is conceived, completed and communicated will change dramatically over the next 10 years. New funding models will emerge, new methods of collaboration will develop, and new ways of conceptualizing research and measuring its impact 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 in the full version of this report. 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

Acknowledgements

Subject matter experts

Expert interviewees

Kent Anderson, CEO, Redlink & Redlink Network, USA
Rick Anderson, Associate Dean for Collections and Scholarly Communication, University of Utah, USA
Jean-Gabriel Bankier, Manging Director, bepress, Elsevier, USA
Jean-Claude Burgelman, Open Science unit head, European Commission, Belgium
Taylor Cohen, USA
Thomas Crouzier, Assistant Professor, Royal Institute of Technology, KTH, Sweden
Lewis Dartnell, Astrobiology Research Scientist, University of Westminster, UK
Anand Desai, Professor, John Glenn College of Public Affairs, Ohio State University, USA
Fabio Figueiras, PostDoc Researcher, CICECO, Universidad de Aveiro, Portugal
David Gavaghan, Professor of Computational Biology, University of Oxford, UK
Gregory J. Gordon, MD of SSRN at Elsevier, USA
Frédérick Gosselin, Associate Professor, Department of Mechanical Engineering, Polytechnique Montréal, Canada
Kazuhiro Hayashi, Senior Research Fellow, NISTEP (National Institution of Science and Technology Policy), Japan
Yun He, Dean, School of Pharmaceutical Sciences, Chongqing University, China
Oscar Jarabo, Co-Founder, Innotholic, Spain/Netherlands
Jing Ping Liu, Founding Director, Centre of Evidenced-Based Chinese Medicine, Beijing University of Chinese Medicine, China
Nicola Millard, Head of Customer Insight & Futures, BT, UK
Ronaldo Mota, Chancellor, Estácio Group, Brazil
Katrina Nevin-Ridley, Director of External Relations, Communications and Public Engagement, UK Research and Innovation, UK
Josh Nicholson, Co-founder and CEO, scite.ai, USA
Sarah Pritchard, Dean of Libraries, Northwestern University, USA
Kerry Purcell, VP, IBM Japan, Japan
Melissa Rethlefsen, Associate Dean, George A. Smathers Libraries, USA
Andrew Till, VP - Technology and Marketing, HARMAN Connected Services, USA
Jane X. Wang, Senior Research Scientist, DeepMind, UK

In addition, we extend our thanks to other interviewees from academia and business who participated anonymously.

Elsevier and Ipsos MORI

Project sponsor
Alexander van Boetzelaer
Senior project director
Adrian Mulligan
Project director
Rachel Herbert
Project team
Andrew Plume
Stephane Berghmans
Daniella Voermans
Gert-Jaap Jong
Max Khan
Theo Pillay
Arnold Pippel

Literature review
Rachel Herbert (Lead)
Daniella Voermans
Geert-Jaap Jong

Interviewers
Jorgos Achtivassilis
Hesham Attalla
Rachel Herbert
Geert-Jaap Jong
Liliane Kuiper-Hoyng
Daniella Voermans

Researcher survey
Gemma Deakin
Rachel Herbert
Alexandra Mitchell
Adrian Mulligan
Andrew Plume

Project administration
Carol McNeil
Isabel Garcia

Ipsos MORI contributors
Project design, interviewing, workshop facilitation and analysis
Graham Bukowski
Sarah Castell
Guillermo Fernandez
Jayesh Shah
Colin Strong
Emily Wayne
Rebecca Wilson

Report authors
Linda Willems, Blue Lime Communications (lead writer and editor)
Adrian Mulligan
Rachel Herbert
Andrew Plume
Sarah Castell
Emily Wayne

Report communications
Sacha Boucherie
Stephane Berghmans

Report design
Alan Chaston, Linesman Design

Thanks to various Elsevier staff who provided valuable support on this project.

Ipsos MORI