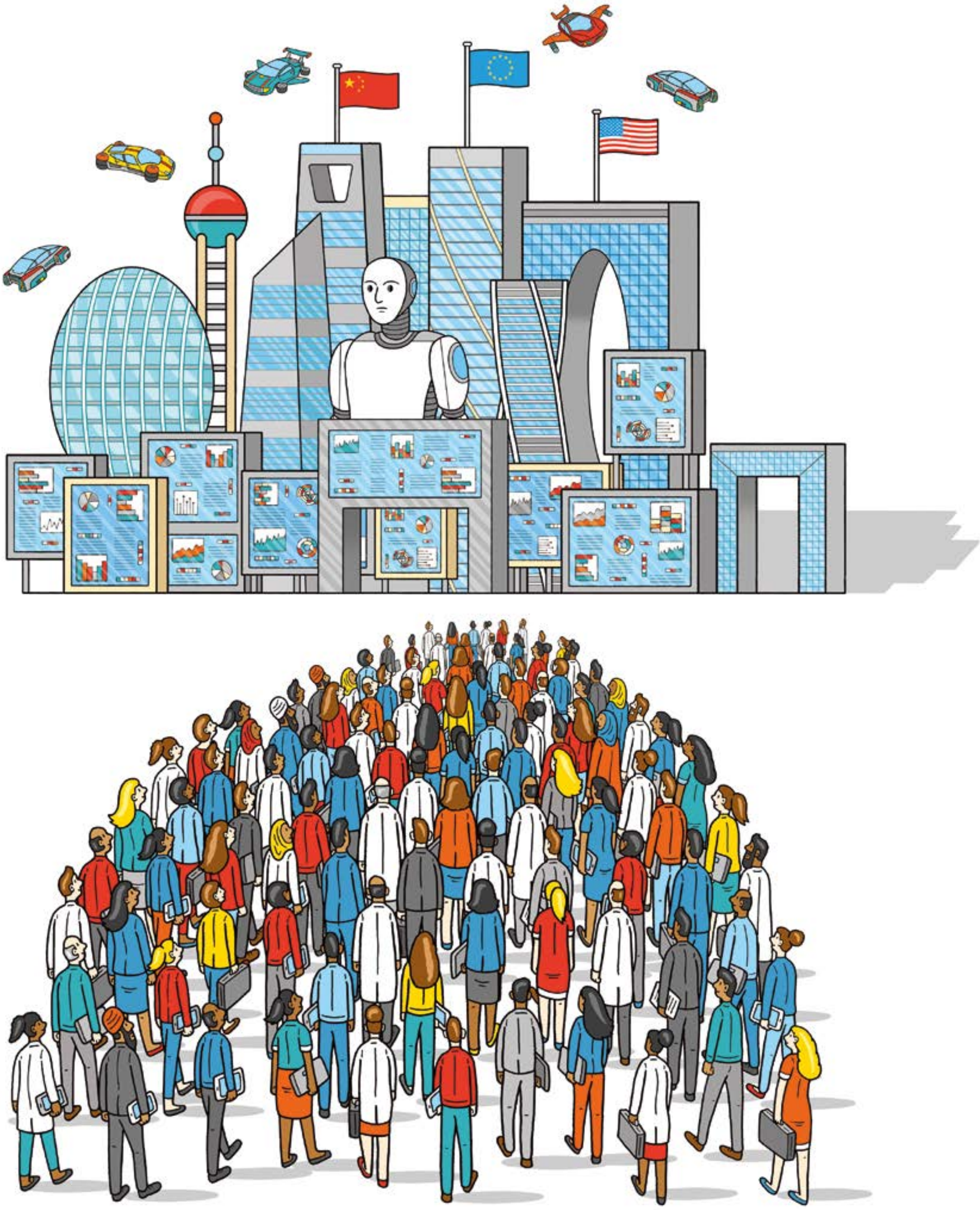
Research Futures 2.0

A new look at the drivers and scenarios that will define the decade



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Research Futures 2.0

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Foreword

At Elsevier, our mission is to help researchers and healthcare professionals to advance science and improve health outcomes for the benefit of society. We continuously adapt and evolve how we support the communities we serve so that we can optimally meet their changing needs, today and in the future. We do this by bringing together content, data, analytics, and technology.

In 2019, we shared our first *Research Futures* report. This was a large-scale study that examined the research landscape to identify what could happen in the decade to come. Notably, we had identified three scenarios for the next 10 years: Brave Open World, with increasing share of open science; Tech Titans, where AI and tech companies play a larger role in the research ecosystem; and Eastern Ascendance, where China's plays a bigger role in the progression of global research.

Three years on, the research ecosystem continues to undergo rapid change, accelerated by COVID-19. Change is being fueled by many factors, including advances in technology, funding challenges and opportunities, political uncertainty, and new pressures on women in research. Our new Research Futures report reflects key findings in these areas, alongside the validation for our three future scenarios.

Our goal is that the insights uncovered in this report will help all of us better prepare for the future. Please do contact us with your thoughts and ideas!

Mirit Eldor

Executive Vice President Strategy, Elsevier

Introduction

What we did in the original study

Back in 2018, with the help of Ipsos MORI, we set out to conduct a study to try to understand how the rapid and profound changes we were witnessing in science, technology and medicine were impacting the research landscape.

Our goal was straightforward: to equip all of us in the industry with the knowledge we needed to navigate the opportunities and challenges that lay ahead. Drawing on a comprehensive literature review, interviews with 56 technology, research and publishing experts around the globe, and a survey of 2,055 researchers, we attempted to build a blueprint for the coming 10 years.

In February 2019, we published the report based on that study—Research futures: Drivers and scenarios for the next decade. It comprised two key pillars:

Pillar one: the six themes

Nineteen key drivers expected to shape developments in the decade ahead were identified during our discovery phase. We grouped these drivers into six themes and explored each of them in essay form.

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

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 interest
6. Metrics will continue to expand, enabled by new technology

How researchers work: change ahead

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

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

Building the future research information system

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

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

Pillar two: the three scenarios

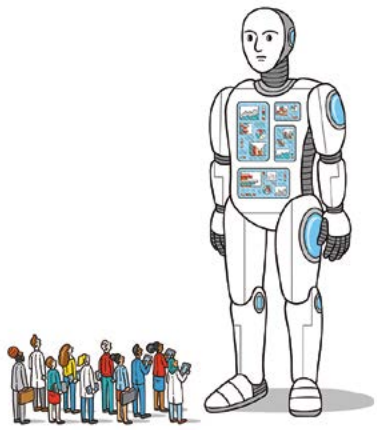
We held three one-day workshops with internal and external experts. Attendees thought about how the 19 key drivers might influence research and came up with three credible scenarios, each envisaging what the future might look like a decade later.

Brave open world

Globally, state funders and philanthropic organizations align in their goals, approaches and principles, resulting in open science taking off, especially in Europe, aided by advances in artificial intelligence-enabled technologies. Platforms are interoperable and content is easy to access.

Signposts: Events that we had thought might indicate this world is emerging

- State and philanthropic organizations unite to develop programs to contain a flu pandemic
- One-third of research articles published gold open access in Europe
- Three-quarters of research articles published green open access in the US, China and India
- Repositories consolidate into one platform, improving access to articles, data, code, etc.



Tech titans

Significant advances in artificial intelligence (AI) products drive innovation, enabling technology companies to support the research ecosystem and become knowledge creators and curators in a world where industry and philanthropic foundations are the key research funders.

Signposts: Events that we had thought might indicate this world is emerging

- Disruption in the EU leads to a recession and a reduction in public R&D spend
- Major tech players become a significant source of published research
- As a result of AI-enabled research in personalized medicine, survival rates for pancreatic cancer increase substantially.

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.

Signposts: Events that we had thought might indicate this world is emerging

- China continues to invest more in R&D; the East/West funding gap widens
- Europe and the US become more protective of resources and commercial applications of their research; the number of East/West partnerships falls
- Chinese institutes start to dominate the global university ranking lists.

Fast forward to today

Since early 2020, the pandemic has transformed every aspect of researchers' work. We felt the time was ripe to revisit our first report and consider how the themes and scenarios we identified two years earlier were playing out, particularly in light of COVID-19.

During 2020 and 2021, we conducted two separate researcher surveys asking questions on a broad range of topics, from collaboration to education and from open science to public engagement. We reviewed the world of research through the changes of the past two years. We also asked researchers to help us understand the impact of the pandemic on their work. In total, 1,066 researchers in 2020 and 1,173 in 2021 from a multitude of disciplines and locations responded to our surveys. We compared the data collected from these surveys with a survey completed in 2018 as part of the original Research Futures study when 2,055 researchers responded to our survey. You can find out more in the Methodology section on page 145. We also examined the latest macro indicators (including R&D expenditure).

What did we find?

The results of our surveys and research are contained in the six essays on pages 9 to 144, which follow the themes outlined on the previous pages and the format of the essays in our original report. Our major findings can be found in the Summary on page 7.

Looking at the three scenarios identified in our 2019 report, we see that elements of each is coming true. We have flagged these elements in the essays – look out for the "scenario match" boxes. That only some aspects are materializing is not surprising: as we noted in the original report, no single scenario has to be correct; aspects of just one could become reality or they might combine in any variety of ways.

We have also flagged progress on the drivers of change identified in our original study that allowed us to formulate the scenarios. We used a traffic light system to convey whether or not we feel a driver is evolving in the way we anticipated: red for no progress, amber for some progress, and green for clear signs of progression.

Importantly, this latest study has confirmed one of the key findings of our original report, which is that we are at a tipping point and the shifts to come would be transformative. If we are to ensure that this change is sustainable, action will be needed in unison across all the areas we've examined. This study underlines that all of us who work in the world of research share responsibility for creating a new environment in which research can flourish. None of us can do it alone, particularly now.

Research Futures 2.0 – Summary

Since our inaugural report in 2019, COVID-19 has had a dramatic impact in every area of science, and indeed, the world. Driven by governments seeking the best ways to safeguard the health of their populations while keeping their economies open, or as open as possible, researchers have been at the forefront of each twist and turn of the pandemic as it moved from continent to continent, evolved from one variant to another and another, and took center stage in contentious decisions about everything from freedom of movement, to access to vaccinations, to widescale lockdowns.

Since our last report, researchers and science have been under enormous pressure to find solutions to free the world from COVID-19. Researchers have stepped up to the challenge, developing vaccines in record time, working under extreme time pressure, across borders and specialties, often in extremely difficult conditions.

A challenging funding landscape but with hope on the horizon

The spotlight on science and research has highlighted the importance of securing adequate funding, a major concern for researchers. 50 percent now say that funding in their field is insufficient, while just one in four (24 percent) believe funding is adequate, a drop from the 30 percent who said that was the case in 2020. Researchers cite fewer funding sources, increased competition, changing priorities and the diversion of funds to COVID-19 related fields as the reasons behind this trend. However, 39 percent do express optimism that funding will increase in the next two to three years, rising from 31 percent a year ago. This sentiment may well have been impacted by stimulus packages initiated in different parts of the world. It is also likely that closer links between the corporate world and science will bring further opportunities for researchers in the years ahead, with 41 percent of researchers expecting that corporate funding of research will increase.

Getting the balance right

As universities closed their campuses and laboratories were shuttered, researchers have had to adapt to the new ways of working imposed by the pandemic, meaning much research has been conducted from home. For some, this has enabled a more flexible and productive working pattern. For others, particularly female researchers, the constant proximity to care responsibilities has made devoting time to research more difficult. Sixty two percent of women indicated they had difficulty ensuring a positive work-life balance during the pandemic, compared to 50 percent for men. However, that did not seem to diminish women's expectation of what can be achieved - 53% of women scientists think the use of technology in research will accelerate over the next two to five years in comparison to 46% of men.

Greater collaboration

Whether or not researchers have found the move to working from home welcome, most researchers (63 percent) have been collaborating more than in the past, up from 48 percent before the pandemic. Researchers have been working across disciplines more often than before the pandemic, reading preprints to stay connected to new ideas and increasingly using new technology such as AI to help analyze the data sources available to them.

Faster and more open knowledge in publishing

The pandemic has undoubtedly accelerated the adoption of open science. The expansion of preprints has been one of the notable hallmarks of the pandemic for researchers who wished to disseminate knowledge quickly and openly. About two-thirds of researchers (67 percent) now consider preprints a valuable source of communication, increased from 43 percent before the onset of the pandemic, a shift driven in part by the increased role of preprints in finding ways to tackle COVID-19. Researchers appreciate the potential of preprints to quickly disseminate research findings and widen their impact. At the same time, however, the potential risks of publishing without peer review remains a very strong concern for many in the scientific community and beyond.

Alongside the expansion of preprints, we also saw an increase in data sharing; over half (52 percent) of researchers say they are sharing more research data than was the case just two to three years ago. We also saw the intention to publish an Open Access article increase from 49% pre-pandemic in 2019 to 54% a year later. Moreover, nearly half of researchers in 2021 (47 percent) expected the drive for Open Science to increase over the next 2 to 5 years.

Making an impact

Another aspect of increasing openness is greater engagement with the public, over the course of the pandemic researchers believe that public engagement with research has increased - 64% now believe that public understanding of their research is good, up 4 percentage points on the prior year. At the same time, researchers recognize they will need to demonstrate impact - 54 percent anticipate there will be a greater emphasis on the societal impact of research going forward. This expectation is higher among women (62 percent) than men (52 percent).

Embracing new technology

New technologies have moved out of the laboratory and into research. AI has been embraced more than ever during the past two years, though some caution remains. 16% of researchers are extensive users of AI in their research, and while high take-up in Computer Sciences does inflate that number (64% of computer scientists are heavy users), there has been growth in usage of AI in research across most specialties.

In education, technology companies have led the switch to online teaching and learning around the world during the pandemic, leading the way to a blended learning environment of in-person and on-line teaching. Hybrid models of online and in-person teaching are expected to continue after the pandemic, with the majority (56 percent) believing that most of their teaching will be online. This is despite only 29% of respondents agreeing the shift online positively impacts teachers and 21% agreeing it positively impacts students.

Getting mobile

Researchers have also been reconsidering their motivations and choices for moving abroad. As the pandemic moves into its third year, many now wish to be closer to home and family, but for others (34% percent), the prospect of greater funding and research opportunities abroad is still attractive. The USA remains the most attractive destination.

The future is now

Since our 2019 report, the pandemic has accelerated changes in many areas of research, leading to increased openness, more collaboration, and greater use of technology. All these trends are important drivers for the three scenarios for the decade ahead we outlined in our 2019 report (Brave Open World, Tech Titans and Eastern Ascendance). And whilst we are only in the third year of that decade, it is already clear we are already seeing tectonic shifts, but as we anticipated, there is no indication that any single scenario is more likely than another to come true, rather we are seeing aspects of each unfold.

It is worth reiterating that the scenarios don't claim to be predictions. Rather, they provide us with a framework that we can build for a future that still remains uncertain. Our ambition is that this and future reports will help us all understand the landscape and the implications of the plans we make today to ensure we are best placed to thrive in the future – whatever it brings.

Funding the future

A quick glance back…

In our original report, we identified three key areas of change – these are featured in the blue boxes below. Each of these is accompanied by a bulleted breakdown of the shifts we anticipated would occur as that change unfolded.

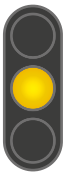
Taken from ***Research futures 2019***

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.
- 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 start-ups.
- 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.

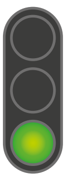
2



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 expected to outpace that of the US soon. 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 and 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 and global problems. This poses challenges for researchers around intellectual property and maintaining competitive advantage, and they will respond in different ways.

Now, three years into the 10-year window and with COVID-19 impacting every element of our lives, how are those predictions standing up?

We have used a traffic light system to give an indication: red for no progress, amber for some progress, and green for a reasonable amount of progress.

Read the original **"Funding the future"** essay in *Research futures*
www.elsevier.com/research-intelligence/resource-library/research-futures

Key findings

- The impact of COVID-19 has affected R&D funding through changes in funders' priorities and financial constraints on funding due to impact of the pandemic on countries' economies. Less than a quarter of researchers think they have sufficient funds, 6 percentage points less than in 2020.
- However, 39 percent express optimism that funding will increase in the next two to three years, versus 31 percent a year ago. (Sentiment has likely been impacted by stimulus packages in different parts of the world.)
- Researchers think I benefit from more corporate funding, 41% believe it will increase over the next two to three years. Some researchers worry about commitment to long-term projects and believe 'blue sky research' could be a casualty.
- Ongoing geopolitical tensions and China's initial rapid economic recovery from the pandemic are shifting the research agenda and power base eastward.

Back in 2019, we stated that despite signs of a strong global commitment to research and development (R&D) funding, many researchers and their institutions remained concerned about securing finance, because most nations were facing shrinking public budgets and increasing calls on the money remaining. Fast forward three years and we are living in a world where COVID-19 has helped rewrite the funding rulebook, and multiple R&D income streams have been put under pressure. Researchers' lack of confidence in funding has been growing. In 2021, just one in four researchers expressed confidence that adequate funding is available for their work-down from nearly one in three a year ago. They cited the impact of less funds being available, increased competition and shifts in priorities due to the impact of COVID-19 (Fig 1).

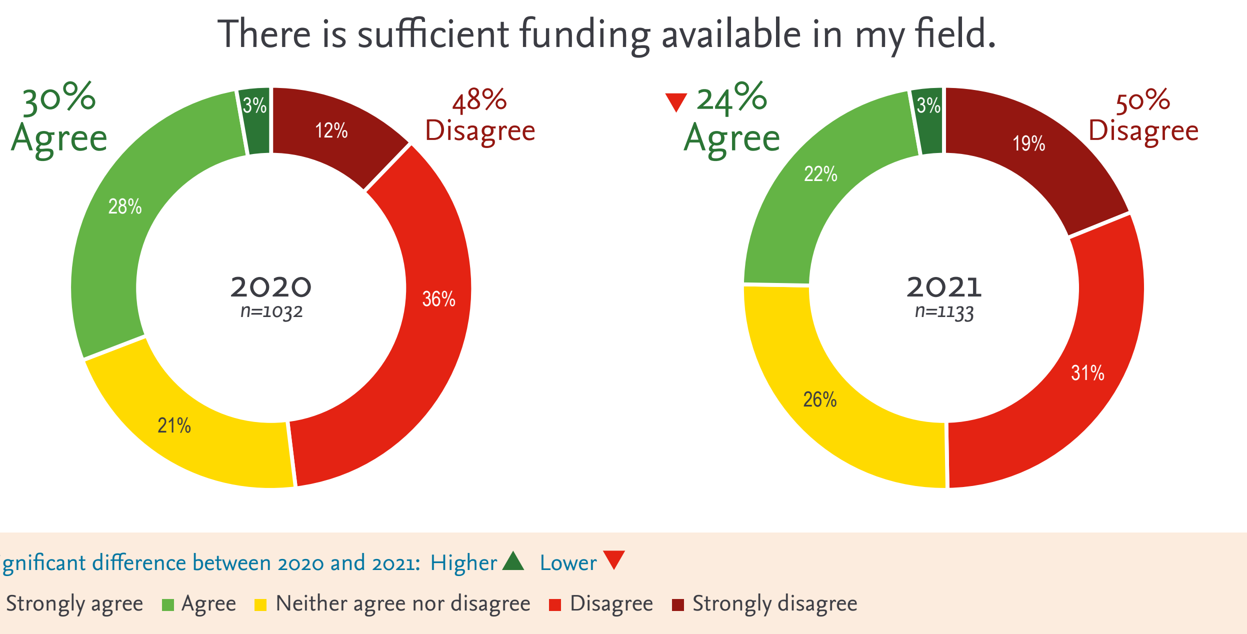


Figure 1: *Question: "Researchers' views on whether there is sufficient funding available in their field'. Source: Researcher survey. Researcher surveys for this study. Base in 2020 and 2021 ==1,032, base in 2021=1,133.*

Around the world, governments have been redirecting budgets to bolster health services and preserve jobs in the wake of the pandemic. For example, in the USA there were several injections of funds into the economy. The Coronavirus Preparedness and Response Supplemental Appropriations Act, signed into law in March 2020, allocated US$8.3 billion to fund research for a vaccine and support actions to fight the spread of COVID-19. This was followed by the US$2 trillion Coronavirus Aid, Relief, and Economic Security (CARES) Act, approved in March 2020. [1] Then in December 2020, a US$900 billion pandemic relief bill containing enhanced unemployment benefits and direct cash payments was passed into law. On 11 March 2021, the American Recovery Plan was passed, bringing an additional US$1.9 trillion towards coronavirus relief. In May 2021, President Biden outlined a US$6 trillion spending request that includes a 9 percent increase in total federal research and development spending for 2022. That would see R&D spending rise to US$171 billion for the 2022 fiscal year, which starts on 1 October. Spending on basic research would increase by 10 percent to US$47.4 billion and spending on applied research would increase by 14 percent to US$51.1 billion.[2] This continues the incremental rises in the US's R&D spending from all funding sources in recent years, rising from 2.6 percent of GDP in 2000 to 2.7 percent in 2010 and 3.1 percent in 2019. That is higher than the OECD average of 2.5 percent in 2019, and ahead of the EU, which averaged 2.1 percent in 2019, China at 2.2 percent and the UK at 1.7 percent.

In July 2020, EU states agreed a €1.1 trillion budget for 2021-2027, plus NextGenerationEU, a COVID recovery fund worth more than €8 billion "to help repair the economic and social damage caused by the coronavirus pandemic." [3] On a country level, many governments introduced some form of wage subsidy or financial incentive scheme to encourage struggling employers to keep staff while lockdowns forced businesses to close or manage reduced income.

Governments also allocated funds to hunt for a vaccine – often in collaboration with industry. For example, Russia's Sputnik V vaccine was financed by the Russian Direct Investment Fund (RDIF), a state-owned investment fund containing money generated by the government. The US federal government had invested more than US$9 billion to develop and manufacture candidate vaccines (some of that in private firm Moderna).[4]

Scenario match

In the scenario **Brave Open World**, we suggested that one of the indicators that the world we had painted was emerging would be state and philanthropic organizations uniting to develop programs and fund research to contain a flu pandemic.

In addition to vaccines, in early October 2021, molnupiravir was heralded as a potential game-changing medicine that reduces the risks of COVID. Originally an influenza drug, molnupiravir is an oral antiviral medicine that has been shown to inhibit replication of the SARS-CoV-2 virus and cut the risk of hospitalization by about one-third. Various parties worked together to ensure the drug was available: it was discovered at Emory University in Atlanta, Georgia and was approved for use to treat influenza by the UK MHRA and the US FDA. It was developed by Merck and Ridgeback Biotherapeutics LP [5] with funding from the US government. [6]

These outlays are also helping the global economy recover more quickly than expected from the economic costs of the pandemic, according to a United Nations Conference on Trade and Development (UNCTAD) report released in September 2021. However, the recovery is progressing at an uneven pace around the world: " ...this year will see the global economy bounce back thanks to the continuation of radical policy interventions begun in 2020 and a successful (if still incomplete) vaccine roll-out in advanced economies. Global growth will hit 5.3%, its fastest rate in nearly five decades. The recovery, however, is uneven across geographical, income and sectoral lines. Within advanced economies, the rentier class has experienced an explosion in wealth, while low-earners struggle." [7]

The economies of emerging markets are also suffering, according to the US Federal Reserve. In an October 2020 article, it noted that these countries often rely on international borrowing sources, [8] which tend to dry up during economic crises, as emerging economies are generally seen as high-risk markets for lending purposes. [9] This "sudden stop" in finance, combined with the issues these economies already face as a result of the pandemic, "could gravely complicate the quest for economic recovery and normalization." [8] Given these hurdles, it seems unlikely emerging economies will play the major role in reshaping the research agenda our original report predicted

War in Ukraine

Following the Russian invasion of Ukraine on 24 February 2022, the funding priorities of many governments around the world underwent swift changes putting pressure on existing budgets. To fulfil immediate needs, spending has increased on humanitarian aid for the growing number of refugees fleeing Ukraine. In the weeks following the invasion, more than 1 million refugees had already left the country to seek shelter abroad.

Both Russia and Ukraine are major growers of grain, wheat and cooking oils, such as sunflower oil. Two weeks after the invasion, the International Monetary Fund had noted increases in the prices of grain and cooking oils as well as rises in energy and fuel prices, leading to higher food and fuel costs for people in many countries. This will increase pressure on governments to provide subsidies to support their populations.

While the situation is very fluid and the financial implications are still unclear, such subsidies are very likely to impact government research budgets. [10]

In addition to these direct costs to be borne by individual governments, international bodies such as the EU will also be redirecting funds to support the Ukrainian government and its people. On top of humanitarian support worth €500 million and €100 million worth of supplies, the EU is also making available €1.2 billion in emergency macro-financial assistance and €120 million in budget support for the country. [11]

By mid-March, the World Bank had put together a financial aid package for Ukraine worth more than US$925 million, part of a package worth US$3 billion. [12] The package includes a multi-donor trust fund comprising contributions and financing from countries including the UK, Austria, Denmark, the Netherlands and Japan.

In the US, President Biden signed US$13.6 billion in aid for Ukraine, which will be spent to help refugees, and on defense equipment and training. [13]

Military spending has now become a priority for many countries as governments move to quickly bolster their defenses. Coming on the heels of the pandemic, this is likely to further increase pressure on government budgets for research.

Almost immediately, Germany announced it will spend €100 million of its 2022 budget on its armed forces, more than double its entire 2021 defense budget. [14] Shortly afterwards Sweden announced it would double its military spending, to 2 percent of GDP military spending "as soon as possible", from the current spend of about 1 percent GDP. [15]

We discuss the war's impact on scientific collaboration in our essay **"How researchers work: change ahead"**.

An evolving funding mix

As we highlighted in our original report in 2019, many across the science, health and technology sectors expect corporate and government funding to grow in the years ahead. In the case of US philanthropic foundations, the pandemic has also prompted a wide-ranging loosening or elimination of grant restrictions, with one foundation leader dubbing the pandemic "a wakeup moment for philanthropy," leading to more grant dollars distributed faster and more efficiently, and more and better collaborations. [16]

According to researchers in our latest study, funding from government or federal sources stayed relatively stable at 41 percent of all funding in 2021, a slight dip from the 42 percent seen in 2020. Institutional funding stood at 35 percent in 2021, back up to the level seen in 2019 after a dip to 29 percent in 2020. Corporate funding stands at 12 percent of overall funding in 2021, up from 9 percent in 2019.

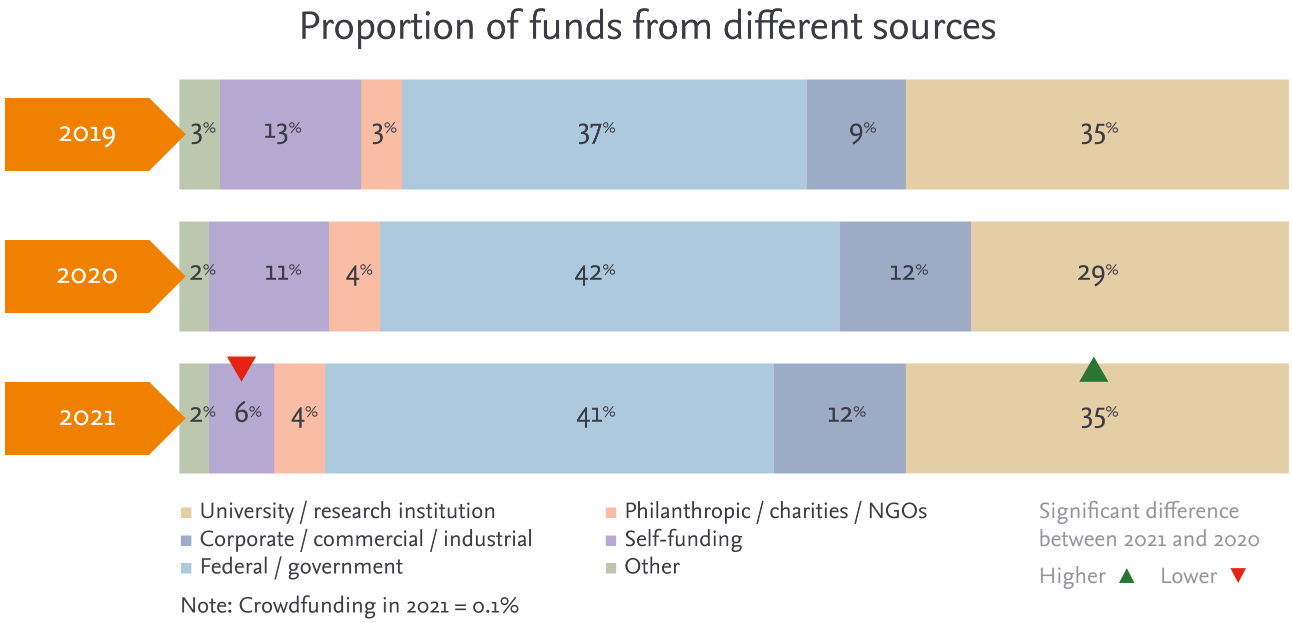


Figure 2: *Researchers' views on the proportion of funds from different sources. Source: Researcher surveys in 2019, 2020 and 2021. Base in 2019=1,438, base in 2020=861 and base in 2021==1,024.*

According to OECD data, the impact of COVID-19 on R&D funding has varied by sector. Those working in digital and pharmaceutical businesses – two industries whose services have been greatly in demand during the pandemic – have fared better than others. Based on the OECD's provisional data for 2020, released in March 2021, businesses continued to invest in R&D throughout the year, though at a reduced pace compared to 2019. The biggest investments were in the information and communications technology and life sciences industries. [17]

Industry funding often goes hand in hand with a corresponding rise in academic/industry collaboration, providing researchers with alternative sources of money and equipment and the ability to speed up results. However, there can be tensions around ownership of the resulting intellectual property, and, for industry, the focus can often be on short-term results as well as applied science. Philanthropic funding can also bring many benefits, including deep pockets on specific projects, such as curing polio, and an understanding that results can take time. On the other hand, the absence of governmental oversight means there are fewer guarantees that either funding source will remain committed to a project long-term.

According to astrophysicist France Córdova, who has recently finished her six-year term as Director of the US' National Science Foundation, "the importance of continuity of funding, taking the long view in funding for preparedness, has never been clearer." [18]

Some of our survey respondents expect corporate and philanthropic sources to contribute an ever-growing share of R&D funding.

"The only process change I could envision is more private foundations arising to support funding for their specific research needs."

Biochemistry, USA, aged 26-35

"I think that more philanthropy institutions will be the funders."

Biochemistry, Mexico, aged 46-55

Some respondents also anticipate that new funding models will emerge to help push innovation forward; for example, crowdfunding, which typically involves raising small amounts of money from a large number of people, usually via the Internet. Crowdfunding accounted for just 0.1 percent of total funding in 2021, but the funding needed to meet climate change goals could see that figure grow. According to *Forbes*, venture capitalists (VC) and others are playing a bigger role in funding climate-friendly technologies and companies.

VC funding was predicted to reach a record high of US$21 billion in 2021 for climate tech-focused funds and US$49 billion for climate tech companies. Crowdfunding is considered to be part of this "green tech" boom, and crowdfunding platform Indiegogo has raised more than US$78 million for sustainable products and sustainable tech, funding projects such as a sustainable air purifier and an instant waste compost bin. [19]

Most agree that funding will increasingly be linked to performance and impact on society.

"I'm guessing that research funding will increasingly follow the "venture philanthropy" model, in accordance with which funders, even those interested in supporting theoretical work and basic research, will be more interested in assessing the quality of deliverables."

Social Sciences, USA, aged 46-55

And many share a fear that fundamental and breakthrough research could be under threat as funding sources evolve.

"The trend of 'funding only research aligning national or institutional strategy' becomes dominant and no blue sky research is possible."

Engineering, Japan, aged 56-65

"I'm afraid it will more and more depend on private funding and on short-term research projects. This is already killing fundamental research, without which no real advancement of knowledge is possible."

Materials Science, France, aged 46-55

"It will get harder to obtain funding for more innovative work. Funding decisions are based on risk, low risk of failure implies very obvious incremental research steps."

Materials Science, USA, aged 46-55

Against a backdrop of changing global priorities, the funding mix continues to evolve. After a sharp drop in 2020, funding from universities and research institutions has regained the share of just over one-third of all funding seen before the pandemic, while over the same time period, self-funding has fallen by more than half.

For universities, public funding remains crucial, even as they continue to seek and develop other income sources. During the pandemic, many institutions used existing research funds to pay researchers. However, those researchers were unable to conduct research while campuses were closed. As a result, researchers subsequently had less money to do the research tied to that funding. At the same time, researchers themselves reallocated funds. A survey conducted by Digital Science and Springer Nature found that 43 percent of respondents whose research had the potential to contribute to the pandemic response had tried to repurpose their existing grants. But, as Jeffrey Lazarus, Head of Health Systems at the Barcelona Institute for Global Health, notes in the report, that approach could prove a double-edged sword: "It's great that researchers can change direction … but they won their grants because they had good ideas related to their research field. For delayed projects, it's often difficult to go back to a funder and say, 'Can we have an extra £35,000 to complete a project?'." [20]

Interestingly, we found that government funding not only remains the most important source of money for our respondents, but it has also increased as a proportion of the overall budget available to researchers since 2019. Twenty percent of researchers in our survey believed the amount of corporate and philanthropic funding increased compared to two to three years ago. This is not as high as some might have expected. With regard to philanthropic funding, this is likely because the entire ecosystem of charities' income was impacted by COVID-19, both in terms of their income and spending priorities. According to Philanthropy-impact.org, "…most charities will be seeing a squeeze on income. Previous economic and financial market downturns have typically impacted on the level of grants from companies, charitable trusts and major donors. The fall in value of investments and property also effects the value, if not the number of legacies. We can expect to see this pattern again in the coming months." [21]

Certainly, the pandemic has changed the priorities of big philanthropic funders. Conditions of philanthropic giving also changed because of COVID-19, with many becoming less onerous in their requirements to ease the burden and to take into account constraints during the pandemic. At the time of going to print, 806 foundations had signed a pledge to ease grant-giving conditions for their non-profit partners. [22] The impact of this commitment, which is still gathering signatories, will be welcomed by the researchers affected. As we discuss later in this essay, many researchers say that overall funding requirements have grown more onerous.

As of January 2022, the biggest philanthropic foundation in the USA, the Bill & Melinda Gates Foundation, had committed more than US$2 billion to supporting the fight against COVID-19 and its knock-on effects. That includes US$770 million in new funding for urgent public health measures, including slowing COVID-19 transmission and, new vaccine development; US$920 million for pandemic related at-risk financing, and US$315 million in redirected program funding to support direct COVID-19 work. [23] Whether this is a short-term shift of commitments or a long-term trend to fight pandemics remains to be seen. The impact of the pandemic is so widespread that it may be difficult to predict exactly where philanthropic funding will be directed. In September 2021, amid reports that world hunger had reached record levels in 2020, likely due to the impact of the pandemic, the Bill & Melinda Gates Foundation announced a US$922 million commitment over the next five years to improve global nutrition.

> *"Philanthropic organizations have a greater role in funding research and recognize the issues with federal funding sources giving more flexibility of the funds and sustainability."*
>
> (Biological Sciences, USA, aged 46-55)

Researchers in the fields of Computer Science and Medicine are most likely to report that they receive more of their funding from corporate or philanthropic sources than they received two to three years ago, while Physics and Social Sciences researchers are less likely than average to say they received more funding from these sources than they did in the two to three years prior.

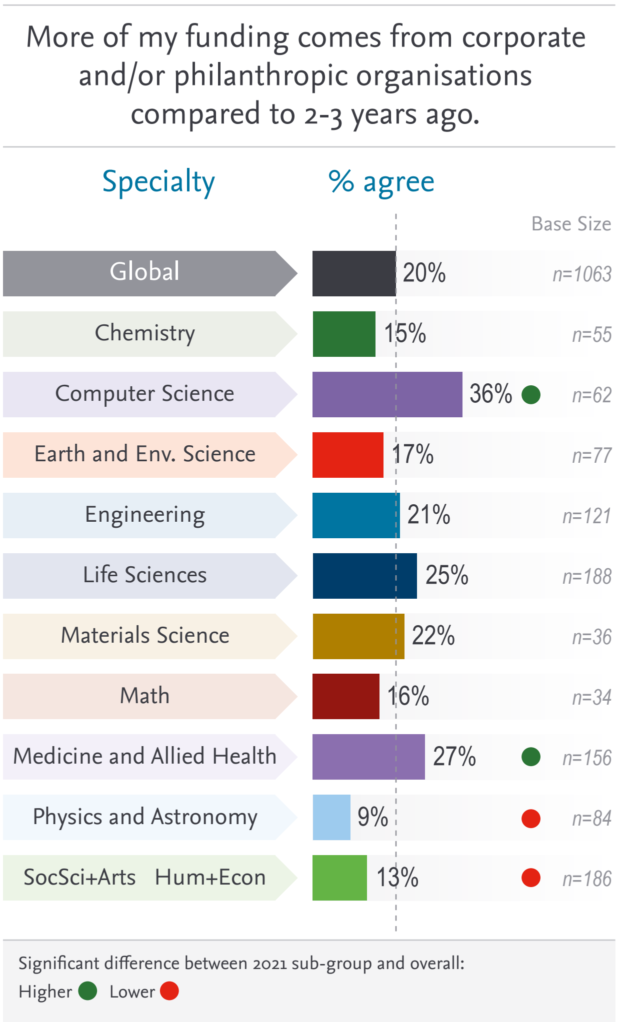


***Figure 3**: Researchers who agree more funding comes from corporate and/or philanthropic organisations compared to 2-3 years ago. Source: Researcher survey 2021. Base=1,063.*

Global factors

When COVID-19 arrived, the funding scene was already turbulent. Priorities were being influenced by factors such as political uncertainty in countries and regions including the USA, Europe, UK and China.
That uncertainty has only escalated since the pandemic and has led to rising tensions within and between nation states. [24] Another major element shaping funding policies has been the "grand challenges" our society faces, including an ageing population and climate change, and all the health and economic considerations they bring.

"Humans face many challenges. Malignant tumors, infectious diseases like COVID-19, and aging diseases such as Alzheimer's disease require funding to support continuous research."

Medicine, China, aged 56-65

"I think investments in environmental technologies are expected to grow (European Green Deal, etc.)."

Environment, Luxembourg, aged 36-45

The UN 2021 Climate Change Conference, COP26, took place in Glasgow from 31 October to 12 November 2021 and had three key aims: to drive increased adoption of 2030 targets and net-zero long-term goals; transparent disclosure and tracking of progress on meeting environmental goals; and building a sustainable financial system. Whether those aims are achieved will depend on the actions taken by individual countries. Most commentaries agreed there was room for cautious optimism on the conference's achievements. The results were summed up by British politician and COP president Alok Sharma: "We can now say with credibility that we have kept 1.5 degrees alive. But, its pulse is weak and it will only survive if we keep our promises and translate commitments into rapid action." [25]

The final summit document, known as the Glasgow Climate Pact, won applause for committing signatories to a doubling of adaptation finance, and for pushing for more ambitious goal setting in 2022. The conference resulted in a series of statements signed by different countries and organizations including a statement on the "Global Transition from Coal to Clean Power". Signatories agreed to make clean power the most affordable and accessible option and "to achieve a transition away from unabated coal power generation in the 2030s (or as soon as possible thereafter) for major economies and in the 2040s (or as soon as possible thereafter) globally."

However, the statement was not signed by China, the biggest coal consumer, or Russia. Russia's president Putin, committed Russia to achieving carbon neutrality by 2060. President Xi Jinping of China made a commitment to a target of reaching peak emissions by 2030 and being carbon neutral by 2060. These new commitments, were welcomed by the World Resources Institute as "a modest improvement" on the commitments under the Paris Agreement. [26]

Scenario match

In the scenario **Eastern Ascendance**, we suggested that a fragmented approach to solving global problems would likely emerge with nation states following different paths.

The COP26 summit was boosted by commitments made by the USA building on President Biden's commitment at the Leaders Climate Summit held virtually in April 2021[27] to bringing the USA back into the Paris Agreement as one of the first official acts of his presidency. However, President Biden's signature "Build Back Better" act has stumbled in Congress, making it unclear whether the USA will be able to meet its commitments and see through the sustained legislation on climate that is considered essential.

Deteriorating trade and political relations between China and the USA are also causing concerns among climate watchers, who fear it will impede coordinated action on climate. "I am worried 2022 will see a fuller display of geopolitical tension dominating the climate agenda," said Li Shuo of Greenpeace East Asia. Other events in the weeks since the summit offer cause for optimism — notably recent reports that South Africa, India and Indonesia are making headway in deals to move away from coal. [28] Tackling the global effects of climate change will continue to require huge investment and dedicated research in the years ahead. As we explored in our previous report, its impact is predicted to be immense, with increased natural disasters, food and water shortages, and homes lost to rising sea levels.

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. It will also bring new opportunities for researchers as governments commit funds. In August 2021, the UK set up a new £450 million fund over the next five years to support the transition to clean energy and help meet the UK's target of achieving net zero emissions by 2050. [29] It will also require a strong commitment: according to global think tank ODI, "prior to Covid-19, concerns were being raised that funding for climate and disaster resilience was insufficient to meet the goals of the Paris Agreement and Sendai Framework. Since the pandemic, initial signals are that the funding gap will widen." [30]

The widespread assumption is that with so many new calls on the public purse, COVID-19 and more recently the war in Urkraine, will accelerate the pressure on public funding for R&D.

"The COVID-19 pandemic has caused unprecedented disruption in the global economy. I think research funding will be less as governments and private organizations try to recover economically."

Medicine, Nigeria, aged 36-45

Funding by specialty

As we mentioned at the start of this essay, just 24 percent of the researchers we surveyed for this report feel that there is sufficient funding in their field. Here we take a closer look at our findings.

As we mentioned earlier, the grant-giving conditions of many foundations will ease for non-profit partners. Changes in funders' priorities are also evident in the subjects that are attracting the most funding. Materials Science has seen the biggest growth in funding satisfaction in 2021, with 35 percent saying that available funding is sufficient – almost three times the 12 percent who were satisfied with funding levels a year earlier. However, researchers in this area are slightly less confident than they were in 2020 that funding will continue to increase in the next two to three years.

At the other end of the scale, researchers in the fields of Chemistry, Earth and Environmental Sciences, Engineering and Math are far less satisfied with the levels of funding available than they were in 2020. Just one in four researchers working in Engineering reported sufficient funding in 2021, down from 39 percent a year earlier. Satisfaction with funding has dropped by about half for those working in Chemistry and Earth and Environmental Sciences over the same period, and has fallen even further for those working in Math, where just 10 percent say they now have sufficient funding, down from 40 percent in 2020.

There is sufficient funding available in my field.

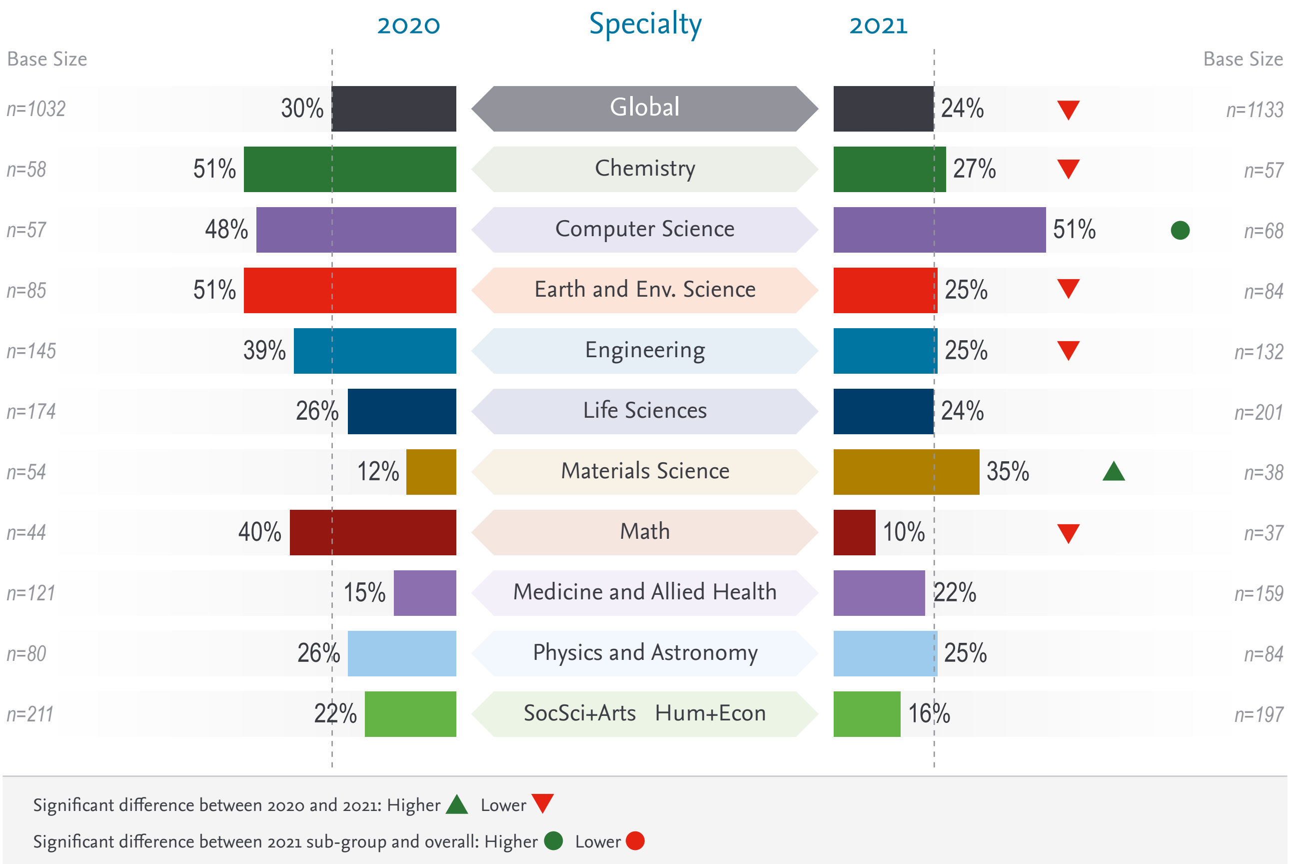


***Figure 4:** Researchers who agree there is sufficient funding available in their field by Source: Researcher surveys 2020 and 2021. Base in 2020 =1,032, base in 2021 =1,133.*

Funding by region

Looking at the results from a regional perspective, we see researchers in APAC are less likely to agree that there is sufficient funding available than they were in 2020. Just 29 percent now say there is enough, compared with 41 percent a year ago. North America has also seen a drop, from 24 percent in 2020 to just 17 percent now. Respondents in North America and Western Europe are generally the most pessimistic about the future availability of funding and the impact of Brexit.

"I am UK based, funding here is very difficult in any field, in particular my field, though one works at the cutting edge, and on a very important topic area in aerospace."

Mathematics, UK, undisclosed age

In the Middle East, much funding comes from a mix of self-funding and institutional funding. For the rest of the world, except Eastern Europe and Africa, government funds are the strongest source of funding, followed by institutional funding. Eastern Europe has also seen less sign of an increase in corporate or philanthropic funding over the last two to three years compared to other regions.

"My field is funded also by the private industry. Moreover, I work in Switzerland where funding for research is much better than in other places."

Economics, Switzerland, aged 65+

There is sufficient funding available in my field.

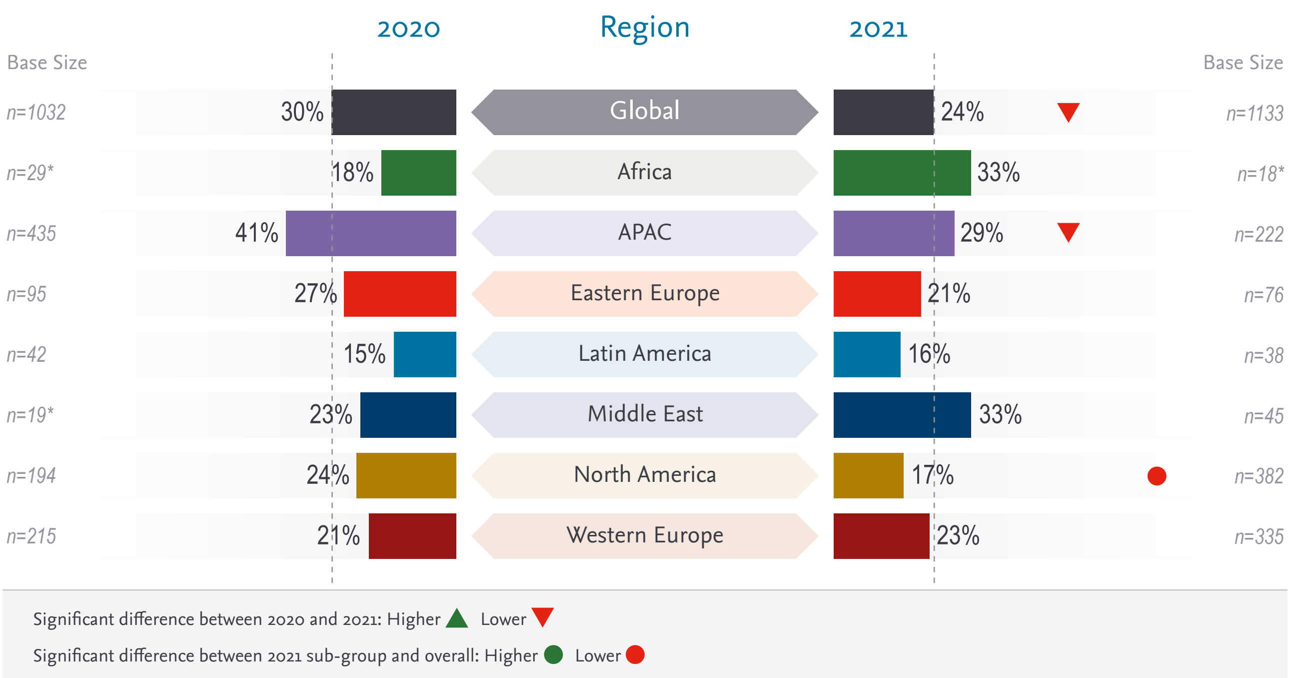


***Figure 5**: Researchers who agree there is sufficient funding available in their field by region. Source: Researcher surveys 2020 and 202. Base in 2020=1,032 and base in 2021=1,133.*

Funding by age and gender

Present funding levels are giving some groups cause for concern. While satisfaction with funding levels has fallen by about the same number of percentage points for both men and women, women are much less inclined than men to be satisfied with current funding levels. Younger researchers—those aged under 36—are now much less likely than they were a year ago to say that there is sufficient funding available for their work. Just 28 percent agree that they have enough funding, compared to 44 percent in 2020.

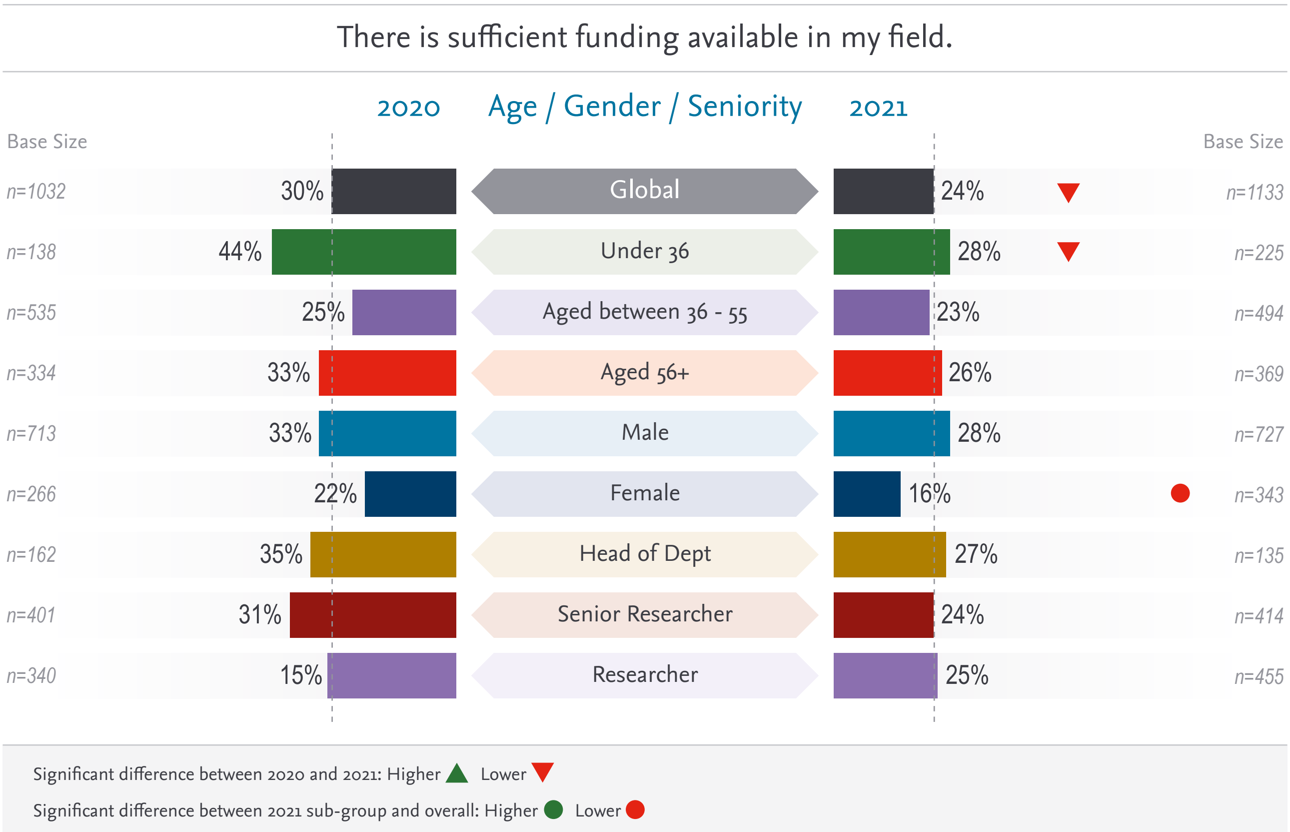


***Figure 6**: Researchers' views on the sufficiency of funding by age, gender and role. Source: Researcher surveys 2020 and 2021. Base in 2020=1,032 and base in 2021=1,133.*

New requirements

When it comes to funding requirements, just over half of researchers (51 percent) agree that there are more requirements than was the case two or three years ago. This is in line with our prediction in our last report that competition for funding would increase. Funders are expecting an increased number of publications, more progress reporting, and evidence of inter-disciplinary collaboration.

Researchers working in the fields of Chemistry and Life Sciences are seeing the greatest number of new requirements. In Chemistry, over half of those who believe there are more funding requirements than two to three years ago say they have seen increased requirements for publication numbers, progress reporting and open access ppublication. Meanwhile, Earth and Environmental Scientists report more requirements for publication numbers and sharing of research data. In Medicine and Allied Health, interdisciplinary collaboration and open access publication are the most reported requirements.

New funding requirements compared to 2-3 years ago.

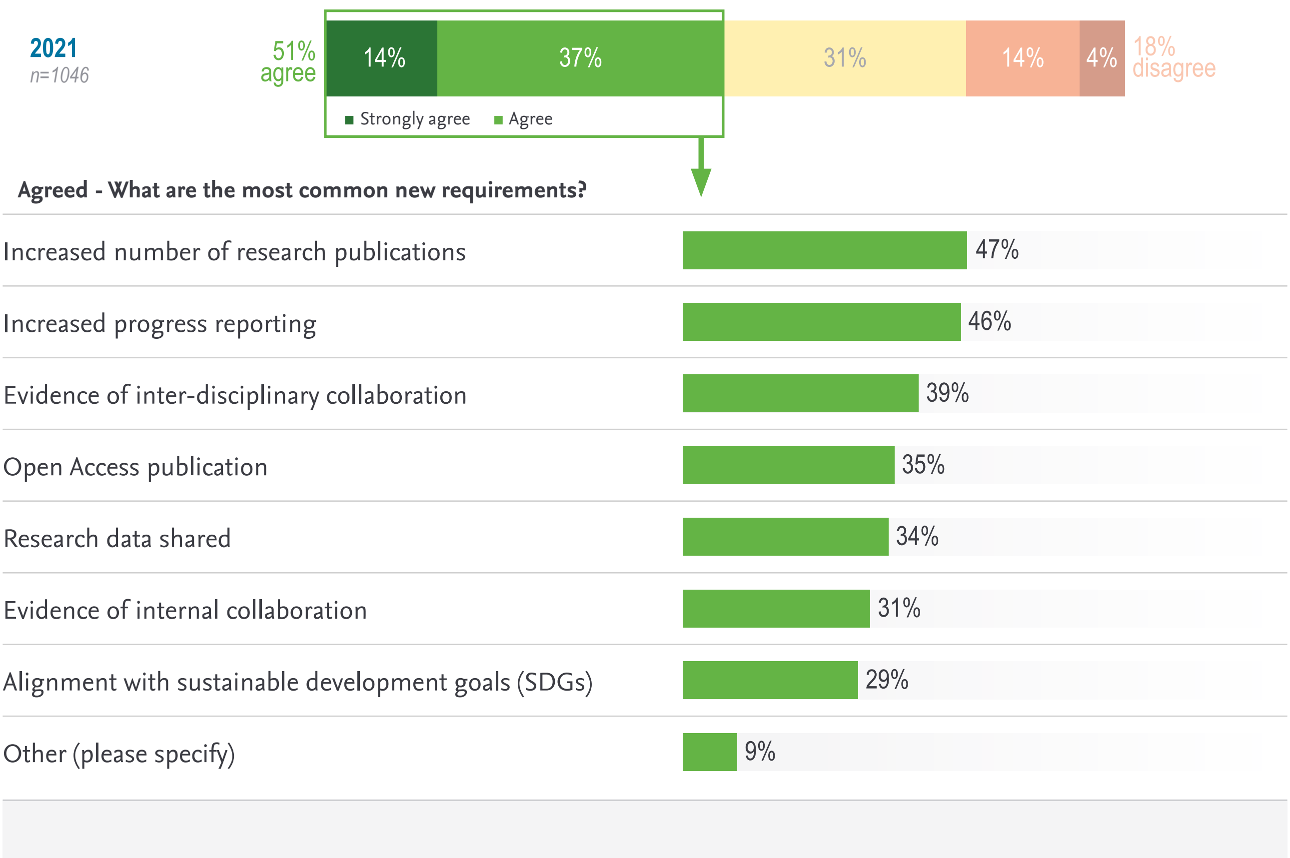


Figure 7: *Question: "To better understand your attitudes towards research and scholarly publishing, please indicate the extent to which you agree or disagree with the following statements: There are more funding requirements compared 2-3 years ago" Base=1,046. Followed by question: "You agreed with the statement 'There are more funding requirements compared 2-3 years ago', what are the most common new requirements?" base = 539. Source: Researcher survey 2021.*

Regionally, researchers in APAC and Eastern Europe are seeing higher requirements for an increased number of publications, while in North America and Western Europe, the emphasis is on increased progress reporting and sharing of research data.

Open access publication is more likely to be cited as a new requirement in Western Europe (45 percent of respondents) than in North America (34 percent) of researchers who are experiencing new requirements.

New funding requirements

By speciality:

Most common new requirements:	Global	Chemistry	Computer Science	Earth & Env. Science	Engineering	Life Sciences	Materials Science	Math	Medicine & Allied Health	Physics & Astronomy	SSE+Arts Hum+Econ.
Increased number of publications	47%	61%	27% 🔴	57%	44%	46%	Base sizes too low	Base sizes too low	45%	48%	51%
Increased progress reporting	46%	53%	33%	40%	44%	51%			32% 🔴	61%	49%
Evidence of inter-disciplinary collaboration	39%	47%	28%	25% 🔴	41%	31%			50% 🟢	45%	34%
Open Access publication	35%	52% 🟢	32%	37%	33%	34%			49% 🟢	16% 🔴	33%
Research data shared	34%	32%	49%	51% 🟢	26%	27%			40%	33%	39%
Evidence of international collaboration	31%	39%	18%	45%	35%	17% 🔴			35%	39%	30%
Alignment with sustainable development	29%	32%	42%	44% 🟢	28%	34%			20% 🔴	24%	21% 🔴
		n=30	n=31	n=37	n=58	n=112	n=18*	n=15*	n=83	n=29	n=93

Significant difference between 2021 sub-group and overall: Higher 🟢 Lower 🔴

***Figure 8**: Researchers' view on what are the new funding requirements compared to 2-3 years ago by specialty. Source: Researcher survey 2021. Base=539 all those who agreed there with the statement "There are more funding requirements compared to 2-3 years ago".*

The China effect

As we touched on in the original report, to date, the USA has been the leading economic force on the global stage, but there are signs its dominance is waning. The number of researchers in China is also rising – and although its research output has been similar in size to that of the USA for many years, there are clear signs that China has now edged ahead at least in some areas. [31]

Scenario match

In our **Eastern Ascendance** scenario, we predicted that China would continue to invest more in R&D.

In our 2019 report, we predicted that China would increase its funding and production of research, and this is proving to be the direction the country is taking.

Since 2010, China has been increasing its expenditure on R&D year on year with an average annual increase of 9% from 2014 to 2019, much greater than any other country. In the USA, R&D funding in 2019 passed the 3 percent milestone for the first time, up from 2.9 percent in 2017. Meanwhile, China's R&D spending as a proportion of GDP in 2019 grew to 2.2 percent, up from 2.1 percent a year earlier. [32]

Global Expenditure on Research and Development (GERD) for key countries 2014 to 2019.

Country	Indicator	2014	2015	2016	2017	2018	2019	CAGR (2014 to 2019)
China	GERD US$m ppp	336,251	366,081	399,390	430,330	464,705	514,798	8.9%
	GERD % Change Year on Year	8.7%	8.9%	9.1%	7.7%	8.0%	10.8%	
	GERD % of GDP	2.0%	2.1%	2.1%	2.1%	2.1%	2.2%	
France	GERD US$m ppp	61,190	61,629	61,077	61,945	62,813	64,053	0.9%
	GERD % Change Year on Year	2.7%	0.7%	-0.9%	1.4%	1.4%	2.0%	
	GERD % of GDP	2.3%	2.3%	2.2%	2.2%	2.2%	2.2%	
Germany	GERD US$m ppp	110,276	114,098	116,904	124,577	128,824	132,511	3.7%
	GERD % Change Year on Year	3.7%	3.5%	2.5%	6.6%	3.4%	2.9%	
	GERD % of GDP	2.9%	2.9%	2.9%	3.1%	3.1%	3.2%	
Italy	GERD US$m ppp	29,761	29,995	31,017	31,620	33,119	34,254	2.9%
	GERD % Change Year on Year	2.9%	0.8%	3.4%	1.9%	4.7%	3.4%	
	GERD % of GDP	1.3%	1.3%	1.4%	1.4%	1.4%	1.5%	
Japan	GERD US$m ppp	173,011	168,514	162,387	169,096	172,610	171,854	-0.1%
	GERD % Change Year on Year	3.1%	-2.6%	-3.6%	4.1%	2.1%	-0.4%	
	GERD % of GDP	3.4%	3.2%	3.1%	3.2%	3.2%	3.2%	
Korea, Republic of	GERD US$m ppp	76,695	76,922	79,365	88,136	95,438	100,055	5.5%
	GERD % Change Year on Year	6.5%	0.3%	3.2%	11.1%	8.3%	4.8%	
	GERD % of GDP	4.1%	4.0%	4.0%	4.3%	4.5%	4.6%	
United Kingdom	GERD US$m ppp	44,476	45,666	46,830	48,268	50,275	51,702	3.1%
	GERD % Change Year on Year	4.2%	2.7%	2.5%	3.1%	4.2%	2.8%	
	GERD % of GDP	1.6%	1.6%	1.6%	1.7%	1.7%	1.7%	
United States of America	GERD US$m ppp	481,544	495,893	517,225	540,406	576,237	612,714	4.9%
	GERD % Change Year on Year	2.9%	3.0%	4.3%	4.5%	6.6%	6.3%	
	GERD % of GDP	2.7%	2.7%	2.8%	2.9%	3.0%	3.1%	

***Table 1:** Source OECD MSTI, data extracted December 2021.*

Against this spending backdrop, China's GDP has been growing at a rate of about 7 percent per year for the last 10 years. It grew by 2.3 percent in 2020, in the middle of the pandemic – a year in which GDP growth was -4.5 percent in OECD countries and -3.4 percent in the USA. [33]

China's 14th Five Year Plan for national economic and social development focuses heavily on supporting scientific research and advanced manufacturing. The targets set in the plan include increasing public and private R&D investment by 7 percent annually between 2021 and 2025, and increasing the ratio of basic research funding as a share of the country's R&D investment to above 8 percent. [34]

The targeted areas for China's scientific research are artificial intelligence, quantum information, integrated circuits, life and health, brain science, biobreeding, aerospace technology, deep earth and deep sea, and the implementation of a series of forward-looking and strategic national science and technology major projects. Incentives will include more tax breaks for R&D expenditure, tax concessions for new and hi-tech enterprises and for technology-based small and medium-sized enterprises (SMEs).

In manufacturing, China plans to develop its information technology, advanced manufacturing and biotechnology sectors, with a focus on strategic emerging industries including next-generation information technology, biotechnology, new energy, new materials, high-end equipment, new energy vehicles, green and environmental protection technology, aeronautics, and astronautics and marine equipment. The plan also includes long-range objectives up to the year 2035, including making significant breakthroughs in core technologies in key areas, with the aim of turning China into a global leader in innovation. [32]

Like the USA, China has been investing heavily in its space program, with three astronauts taking part in the country's longest ever space mission. On 16 October 2021, the three astronauts began a six-month mission to China's Tiangong space station. In the private sector in the USA, Amazon founder and billionaire Jeff Bezos launched a space tourism venture in July 2021 with a 10 minute rocket ride. This followed in the tracks of fellow billionaire Elon Musk, who had sent several tourists into space in his SpaceX venture.

These space projects have been putting pressure on basic science funding in recent years. In our original report we conjectured that we are likely to see funders increase their support for these types of projects.

However, there are headwinds to China's continued growth. China's latest census revealed a society that is ageing more quickly than expected and a falling working age population [35]. Twelve million babies were born in 2020, the lowest number since the country's famine in the 1960s, resulting in a fertility rate of 1.3 children per woman, similar to the rates in Japan and Italy. That will lead to a peak population in 2030, with a shrinking labour force and an over-65 population of 240 million, according to the World Population Review (WPR). [36] The changing demographics are predicted to negatively impact investment and manufacturing output, and a falling number of 20- to 40-year-olds could upset China's innovation and technological ambitions. According to the WPR, "Much of China's economic growth has been attributed to its abundant and cheap workforce, combined with low social costs. However, with the number of young Chinese falling and the number of elderly Chinese increasing, it is not certain whether China's economy can continue to grow at the same rapid rate." China quickly amended its population policy and is now allowing—and even encouraging—couples to have up to three children. The rule change, announced in May 2021, replaces a two-child policy that was in place since 2016, which in turn replaced a stringent one-child policy that was in force since about 1980.

The high cost of raising children in China, including education, tutoring, childcare and housing, is seen as a main reason for the declining birth rate. Some of China's recent regulation-tightening moves, including the crackdown on private tutoring companies, are aimed at encouraging couples to have more children.

For many countries, the arrival of COVID-19 proved catastrophic, but China's early and sweeping measures to contain the virus appear to have borne fruit, with reported cases and deaths substantially below other nations. [37] As a result, China's economy was among the first to recover globally: a November 2020 article in *The Diplomat* labeled the pandemic's impact on the country as "more like stagnation than a recession." [38]
The article went on to note that the shock of COVID-19 has only reinforced the existing trend toward digitization and innovation investment in China.

However, following its initial show of resilience in the face of the pandemic, China's economy has slowed recently. The World Bank adjusted its forecasts for China's economic growth. The previous 2022 forecast of a rise of 5.4 percent was adjusted down to 5.1 percent. That would be the slowest rate of growth in China since 1990. The Global Economic Prospects report cites the possibility of more COVID-19 outbreaks resulting in "broad-based and longer-lasting restrictions" [39] that would lead to further disruptions to economic activity. It also cited the risk of "a severe and prolonged downturn" in the country's heavily debt-burdened property market. [39]

In September, Nomura's chief China economist cut his forecast for China's GDP growth from 8.2 percent to 7.7 percent for 2021. "Markets now are so perplexed by the fallout of the property sector that they may ignore Beijing's unprecedented curbs on energy consumption and energy intensity," he wrote. [40] Fitch also lowered its forecast from 8.4 percent to 8.1 percent, citing an expected slowdown in the property market.

In the third quarter of 2021, factories were shut down regularly across China to save power, slowing production and exports. At the same time, Evergrande, a massive Chinese property developer with US$300 billion in debts, has been teetering on the edge of bankruptcy after failing to make several interest payments and the company's stock value has fallen 90 percent from its 2020 high. [41] The company's collapse could have a catastrophic ripple effect on the country's property and construction sector, which accounts for more than a quarter of the economy and whose performance is also critical to maintaining social stability. Chinese people have been encouraged to invest in property and more than a million Evergrande homebuyers have been left with unfinished properties. The combination of power shortages, supply chain delays and the potential for a property bubble have taken place at the same time as a series of far-reaching regulatory changes that signal a change in the country's economy, with regulations tightened for high-performing industries from the technology sector to private tutoring. A reset in the country's priorities could have a potential impact on R&D spending and affect the long-term attractiveness of China as an R&D destination for researchers.

Geopolitical relations

Existing tensions between China and the USA accelerated during the crisis, with claims that China had not been fully transparent in the early days of the pandemic. The USA encouraged allies to "scrutinize" collaborations with Chinese companies, including telecoms giant Huawei, which has spent millions of dollars setting up joint research centers with universities in other countries in recent years. [42]
On 15 November 2021, President Biden and President Xi Jinping held their first meeting by way of a virtual summit. Expectations for any outcomes of substance were kept low on both sides in advance of the meeting, and indeed, no substantive agreements or statements emerged from it. According to the official White House readout of the meeting, the two leaders discussed "the complex nature of relations" between the two countries and the importance of managing competition responsibly."

Scenario match

In the scenario **Eastern Ascendance**, we anticipated that a shift in economic powers would see Europe and the US become more protective of their resources and the commercial applications of their research.

On the China side, the *Global Times* reported that the three-and-a-half-hour meeting injected "certainty into the bilateral ties". President Xi said it was "crucial for China and the USA to work together in addressing common challenges" and emphasized the need to "increase communication and cooperation" between the two and "shoulder their share of international responsibilities...no conflict and no confrontation is a line that both sides must hold", the paper reported China's president as saying, as well as expressing the hope that President Biden would steer "US' China policy back on the track of reason and pragmatism." [43]

Meanwhile, the relationship between the UK and China took a major knock in July 2020, when the government announced that mobile providers were banned from buying new Huawei 5G equipment after 31 December, and must remove all the Chinese firm's 5G kit from their networks by 2027. [44]

In September 2021, adding to the tensions between China and Australia due to the trade conflict, the USA, UK and Australia formed an alliance called Aukus. The deal allows Australia to join the UK in gaining access to US nuclear-powered submarine technology and is likely to increase collaboration between the three countries on emerging technologies. It is also likely to add to already strained regional tensions, which could affect mobility and cooperation between China and the members of the alliance. [45]

There have been signs that China is seeking to smooth out the bumps in these relationships. Following the release of details about the country's new five-year plan in October 2020, the central government emphasized the need for other countries to collaborate with China, "amid rising global uncertainty from the coronavirus pandemic and protectionism." [46] Finance and economic official Han Wenxiu claimed: "Decoupling is basically not realistic, and there's no benefit for China or the U.S., or the entire world." [46] It's a view that many in the academic sector share, and they have been vocal in calling for more cooperation between the USA and China. [47,48, 49]

A study published in *The Journal of Higher Education* in November 2020 found that cross-border scientific research rose during the early months of the pandemic, and that "despite geopolitical tensions, the highest number of internationally coauthored S&E COVID-19 articles between two countries involve the US and China. Their collaboration rate on COVID-19 is higher than during the past five-years as well as on non-COVID-19 articles published during 2020." [50]

Scenario match

In the scenario **Eastern Ascendance**, we anticipated that China would invest resources in building home-grown innovation.

In the meantime, China has been focusing on introducing improvement measures in areas that have also been identified as weak points in recent years: research integrity and impact. In the summer of 2020, the country introduced its most comprehensive rules to deal with research misconduct to date. They apply to anyone engaged in science and technology activities, including researchers, reviewers and heads of institutions. [51] At the same time, China has announced a reform of its academic evaluation system, moving away from rewarding high numbers of publications and focusing on quality over quantity. [52]

China is also focusing heavily on building innovation and increasing international collaboration. The Zhongguancun Science Park in Beijing will be turned into an "innovation highland", a senior member of China's politburo said at a forum held at the park in September. The park is designed to be a global magnet for tech talent and entrepreneurs. China would learn from advanced international experience and is willing to share more of China's science and technology fruits with the rest of the world, China's minister of science and technology said at the forum. [53]

This prioritization of talent attraction is nothing new. At the time of our original report, China was looking to build domestic research expertise by educating future researchers outside the country and making funds available for international exchanges. Over the past few years we've also seen China actively recruiting experienced researchers from other nations. This has sparked concerns about a technology brain drain in Japan, [54] and claims by the Australian Strategic Policy Institute that China has set up 600 international outposts to recruit foreign experts and scientists, with the goal of acquiring "advanced technology and protected intellectual property." [55]

China's five-year plan also envisages that businesses will be given a bigger role "to take the lead in innovation consortia and undertake major national science and technology projects." [56] We explore the impact of this focus on tech in our essay **"Technology: revolution or evolution"**.

In 2019 China overtook the USA as the most prolific producer of research articles, with 671,607 published in China versus 592,957 in the USA (source: Scopus). In August 2021, China overtook the USA to become the leader in output of highly cited natural science papers. [57] Japan's National Institute of Science and Technology Policy counted the number of research publications among major economies and worked out each country's three-year average. It found that among papers in the top 10 percent of citations, China was the leader in five fields, including Materials Science (48.4 percent), Chemistry (39.1 percent) and Engineering (37.3 percent). In the top papers that are in the top one percent of citations, the USA holds a narrowing lead, with a share of 27.2 percent versus China's 25 percent.

In artificial intelligence (AI), China has already made spectacular progress in catching up with the USA. It publishes more research papers than any other country, including the USA, and also files the most patents. China had 1,189 AI firms in 2019, second only to the USA. [58] But it is not a simple numbers game; according to the *Harvard Business Review*, "Unlike in Western developed economies where companies are the primary holders of AI patents, in China the majority of AI patents are filed by universities and research institutes, most of which are government owned or sponsored. However, university-industry linkages in China are relatively weak, and technology transfer remains rather limited."

China has also been investing in the development of its own English-language academic journals. The China Association for Science and Technology announced a plan to invest more in 30 English-language journals focusing on science, technology and medicine. The plan states that China "lacks world-class science and technology journals with global influence" and "is in an obviously disadvantageous position in global science research competition." [59]

Scenario match

In the scenario **Eastern Ascendance**, we predicted that China would open new institutions focused on innovation and that it would start to dominate universities rankings.

When it comes to education, many US and European universities have long benefited financially from Chinese student enrolments, with Chinese students comprising roughly 30 percent of the USA's international students. [60] China accounts for the largest percentage of overseas students in the USA. In the 2019-2020 academic year, 373,000 undergraduate and graduate students were studying there, accounting for 35 percent of the international student population. The number dropped to 317,000 in the 2020-2021 academic year, a fall of 15 percent year-on-year. This was because services were closed and many students returned to China due to the pandemic. [61] Since May 2021, the USA has been accepting student visa applications again.

China's rising focus on quality has seen a growing number of students from Europe, the USA and beyond choose to study at Chinese universities over the past few years. In the QS World University Rankings 2021 and 2022, conducted in partnership with Elsevier, eight Chinese universities were among the top 50, including four in Hong Kong. [62] However, at the time of writing, most foreign students enrolled in universities in China were still not allowed back into the country due to concerns they may import COVID-19. [63] What that will mean for studying in China over the long-term is currently hard to predict. As of January 2022, the Chinese government had given no indication about when international students could return to their studies in the country. [64]

There are a few exceptions—for South Korean students, and for students studying at Tianjin Juilliard, NYU Shanghai and at Georgia Institute of Technology Shenzhen's Nanshan Campus.

Looking ahead

According to the OECD, research spending levels often move in tandem with a country's GDP. It notes the decline of spending on R&D during the economic downturns of 2001-02 and 2008-09. Unlike those downturns, the impact of COVID-19 has – at least so far – had an uneven impact on different economic sectors, as we noted earlier in this essay. Rising public debt levels due to high government spending and lowered revenues during the pandemic could lead to less funding being available for research. The impact could be compounded by a loss or reduction in international student fees to universities as travel has become difficult. At the same time, however, the newly recognised importance of science in fighting the pandemic is expected to lead to higher levels of government funding and investments in research, particularly in health-related areas, due to heightened awareness of the damage pandemics can wreak and the perceived likelihood of new pandemics emerging in the future. [65]

The USA, the EU and China have named technology and innovation as high priorities for investment. As part of his infrastructure investment plan, President Joe Biden is proposing an additional US$325 billion for funding research, innovation and pandemic preparedness. [66] President Biden said he aimed to "boost America's innovative edge in markets where global leadership is up for grabs — markets like battery technology, biotechnology, computer chips, clean energy, the competition with China in particular," reported *Science Business*. The whole R&D dynamic in the US could change, not only bringing new funding but, as we explore in this section, shifting the country's position on global policies such as climate change and collaboration with China, and reframing his administration's relationship with research and researchers.

Opportunities for cooperation between China and the USA on climate-related issues could be on the horizon. In a surprise move a week before their virtual summit, on 10 November, 2021, the USA and China issued a joint climate declaration agreeing to work together to address the climate crisis and to reduce methane emissions, "phase down" coal and promote decarbonisation, protection of forests and to conduct technical cooperation. They also committed to setting up a working group on climate action, which will meet regularly. [67]

The €95.5 billion the EU has earmarked for research and innovation via the Horizon Europe strand of its funding package (which runs from 2021-27 and includes money from the coronavirus recovery fund, NextGenerationEU), is its largest funding pot to date.[68] In December 2020, the EU-UK trade deal was signed following months of fraught negotiation over the terms governing Brexit. The deal means the UK will be able to pay into, and participate in, Horizon Europe. The UK will have to pay back the difference if it wins more than eight percent of its contribution two years in a row. The UK government is committed to increasing R&D investment to 2.4 percent of GDP by 2027. [69] However, the UK will no longer have any influence over the program and how the money is spent; these decisions will be made by EU countries. [70]

The researcher view on future funding

When we asked researchers most recently about their views on the outlook for funding, they were more optimistic about future prospects, with 39 percent expecting an increase in funding in the next two to three years – a rise of 8 percentage points on 2020. Many more Math researchers expect funding to increase in the next few years than was the case last year, with 38 percent reporting optimism about this versus just 7 percent a year ago. In Medicine and Allied Health, many more expect funding to continue to increase, which is not a surprise given COVID-19, but there is also increased optimism among those working in Life Sciences. While there was also increased optimism in Social Sciences, Arts, and Economics compared to the previous year, the proportion who expect to see funding grow in the coming years in these fields remains significantly lower than average.

I expect funding for research in my area will increase in the next 2 - 3 years. (beyond inflation)

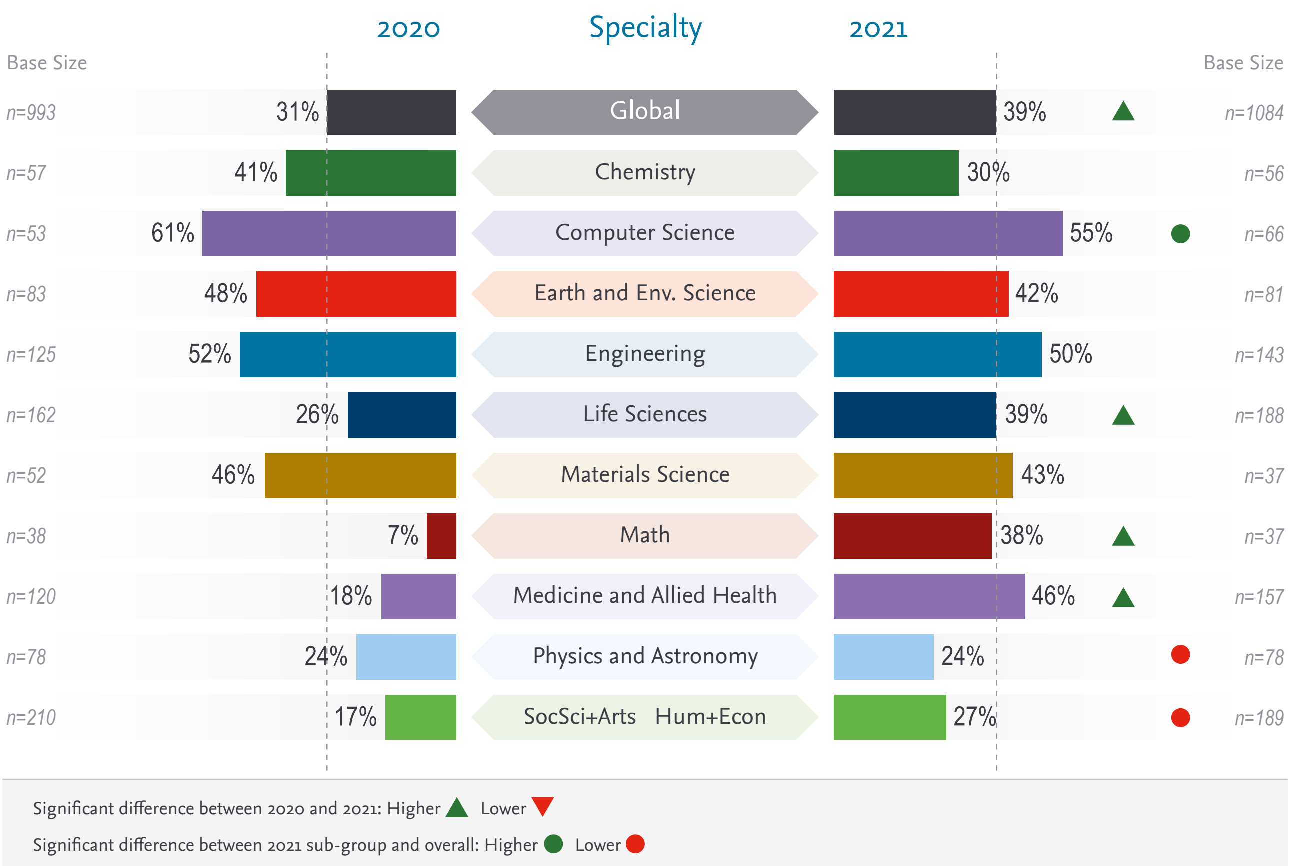


***Figure 9**: Researchers' views on the expectations of funding increases in their field by subject Source: Researcher surveys 2020 and 2021. Base in 2020=993, and base in 2021=1,084.*

Expected source of future funding

At an event held on the sidelines of the United Nations General Assembly in September 2021, philanthropy experts discussed how the pandemic had pushed funders to make welcome changes, including increasing funds and offering more flexibility to the recipients. “The question now is, was that a blip or will this be sustained?” said Phil Buchanan, president at the US-based Centre for Effective Philanthropy. [71] According to our 2021 survey, researchers are more optimistic about philanthropic funding with 21 percent believing that their funding will increase over the two to three years compared to 16 percent in 2020.

Apart from inflationary increases, do you think over the next two to three years your research funding from the following sources will decrease or increase.

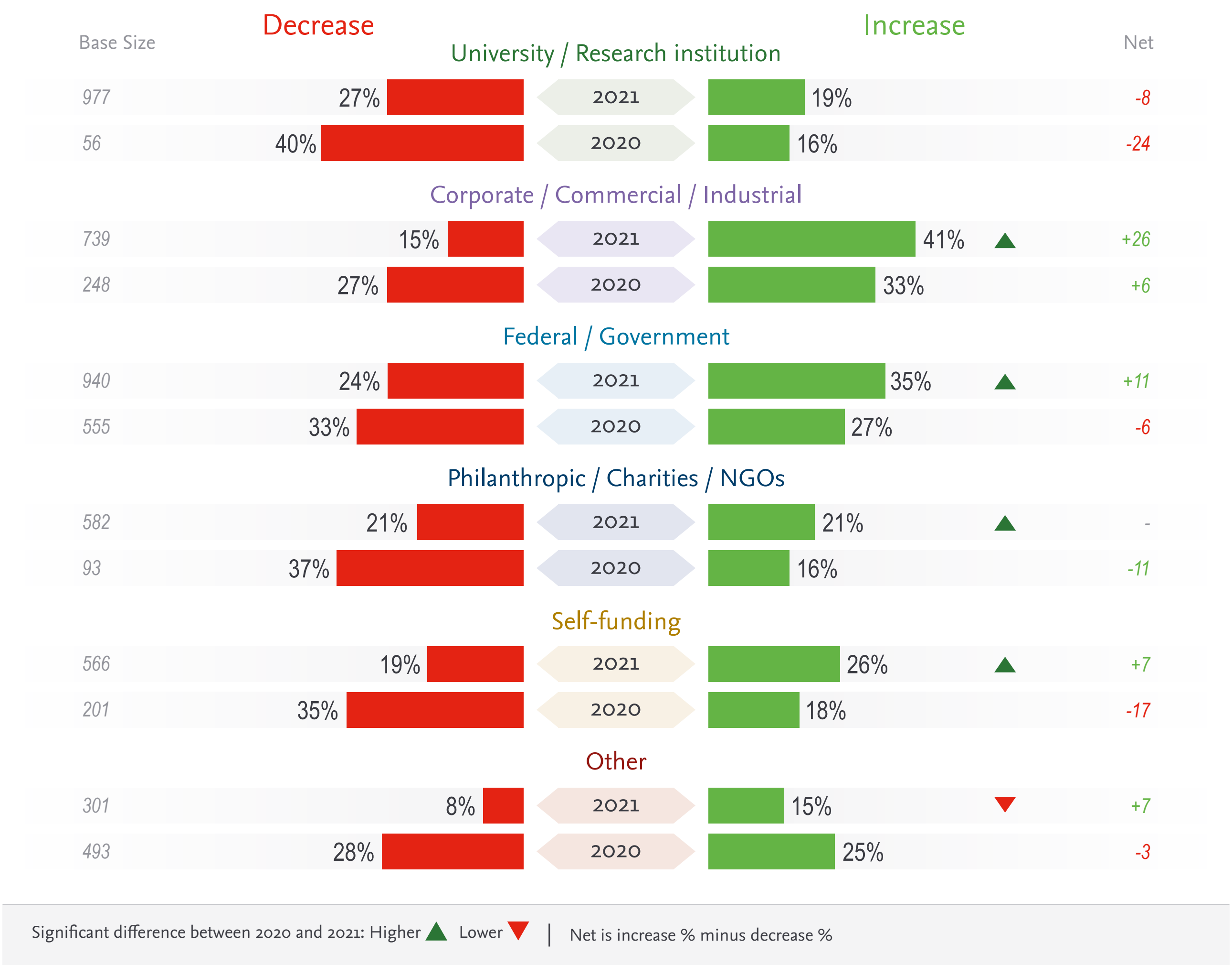


***Figure 10**: Proportion of researchers who think their funding will decrease or increase from different funding sources. Source: Researcher surveys 2020 and 2021. Base in 2020 =977 and base in 2021=1,173.*

Men are more likely than women to expect the funding situation to improve in their fields. However, women’s confidence has increased markedly in this respect, from 19 percent in 2020 to 34 percent now. Heads of Department are particularly confident about future funding prospects—an encouraging sign as this role is typically responsible for budget management.

A growing focus on collaboration among funders is one likely long-term outcome of the timing of the pandemic, according to Heather Grady of Rockefeller Philanthropy Advisors. The pandemic has taken place against a backdrop of global crises such as climate change, economic inequality and racial inequity. Grady says these problems are too complex for a single funder to solve. [71]

References

1 Lobosco, K. & Luhby, T. Here's what's in the second stimulus package. CNN. 28 December 2020. https://edition.cnn.com/2020/12/20/politics/second-covid-stimulus-package-details/index.html

2 SCI Science.org 28 May 2021. https://www.science.org/content/article/biden-seeks-big-increases-science-budgets

3 Recovery plan for Europe. European Commission website. n/d. https://ec.europa.eu/info/strategy/recovery-plan-europe_en

4 Weintraub, K. & Weise, E. Federal spending on COVID-19 vaccine candidates tops $9 billion, spread among 7 companies. USA Today News. https://eu.usatoday.com/story/news/health/2020/08/08/feds-spending-more-than-9-billion-covid-19-vaccine-candidates/5575206002/

5 Gale J. Why a new pill to treat COVID could be a game-changer. Bloomberg. 5 October 2021. https://www.bloomberg.com/news/articles/2021-10-05/why-a-new-pill-to-treat-covid-could-be-a-game-changer-

6 Herman B. Taxpayers funded development of COVID-19 antiviral pill. Axios. 5 October 2021. https://www.axios.com/molnupiravir-merck-ridgeback-emory-nih-taxpayers-e0dfda1e-78ec-4a1e-a09f-1437fb20deb9.html

7 From recovery to resilience: Hanging together or swinging separately? 15 September 2021. https://unctad.org/news/recovery-resilience-hanging-together-or-swinging-separately

8 Ahmed, S. et al. The Impact of COVID-19 on Emerging Market Economies' Financial Conditions. Federal Reserve. 07 October 2020. https://www.federalreserve.gov/econres/notes/feds-notes/the-impact-of-covid-19-on-emerging-markets-economies-financial-conditions-20201007.htm

9 Onyiriuba, L. Emerging Market Bank Lending and Credit Risk Control. Academic Press. 2016. https://www.sciencedirect.com/book/9780128034385/emerging-market-bank-lending-and-credit-risk-control

10 IMF staff. 5 March 2022. https://www.imf.org/en/News/Articles/2022/03/05/pr2261-imf-staff-statement-on-the-economic-impact-of-war-in-ukraine..........

11 Europa.eu Accessed on 21 March 2022. https://ec.europa.eu/info/strategy/priorities-2019-2024/stronger-europe-world/eu-solidarity-ukraine_en

12 World Bank. 14 March 2022. https://www.worldbank.org/en/news/press-release/2022/03/14/world-bank-announces-additional-200-million-in-financing-for-ukraine

13 Pramuk J. 15 March 2022. https://www.cnbc.com/2022/03/15/biden-signs-government-funding-bill-with-ukraine-aid.html

14 Sheahan M and Marsh S. Reuters. 27 February 2022.https://www.reuters.com/business/aerospace-defense/germany-hike-defense-spending-scholz-says-further-policy-shift-2022-02-27/

15 France24.com 10 March 2022. https://www.france24.com/en/live-news/20220310-sweden-to-raise-military-spending-over-ukraine-war

16 Orensten, N. & Buteau, E. FOUNDATIONS RESPOND TO CRISIS: A Moment of Transformation? The Center for Effective Philanthropy. 2020. https://cep.org/portfolio/foundations-respond-to-crisis1/

17 OECD (2021). "OECD Main Science and Technology Indicators. R&D Highlights in the March 2021 Publication", OECD Directorate for Science, Technology and Innovation. www.oecd.org/sti/msti2021.pdf.

18 Bogle, D. How will COVID-19 affect research collaboration? University World News. 5 September 2020. https://www.universityworldnews.com/post.php?story=20200904133935 95

19 Marquis, C. Greentech is on the rise and crowdfunding platform Indiegogo is leading the charge. Forbes. 9 August 2021. https://www.forbes.com/sites/christophermarquis/2021/08/09/greentech-is-on-the-rise-and-crowdfunding-platform-indiegogo-is-leading-the-charge/?sh=70b405cfd2b0

20 Grove, J. Spike in research misconduct feared after Covid disruption. Times Higher Education. 6 August 2020. https://www.timeshighereducation.com/news/spike-research-misconduct-feared-after-covid-disruption

21 https://www.philanthropy-impact.org/expert-opinion/charities-time-covid-19

22 https://www.cof.org/news/call-action-philanthropys-commitment-during-covid-19

23 Funding Commitments to fight Covid-19. Gates Foundation. 12 January 2022. https://www.gatesfoundation.org/ideas/articles/covid19-contributions

24 Dudley, D. Coronavirus Crisis Likely To Lead To Surge In Political Unrest, Says Report. Forbes. 10 June 2020. https://www.forbes.com/sites/dominicdudley/2020/06/10/coronavirus-crisis-likely-to-lead-to-surge-in-political-unrest-says-report/

25 UKCOP26.org. 13 November 2021. https://ukcop26.org/cop26-keeps-1-5c-alive-and-finalises-paris-agreement/

26 China releases new climate commitment ahead of COP26. World Resources Institute. 21 October 2021. https://www.wri.org/news/statement-china-releases-new-climate-commitment-ahead-cop26

27 China releases new climate commitment ahead of COP26. World Resources Institute. 21 October 2021. https://www.wri.org/news/statement-china-releases-new-climate-commitment-ahead-cop26

28 McGrath M. Climate Change: storm clouds gather after COP26. BBC.com 29 December 2021. https://www.bbc.com/news/science-environment-59744522

29 UKRI . 31 August 2021. https://www.ukri.org/news/450m-fund-to-unlock-innovation-in-gas-and-electricity-networks/

30 Quevedo, A., Peters, K. & Cao, Y. Briefing paper: The impact of Covid-19 on climate change and disaster resilience funding: trends and signals. ODI. October 2020. https://www.odi.org/publications/17435-impact-covid-19-climate-change-and-disaster-resilience-funding-trends-and-signals

31 Koshikawa, N. China passes US as world's top researcher, showing its R&D might. Nikkei Asia. 08 August 2020. https://asia.nikkei.com/Business/Science/China-passes-US-as-world-s-top-researcher-showing-its-R-D-might

32 OECD: COVID impact on R&D Funding. March 2021. https://www.oecd.org/sti/msti-highlights-march-2021.pdf

33 https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG

34 Hong Kong Trade and Development Council. China's 14th Five-Year Plan: Research Priorities and Industrial Policies . 5 July 2021. https://research.hktdc.com/en/article/Nzk3NTY5NzUx

35 Chipman Koty A. Why China has amended its population policy. Dezan Shira China Briefing. 8 June 2021. https://www.china-briefing.com/news/chinas-three-child-policy-what-it-means-for-the-economy/

36 WPR China population: https://worldpopulationreview.com/countries/china-population

37 WHO Coronavirus Disease (COVID-19) Dashboard. World Health

Organization. Data extracted 01 December 2020. https://covid19.who.int/

38 Kang, X. & Chen, D. Why China's Economy Keeps Booming Even After COVID-19. The Diplomat. 10 November 2020. https://thediplomat.com/2020/11/why-chinas-economy-keeps-booming-even-after-covid-19/

39 https://www.worldbank.org/en/news/opinion/2022/01/12/rebalancing-act-china-s-2022-outlook#:~:text=Following%20a%20strong%208%20percent,of%20output%20at%20full%20capacity.

40 Cheng E. CNBC. 27 September 2021. https://www.cnbc.com/2021/09/27/nomura-cuts-china-gdp-forecast-as-power-crunch-drags-down-growth.html

41 Shen H. et al. China's nightmare Evergrande scenario is an uncontrolled crash. Bloomberg. 16 September 2021. https://www.bloomberg.com/news/articles/2021-09-16/china-s-nightmare-evergrande-scenario-is-an-uncontrolled-crash

42 Sharma, Y. Huawei research ties with world's top universities at risk from US advice. University World News. 25 January 2019. https://www.universityworldnews.com/post.php?story=20190125061623487

43 Global Times, 16 November 2021. https://www.globaltimes.cn/page/202111/1239087.shtml

44 Kelion, L. Huawei 5G kit must be removed from UK by 2027. BBC. 14 July 2020. https://www.bbc.com/news/technology-53403793

45 Wong C. South China Morning Post. 21 September 2021. https://www.scmp.com/news/china/diplomacy/article/3149052/china-hits-out-highly-irresponsible-aukus-defence-pact-between?module=perpetual_scroll&pgtype=article&campaign=3149052

46 Cheng, E. China talks up a future in which it needs collaboration with the U.S. and other countries. CNBC. 30 October 2020. https://www.cnbc.com/2020/10/30/china-talks-up-a-future-in-which-it-needs-collaboration-with-the-us-.html?&qsearchterm=china%20talks%20up%20a%20future

47 Yang, L. The US and China must learn to balance competition and cooperation in the coming era. World Economic Forum. 22 May 2020. https://www.weforum.org/agenda/2020/05/will-china-and-the-us-compete-or-collaborate-in-the-post-covid-era/

48 Tiankai, C. China and the U.S. Must Cooperate Against Coronavirus. The New York Times. 05 April 2020. https://www.nytimes.com/2020/04/05/opinion/coronavirus-china-us.html

49 Roach, S. Time for the U.S. and China to Collaborate, Not Complain. Bloomberg. 31 March 2020. https://www.bloomberg.com/opinion/articles/2020-03-31/u-s-and-china-need-to-collaborate-against-virus-not-compete

50 Lee, J. J. & Haupt, J. P. Scientific Collaboration on COVID-19 Amidst Geopolitical Tensions between the US and China. The Journal of Higher Education. 2020 DOI: 10.1080/00221546.2020.1827924

51 Mallapaty, S. China's research-misconduct rules target 'paper mills' that churn out fake studies. Nature. 21 August 2020. https://www.nature.com/articles/d41586-020-02445-8

52 Mallapaty, S. China bans cash rewards for publishing papers. Nature. 28 February 2020. https://www.nature.com/articles/d41586-020-00574-8

53 Qu T. South China Morning Post. 27 September 2021. https://www.scmp.com/tech/policy/article/3150312/china-puts-greater-emphasis-beijing-and-zhongguancun-it-looks-burnish?utm_source=pocket-app&utm_medium=share

54 Misumi, Y. China snaps up Japanese scientists, sparking fears of technology outflow. Nikkei Asia. 28 November 2020. https://asia.nikkei.com/Politics/International-relations/China-snaps-up-Japanese-scientists-sparking-fears-of-technology-outflow

55 Trager, R. China has 600 outposts across the world to recruit scientists. Chemistry World. 28 August 2020. https://www.chemistryworld.com/news/china-has-600-outposts-across-the-world-to-recruit-scientists/4012365.article

56 Wong, D. What to Expect in China's 14th Five Year Plan? Decoding the Fifth Plenum Communique. China Briefing. 12 November 2020. https://www.china-briefing.com/news/what-to-expect-in-chinas-14th-five-year-plan-decoding-the-fifth-plenum-communique/

57 Nikkei. 10 August 2021. https://asia.nikkei.com/Business/Technology/China-passes-US-to-top-output-of-influential-science-papers

58 Li D et al. Is China emerging as the global leader in AI? Harvard Business Review. February 2021. https://hbr.org/2021/02/is-china-emerging-as-the-global-leader-in-ai

59 Liu J. China Takes on big publishers on in world class journal drive. Times Higher Education. 26 September 2021. https://www.timeshighereducation.com/news/china-takes-big-publishers-world-class-journal-drive

60 Watanabe, S. US visas for Chinese students tumble 99% as tensions rise. Nikkei Asia. 04 November 2020. https://asia.nikkei.com/Politics/International-relations/US-visas-for-Chinese-students-tumble-99-as-tensions-rise2

61 Open Doors data https://opendoorsdata.org/fact_sheets/china/

62 https://www.topuniversities.com/university-rankings/world-university-rankings/2022

63 Lau, J. International Students Want to Return to China. Inside Higher Education. 25 November 2020. https://www.insidehighered.com/news/2020/11/25/international-students-want-return-china

64 International students in China: https://www.china-admissions.com/blog/update-covid-and-online-classes/

65 OECD. 23 June 2021.https://www.oecd-ilibrary.org/science-and-technology/how-will-covid-19-reshape-science-technology-and-innovation_2332334d-en

66 Kelly E and McCabe J. Sciencebusiness.net 1 April 2001. https://sciencebusiness.net/news/biden-unveils-historic-325b-research-and-innovation-plan

67 Cop 26 outcomes https://www.carbonbrief.org/cop26-key-outcomes-agreed-at-the-un-climate-talks-in-glasgow Kelly, E. & Naujokaitytė, G. EU announces budget breakdown for Horizon Europe after 14-hour talks.

68 Science Business. 11 December 2020. https://sciencebusiness.net/framework-programmes/news/eu-announces-budget-breakdown-horizon-europe-after-14-hour-talks

69 The Guardian. 1 April 2021. https://www.theguardian.com/science/2021/apr/01/uk-pledges-extra-250m-for-hi-tech-research-collaboration-with-eu

70 Wallace N. Science.org 28 December 2020. https://www.science.org/content/article/brexit-deal-secures-uk-access-european-research-funds

71 Cheney C. What's changed in global philanthropy and what more is needed? Devex. 23 September 2021. https://www.devex.com/news/what-s-changed-in-global-philanthropy-and-what-more-is-needed-101642

Pathways to open science

A quick glance back…

In our original report, we identified three key areas of change – these are featured in the blue boxes below. Each of these is accompanied by a bulleted breakdown of the shifts we anticipated would occur as that change unfolded.

Taken from ***Research futures 2019***

1

Research grants will increasingly have open science conditions attached

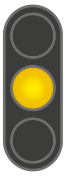
- Key state and philanthropic funders already embrace aspects of open science and there are signals this commitment is long-term. While there is no agreed definition of open science, and no clear plan on how it can be achieved, the pace of funder policy interventions will accelerate, and conditions attached 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 new 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).

Now, three years into the 10-year window and with COVID-19 impacting every element of our lives, how are those predictions standing up?

We have used a traffic light system to give an indication: red for no progress, amber for some progress, and green for a reasonable amount of progress.

Read the original **"Pathways to open science"** essay in *Research futures*
www.elsevier.com/research-intelligence/resource-library/research-futures

Key findings

- **More open knowledge.** The pandemic has accelerated adoption of open science and open access publishing. The intention to publish an article Open Access increased from 49 percent in 2019 to 54 percent in 2020. More articles are being published Open Access than ever before.
- **Transformative agreements are accelerating the transition to Open access.** Nearly half of the researchers expect one of lasting impacts of the pandemic will be more Open Science over the next 2 -5 years.
- **More funding requirements.** Over half of researchers (51 percent) believe there are more requirements, notably increased number of research publications and more progress reporting.
- **Researchers have increased their collaboration** across disciplines and borders during the pandemic. 63 percent of researchers believe there is more collaboration, a 15 percent point increase on 2020.
- **Data sharing became more widespread** during the pandemic (52 percent agree they share more compared to 2 to 3 years ago), although not as high as some hoped. Researchers expect this increase in data sharing to be one of the longer-lasting impacts of COVID-19. Researchers expect sharing to rise further over the next 2 to 5 years.
- **Public recognition of the importance of science has increased during the pandemic**, with more researchers agreeing that public understanding of their work is good than was the case in 2020 (64 percent in 2021. versus 60 percent in 2020).
- **In spite of difficulties presented by the pandemic**, 61 percent researchers in 2020 shared research findings with the wider public, although this dipped to 57 percent in 2021.

In our previous report, we kicked off our open science essay by listing just some of the many definitions in circulation. While much has evolved in the intervening three years, it appears there is still a general lack of alignment on what the term means. However, most would agree that open science describes new and more transparent ways of working and sharing, often drawing on technology. Together, these new methods support open collaboration and allow everyone to access, participate in and benefit from scientific endeavor.

Back in 2019, it was already clear that the movement was rapidly gaining momentum, with national and regional initiatives designed to drive adoption. A number of these were instigated by funding bodies, who were increasingly attaching open science conditions to their grants around the sharing of data, speed of access and communication of results (see Ensuring research is accessible and accountable in our "**Funding the future"** essay in this report). Importantly, many of these mandates stipulated that research findings must be published open access in some form, although the form chosen varied per country/region – we explore this further in *Bridging the geographical* divide in this essay.

> *"More journals and publishers require [openness] as do many research institutions where the work is done and also funding sources."*
>
> Computer Science, US, aged 65+

1,022 respondents in our 2020 survey were asked whether they planned to publish in an OA journal in the next 12 months, and 54 percent answered yes, an increase of 5 percent since 2019. 26 percent of our respondents said they intended to publish in a hybrid journal in the coming 12 months – in 2019, that figure was 18 percent. We also saw a corresponding drop in the number opting for subscription journals – from 81 percent to 76 percent.

Channels to be used over the next 12 months for making research available.

% intending to make research articles available via these channels in the next 12 months (among those planning to publish at least one article)	2019 n=1450	2020 n=1066
Journal (subscription based)	81%	76%
Conferences and posters	47%	48%
Books or book chapters	24%	29%
Open access journal	49%	54%
Hybrid journal	18%	26%
Academic Social Networking site*	17%	30%
Institutional repository	11%	14%
Subject repository	5%	8%
My own website	7%	11%
Pre-print server	7%	16%

*e.g. ResearchGate, Academia.edu, Mendeley

***Figure 11**: Question: "Which of the below, if any, do you believe you will use within the next 12 months to make your research articles available?" Source: Researcher survey 2020 and 2019 survey. Base in 2019 = 1450 and base in 2020 =1066*

The OA publishing figures mentioned above suggest that the share of open access articles will continue to grow towards the 100 percent target set by cOAlition S and others. As many see achieving full open access as central to the open science story, it's an indicator that there are still bumps on the road ahead. As we explored in our previous report, there are many complex issues to be overcome.

Researchers also say that funders are increasingly making open access publication a requirement for funding. In our latest survey (2021), just over half of researchers (51 percent) told us that there are more funding requirements than was the case two or three years ago. We explore these new requirements in the 'Funding the future' essay. As well as more research publications and greater progress reporting, 35 percent say there are more requirements for them to publish open access.

By discipline, Chemistry (52 percent) and Medicine (49 percent) are most likely to be required to publish open access as a new funding requirement. We also see that those in Medicine and Allied Health believe there are more requirements to show evidence of inter-disciplinary collaboration. (see figure 12).

At the time of writing the original report in 2019, a group of national research funding organizations had just joined forces to form cOAlition S, coordinated by Science Europe and supported by the European Commission and the European Research Council. In late 2018, they published Plan S, designed to make full and immediate open access to research publications a reality, with their stated intention that starting from 2021, "all scholarly publications on the results from research funded by public or private grants provided by national, regional and international research councils and funding bodies, must be published in open access journals, on open access platform, or made immediately available through Open Access Repositories without embargo."[1]

At its launch, cOAlition S comprised 13 national research funding organizations and three charitable foundations, largely based in Europe. Their goal was to ensure that scientific publications funded by research councils and funding bodies would be published in compliant open access journals or on compliant open access platforms. Today, there are 19 national funders involved, along with seven charitable and international funders, including the US-based Bill & Melinda Gates Foundation and the World Health Organization. Plan S' deadline has moved to 2021, and its list of accepted publication channels has now expanded to include the ever-rising number of open access repositories.[1] As of end December 2021, 24 of these funders had implemented OA policies aligned with Plan S. Most of these policies applied to all new funding calls opened or all research articles submitted for publication from January 2021. UKRI (United Kingdom Research & Innovation) has committed to making all of its funded peer-reviewed research immediately available OA upon publication from 1 April 2022. In June 2021, Quebec Research Funds (QRF), representing about one-quarter of Canada's scientific community, became the group's first North American public funder member. QRF committed to make all its funded research OA from March 2023.

In mid-2021, COAlition S and six other organizations committed to helping smaller independent publishers transition to OA publishing in scalable, sustainable and revenue-neutral ways.

In mid-December 2021, cOAlition S announced the commencement of a Journal Comparison Service, which is aimed at helping the research community to better assess publishing services and prices, increase transparency and make it easier for researchers to compare publishing options. As we noted in our original report, clarity about publishing options and possible discounts has sometimes been low in countries with lower funding as well as among younger researchers. The online service is expected to be available to authorized users in the summer of 2022.

In 2018, cOAlition S' 8th principle stated that the hybrid model of publishing – publishing an article open access in a subscription journal – was not compliant with its goals. Fast forward and its position had shifted slightly by 2021: "…as a transitional pathway towards full Open Access within a clearly defined timeframe, and only as part of transformative arrangements, funders may contribute to financially supporting such arrangements." [1]

Open access (OA) publishing models explained

A key component of open science is open access (OA) publishing, which ensures that an article is freely available. 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.

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.

Bronze open access:

Generally, no APC is paid, but the publisher makes the article freely available to read, either immediately or following an embargo. However, the article usually lacks a formal license for reuse.

But what are these transformative agreements? For the global Open Access 2020 Initiative (OA2020) they are about fostering "innovative forms of scholarly inquiry" and enabling "faster and more impactful communication of results by transforming the way research is published and disseminated." [2] In practice, the term is commonly used to describe a shift in the contracts drawn up between publishers, institutions and/or national and regional consortiums – instead of pay to read, they are increasingly pay to publish and read (or read and publish) agreements. As Lisa Hinchliffe, a librarian at the US' University of Illinois at Urbana–Champaign, notes in *The Scholarly Kitchen*, while the form of these deals may vary, they are based on the idea that subscription-based reading payments will eventually be phased out. [3]

While transformative agreements existed before the arrival of cOAlition S, the past couple of years have seen them increase in number and scope. OA2020, a global initiative to accelerate the transition to open access, reported in the spring of 2021 that nearly 100,000 articles had been published under transformative agreements by December 2020.[4]

Examples include in 2020, Springer Nature and Germany's Projekt DEAL signed a transformative open access agreement [4] as well as the transformative deal between Elsevier and the Dutch university organization VSNU in 2019. Hailed by the Dutch Research Council NWO as "a major breakthrough for open science in the Netherlands", it aims to help the country achieve its goal of 100 percent open access publishing. The agreement provides Dutch researchers with full reading access to all Elsevier journals and (unlimited) open access publishing in Elsevier journals. In addition, a range of pilots were arranged to develop interoperable, vendor/publisher neutral tools and services that support open science and research intelligence. [5]

We are also witnessing a rise in transformative journals – subscription or hybrid titles that have pledged to transition to full OA at some point in the future. In 2021, for example, both Elsevier [6] and Springer [7] provided journals that are transformative journals. The journals offer optional open access on all primary research with a choice of gold OA or subscription publication.

There are other clear signs of the growing desire among publishers and information providers to meet the rising demand for open science options. For example, in the past few years the number of gold open access journals has increased. These are typically newly-launched journals or subscription titles that have flipped to the gold OA model. Elsevier has over 600 fully open access journals and more than 90% of journals that Elsevier now launches are OA. While in 2020, Springer Nature introduced Discover, a new fully OA journal series. [8] In January 2021, publisher Wiley announced it had acquired fast-growing open access publisher Hindawi Limited for a total purchase price of $298 million to add "quality, scale and growth" to its own OA program. [9] In October 2021, the University of Maastricht in the Netherlands launched its UM/MUMC+ Open Access Journal Browser with information on more than 35,000 journals, with the aim of enabling users to finding information about publishing OA and article publishing charge (APC) discounts. [10] IOP Publishing launched three new OA journals covering environmental topics in 2021, with the APC waived for all articles submitted to the three new publications up to 2024, and permanently waived for researchers from low and middle income countries. [11]

Some of the new OA journal launches focus on traditional research articles while others are designed to openly share the elements generated during the research process, including data, software and methods. New article types have also emerged to support these elements.

Scenario Match

In the scenario **Brave open world**, we suggested researchers would benefit from access to data in a variety of ways, for example, via bite-sized publications.

While open access is not yet the dominant model, its share of the market is growing. According to STM Global Brief 2021, 7 percent of the total journal publishing market value is made up of paid-for open access articles, which is the equivalent of just over 30 percent of all scholarly articles. “Open Access publishing is growing much faster than the underlying market with revenues projected to increase at 11.5 percent and output at 12.5 percent (compound annual growth rate) from 2019-2022.” STM found that about one-third of all global research articles are now published OA in some countries, with UK researchers predicted to publish 90 percent of articles OA within one year.[12]

Market studies suggest that OA publishing continues to make steady progress; for example, calculations by consultants Delta Think show that the open access market continues to grow faster than the underlying journals publishing market. “Based on current trends, we estimate it to have been worth around US$763m in 2019 and on track to grow to around US$850m in 2020.”[13] That predicted growth appears to have been surpassed with estimates that the OA market grew to about US$975 million in 2020 and predicted to grow to about US$1.1 billion in 2021. [14]

In the European Union, 81 percent of scientific papers from Horizon 2020-funded projects were published in open access. Of these, 56 percent were published in open access journals and the rest were published behind a paywall, but accessible in open access repositories, where they were filed by the authors.[15]

Scenario match

In the scenario **Brave Open World**, we suggested that one of the indicators that the world we had painted coming true was that a third of research articles are published gold open access in Europe.

In its December 2021 report, RoRI assessed whether the call by Wellcome on ‘Sharing research data and findings relevant to the novel coronavirus (COVID-19) outbreak’ had been met. In respect to commitments made to publish open access, the report found that overall, 88 percent of peer-reviewed COVID-19 outputs are freely or openly accessible. 44 percent of these outputs were published in an open access journal. 10 percent were hybrid open access, meaning they are openly accessible in a subscription-based journal. 28 percent were bronze open access and are freely accessible in a subscription-based journal, and the remaining six percent were green open access.[16]

The impact of COVID-19

Unsurprisingly, the emergence of COVID-19, and the urgent need to find effective vaccines and therapeutics, saw a new surge of support for open science. More than 50 publishers and information providers around the globe committed to making all of their COVID-19 and coronavirus-related publications, and the available data supporting them, immediately accessible in PubMed Central (PMC) and other public repositories. [17] According to the Publishers’ Association, other activities included fast tracking crucial pandemic-related research and supporting remote learning. [18] Many publishers also launched their own dedicated COVID-19 sites, with some offering data mining opportunities and free access to textbooks and online solutions. [19] Open access publishing platforms and preprint servers (see “**Building the future research information system”** essay in this report) have reported spikes in usage.

Many other organizations including funders, governmental organisations and NGOs around the globe were quick to respond too: the UK funder Wellcome Trust called for researchers, journals and funders to share relevant research data and findings rapidly and openly; the China National Knowledge Infrastructure launched a free website, urging researchers to publish coronavirus articles open access; and in scientific journal Nature, an editorial encouraged researchers to “keep sharing, stay open”. [19A] In the USA, the White House and a coalition of leading research groups, including NIH (National Institutes of Health), Chan Zuckerberg Initiative and Allen Institute for AI, launched CORD-19 (COVID-19 Open Research Dataset), a freely-available resource of machine-readable data sets and scholarly articles about COVID-19, SARS-CoV-2, and related coronaviruses. It also called on the world’s artificial intelligence (AI) experts to develop text, data mining and other tools to mine the content for new insights. [20]

Scenario match

In the scenario **Brave Open World**, we envisaged that governments and philanthropic organizations would work together to counter a pandemic.

According to a study published in the New England Journal of Medicine in April 2021, the pandemic created an imperative to accelerate the adoption of open science. The initial sharing of the genome sequence of SARS-CoV-2 in January 2020 in an open access data base set a precedent for data-sharing and metadata that was later used to investigate new variants. In the USA, the National Institutes of Health (NIH), which had funded about US$2 billion in COVID-19-related research as of January 2021 and has received almost US$4.9 billion to date to fund COVID-19 research, set up a sharing platform for the pandemic. "Support for preprint servers has promoted awareness of research successes and failures, and journals have helped accelerate the distribution of actionable information, including by means of dedicated Covid-19 web pages, endorsement of preprints, and an emphasis on sharing data with public health authorities." [21] We discuss the growth of preprints in our essay in this report **"Building the future research information system."**

In the Netherlands, the Dutch Research Council (NWO), which provides research funding of about €1 billion euro annually, pointed to the boost to open science from the free sharing of data related to COVID-19, calling it "A fantastic illustration of the importance and relevance of open science. A vaccine could only be developed so quickly because of the intensive collaboration of researchers worldwide and their willingness to share the results." In 2020, 67.4 percent of the council's funded research was published open access in a steadily increasing curve that has grown from 19 percent in 2015. [22]

More than three quarters (76 percent) of COVID-19 publications were published open access between January and October 2020, according to analysis of PubMed data by Organization for Economic Co-operation and Development (OECD). Of these, the largest number was published by the USA, followed by China and the UK. This compares to 43 percent for diabetes and 40 percent for dementia publications over the same period. [23]

In October 2020, UNESCO, the World Health Organization (WHO) and the United Nations High Commissioner for Human Rights joined forces to issue a declaration in favor of open science. According to UNESCO Director-General, Audrey Azoulay: "As countries call for international scientific collaboration, as the scientific community, civil society, innovators and the private sector mobilize in these unprecedented times, the urgency of the transition to Open Science has never been more clear." [24] For all three organizations, open science also holds the key to increasing confidence in science "at a time when rumors and misinformation are proliferating to the point of becoming an "infodemic"." [24] We explore the importance of research integrity later in this essay.

"I think that there is a push to make all aspects more transparent. Perhaps it is in part a response to "fake news" and trend to more and more people not trusting science --making all stages open makes it harder to hide misdeeds and misinformation."

Biochemistry, Genetics, and Molecular Biology, US, aged 46-55

In line with the move towards Open Science, we saw collaboration levels rise strongly in our 2021 global survey. In 2021, 63 percent of researchers believed there was more collaboration on their project than previously, a 15 percentage point increase on 2020. Technology advances and the restrictions imposed to contain COVID-19 have made collaboration easier and more common, as well as being increasingly demanded by funders. Those working in Computer Science and Medicine are most likely to agree that their collaboration levels have increased: 76 percent of those working in Computer Science agreed, followed by 70 percent of those working in Medicine. See figure 27 in the essay **"How Researchers work: the change ahead"** where these changes are explored.

More collaboration on research projects than previously

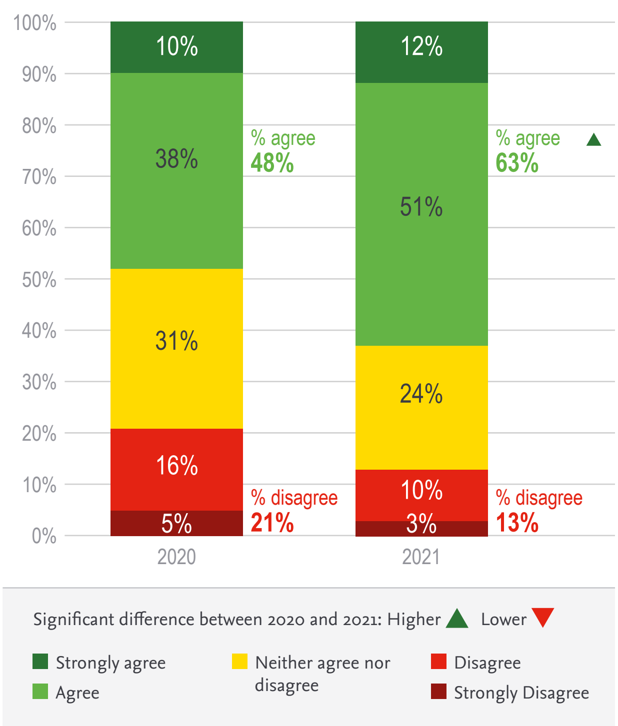


***Figure 12**: Question: "To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: 'There is more collaboration on my research project(s) than previously.' Source: Researcher survey 2021 base=1,141 and researcher survey 2020 base=1,041*

Other aspects of open science are also on the rise. In our previous report, we touched on the rise of open peer review, which can take on many forms, from publishing reviewer names and/or the full peer review reports (with DOIs), to collaborative peer review, where reviewers and editors conduct the review process in partnership.

But while many in the community support the principle of transparency in peer review, take-up remains fairly low. In a 2020 paper on the topic, authors Wolfram et al. noted that despite the fact that open peer review (OPR) is growing, it remains "one of the last aspects of the open science movement to be widely embraced." [25] They found that the majority of growth had been spurred by a small number of primarily Europe-based publishers with adoption most common in Medical and Health Sciences and the Natural Sciences.

They also found that the number of OPR journals remained a very small percentage of scholarly journals, overall, and only a minority of those had "adopted complete transparency". The authors added: "The fact that there are multiple approaches to the adoption of OPR indicates there is no consensus at present regarding best practices." [25]

We explore the role of the journal later in this report in the essay **"Building the future research Information system"**.

Looking ahead to the likely longer term impact of the pandemic, researchers are more confident than they were in 2020 that COVID-19 will prove a boost to open science. In 2021 the net percentage of researchers who indicated there will be more open science in the next 2-5 years is 43 percent up from 31 percent in 2020 (net percentage is the percentage of respondents that selected there will be 'more' Open Science minus the percentage who said there will be 'less' Open Science) . Just 4 percent disagreed.

We also see other anticipated long-lasting impacts of Covid-19. The majority view overall is that flexible working will become more common. Researchers increasingly think there will be more cross-discipline working, a greater emphasis on societal impact of research, more research data shared, and additional collaboration with international colleagues - all likely to contribute to greater openness in science in the future.

Researchers are, however, less optimistic about future funding (a topic we discuss in **Funding the future** essay) which will likely put pressure on funding for open access.

Anticipated longer term impact of Covid-19 on research (next 2-5 years)

Do you think the longer term impact of COVID will lead to...

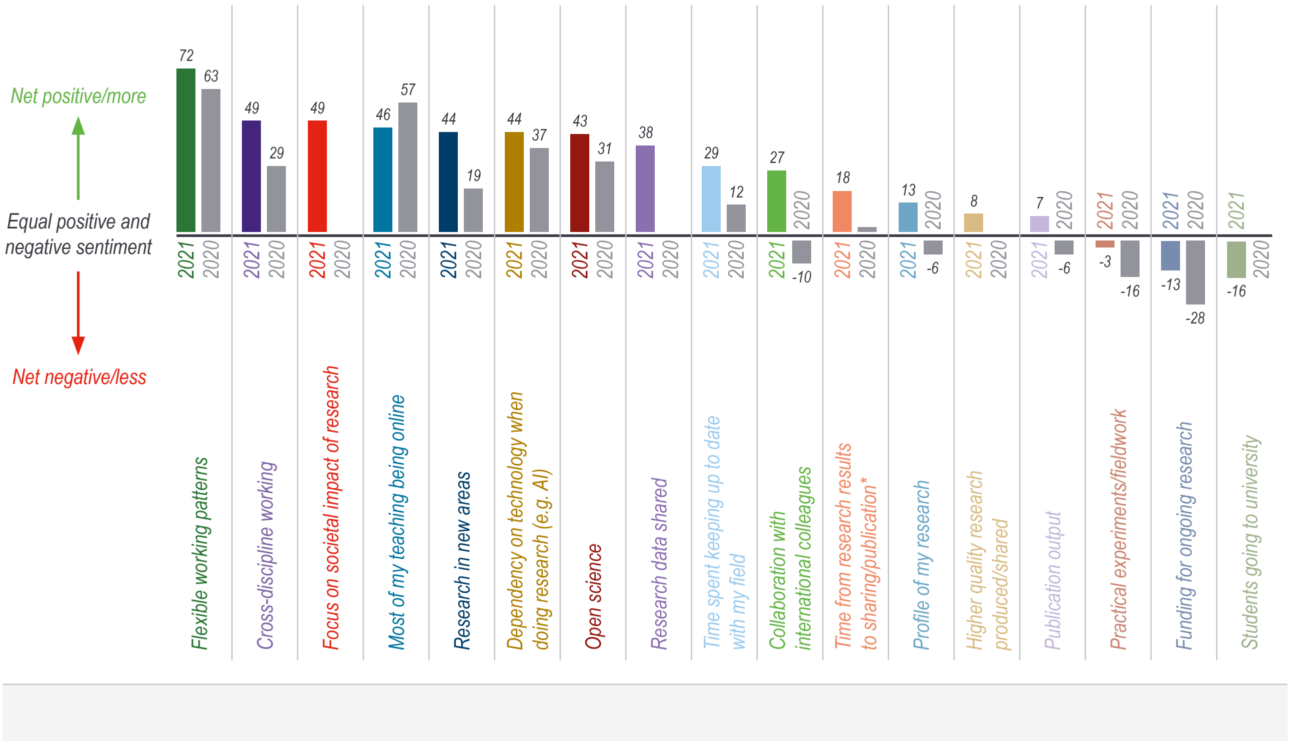


***Figure 13**: Question: Do you think the longer term (next 2-5 years) impact of COVID-19 will lead to...... scale was '+' 'no change' '-', the 'Net' figures shown in chart is % positive score minus % negative score. Source: Researcher survey 2020. Base varies from 646 to 972. Researcher survey 2021 base varies from 1035 to 1139. Respondents were offered a 'not applicable' option and these responses are not reported. Note 'Research data shared', 'Higher quality research produced/shared', 'Students going to university', 'Focus on societal impact of research' not asked in 2020.*

Data sharing

COVID-19 has thrust the benefits of sharing data quickly and freely into the spotlight. According to the European Data Portal, healthcare workers are "sharing information on COVID-19 with a new sense of transparency and at speeds that have not been seen before." It believes this trend has created new opportunities for the development of AI. "Before the pandemic, AI had a minor presence in healthcare solutions as researchers did not always see the importance…or did not have the data needed to provide solutions. However, when we look towards the future it is likely that AI will play a more prominent role in healthcare." [26] It highlights developments such as the US' CORD-19, and an algorithm that diagnoses COVID-19 patients in just seconds, released by China's Alibaba in the early stages of the outbreak.[26] We explore the role of tech in healthcare further in our **"Technology: revolution or evolution"** essay.

As mentioned earlier, researchers expect to share more in the future, and also see this is building on a base of increased sharing. Data sharing became more common during the pandemic, with 52 percent of researchers agreed that they are sharing more data now than they did two to three years ago. The reasons for this include increased availability of data, having more data to share, and being encouraged or required by funders to share it. Younger researchers and heads of department were most likely to agree.

However, while researchers have been sharing more data than before, as the pandemic progressed, the level of data sharing did not keep pace with the levels that some had anticipated. After the pandemic began, a statement on 'Sharing research data and findings relevant to the novel coronavirus (COVID-19) outbreak' was issued by Wellcome and signed by 160 organizations worldwide, including research funders, publishers, infrastructure providers, and research institutions. A study of COVID-19 research by RoRI found that less research data was shared and fewer preprints were published than hoped for. [16] The report estimates that 150,000 peer-reviewed COVID-19 articles were published between January 2020 and April 2021 and an estimated 40,000 COVID-19 preprints posted over the same period.

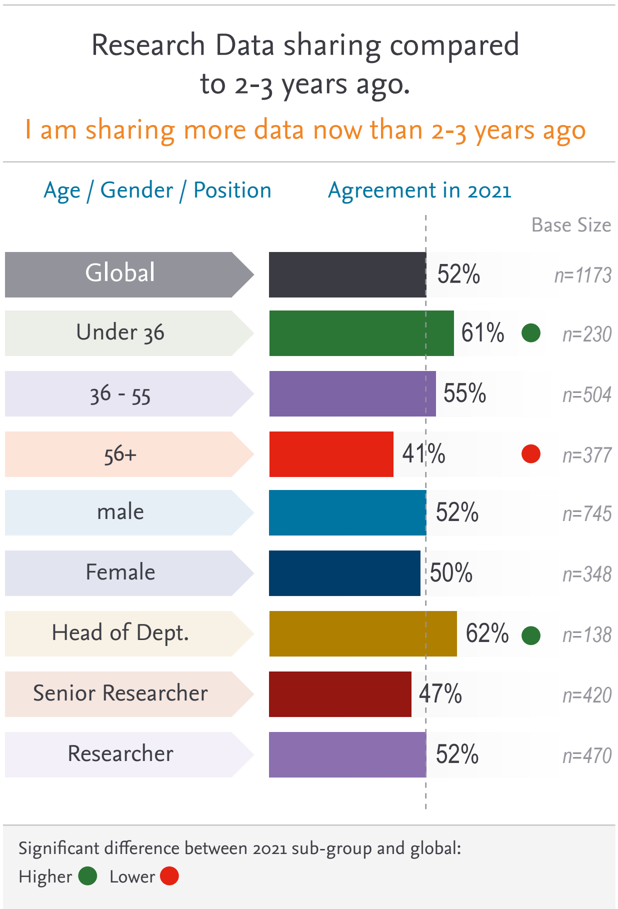


***Figure 14**: Question I am sharing more research data now than 2-3 years ago. Source: Researcher survey, 2021. Base = 1,173*

While the report finds that about 90 percent of all peer-reviewed COVID-19 outputs were either open or freely accessible, fulfilling the commitment made at the start of the pandemic, the commitments relating to preprints and data were not fulfilled.
"The commitment made at the beginning of the pandemic to post COVID-19 research on a preprint server before it appears in a journal, or in some other peer-reviewed outlet, has not been fulfilled. Only a small share of all COVID-19 research was posted on a preprint server. We were able to identify a preprint for 5% of all peer-reviewed COVID-19 outputs (but the actual percentage of peer-reviewed COVID-19 outputs that have a preprint is likely to be a little higher)." [16]
We explore the growth of preprints during the pandemic in our **Building the Future Research Information System** essay.

Impact and outreach

For some time now, there has been a growing feeling that members of the public should be impacted by the outcomes of the studies their tax money funds. As we noted in the original report, this has led to many funders requiring applicants to explain the findings in a way that is easy to follow and demonstrate how the research proposed will benefit society – particularly its alignment to the UN's Sustainable Development Goals (SDGs). In figure 10, earlier in this essay, nearly at third of researchers who said there were more funding requirements compared to 2-3 years ago, indicated they needed to demonstrate alignment with SDGs. The increased focus on societal impact on research is something that many of our respondents expect to see increase (see figure 13).

Increasing public understanding of scientific research is also one of the goals of open science. The depth of disruption and uncertainty caused by the pandemic in every sphere of life has helped science and scientists to become more prominent in the public sphere as people seek answers and information. Almost two-thirds of researchers in our latest survey say that the public understands the purpose and outcomes of their research, up from 60 percent a year earlier. The number of those who disagree has also dropped to 13 percent, down from 20 percent in 2020. Public understanding builds support for research funding, some believe, while those who disagree cite the complexity of their work and the effort needed to share their findings in language that the layman can understand. This increase in public trust in science is one of the markers driving our Brave Open World scenario. We explore researcher views of what they believe the public needs to know about research in the essay "**Building the future research information system**".

Scenario match

In our **Brave Open World**, scenario, we anticipated an increase in public trust in science.

Figure 15: *Question: "To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: Public understanding of the purpose and outcomes of my research is good". Source: Researcher surveys 2019, 2020 and 2021. Base: 2020=1066; 2021 =1173. Chart excludes don't know answers.*

As we mentioned earlier, researchers are being asked by funders to do more; in particular to increase the number of research publications and submit more progress reports, as well as demonstrating more inter-disciplinary collaboration, open access publication and sharing of research data. This ties in with our expectation of an increased focus on making research more available as we move towards an open science scenario. In addition, a number of funders now require that the results are made freely available in some form.

We suggested that this move toward accountability and transparency had the potential to not only influence what is being funded, but increase the existing pressures on researchers, who must learn to communicate their findings in a way that engages people, whatever their level of scientific knowledge.

"Since the outbreak of Covid-19 I think the general public has become more aware and interested in how research may impact global health strategies. Until this moment, research was viewed as a background profession without an immediate impact in people's lives."

Biochemistry, Genetics, and Molecular Biology, Portugal, aged 36-45

When we look at responses by specialty, Earth and Environmental researchers believe that public understanding of their work is good, with 74 percent significantly higher than the global value. Life Sciences are also increasingly convinced of public understanding with 69 percent agreeing, up from 55 percent in 2020.

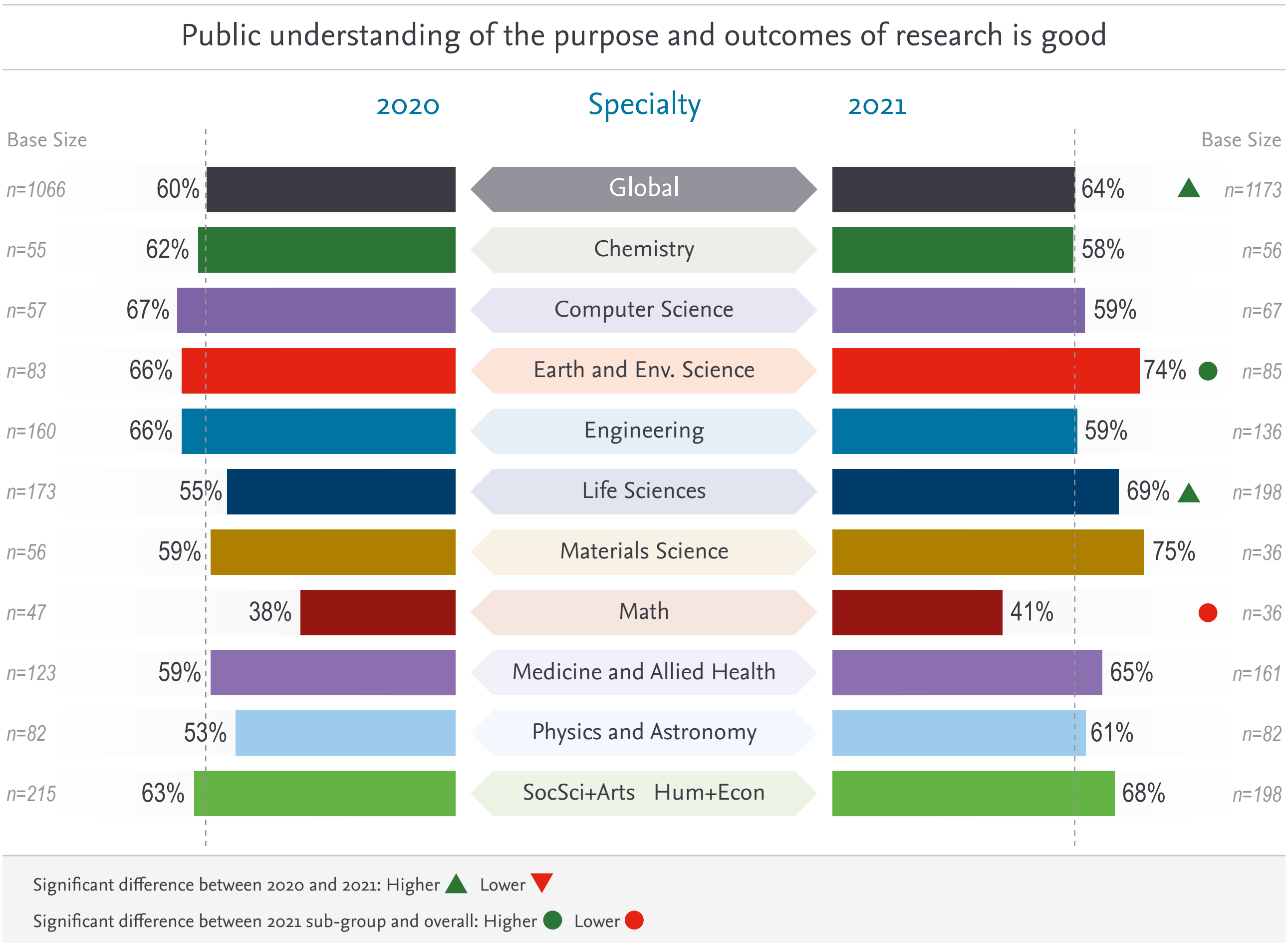


Figure 16: *Question: "To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: Public understanding of the purpose and outcomes of my research is good ." Source: Researcher surveys 2020 and 2021. Base in 2020 1066, base in 2021 1173.*

"As the research impact our lifestyle, concerns environmental and public health as well, it is of great importance to keep the public aware."

Biological Sciences, Armenia, aged 65+

Greater transparency in science is also seen as a vital step toward restoring public faith in research.

"Confusing stories from politicians versus scientists has led to mistrust of both entities by the public."

Immunology and Microbiology, US, aged 65+

At the same time, views about the need for research to show real world benefits is split almost down the middle among researchers. 43 percent see it as essential that research should benefit society while 39 percent don't and may instead believe that knowledge building is important for its own sake or that benefits to society may take time to become apparent.

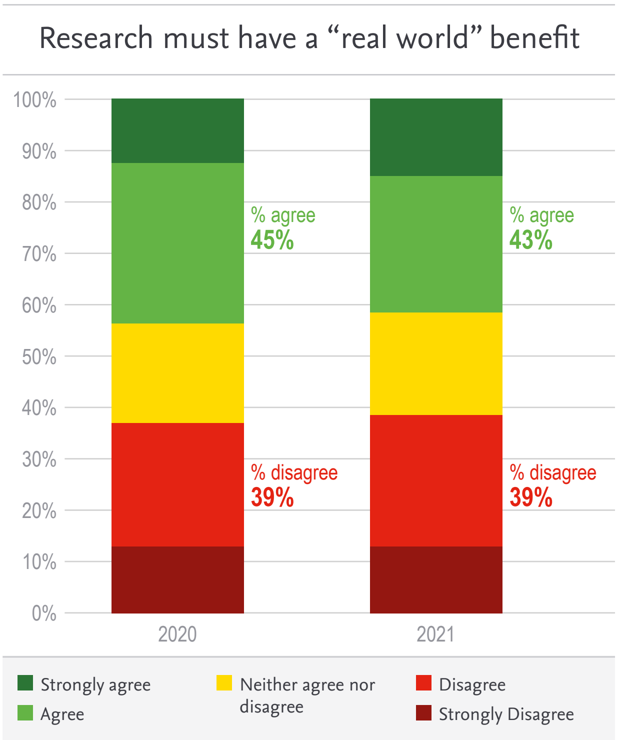


Figure 17: Question: " To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: Research must always have a "real world" benefit. Source: Researcher surveys 2020 and 2021. Base: All researchers 2020 (n=1066); 2021 (n=1173). Chart excludes don't know answers

"Fundamental research dos not always have immediate benefits, they may come later."

(Astronomy, France, aged over 65)

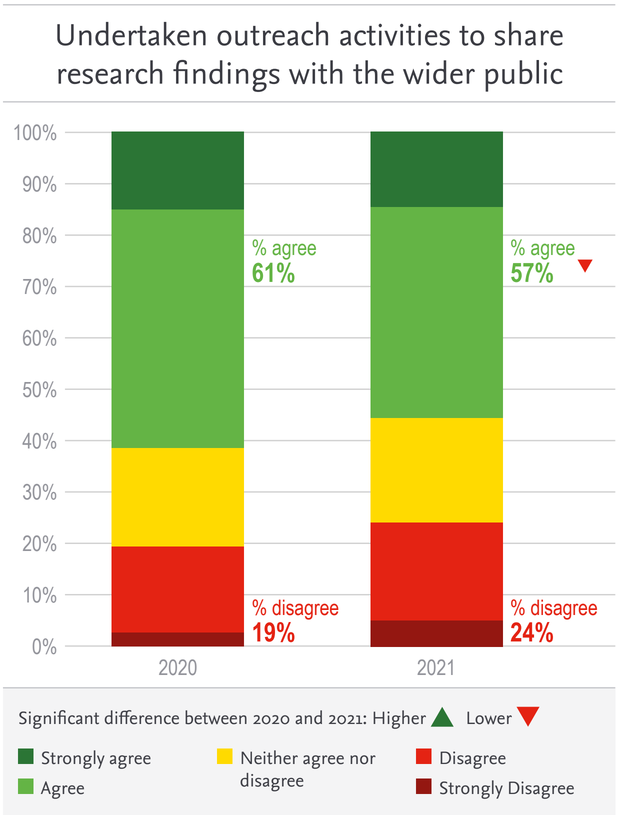
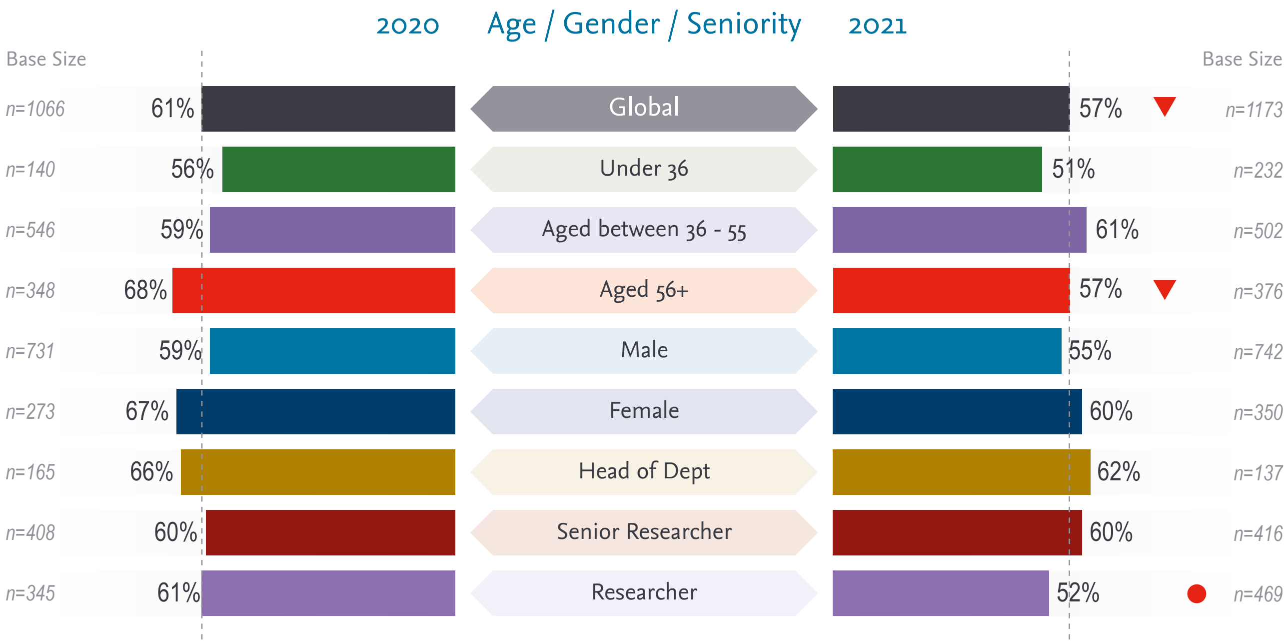


Figure 18: Question: " To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: I have done outreach activities to share my research findings with the wider public (e.g. non-expert summaries, speaking at schools, media appearance) ." Source: Researcher surveys 2020 and 2021. Base: All researchers 2020 (n=1066); 2021 (n=1173). Chart excludes don't know answers.

Despite the difficulties of the pandemic, more than half of researchers (57 percent) carried out public outreach activities to share their research findings, a significant decrease from the 61 percent seen in 2020, perhaps due to limited opportunities to participate in live events during COVID-19 restrictions. Researchers also cite time constraints and lack of familiarity with this kind of public engagement. These activities take various forms, including public speaking, media interviews, social media, and talking at trade shows, seminars or in schools.

Older researchers (56 and over) reduced their outreach activities the most this year, with 57 percent participating compared to 68 percent a year earlier. When examining by level, researchers are the least likely to have carried out public outreach activities (52 percent).

Undertook outreach activities to share research findings with the wider public



Significant difference between 2020 and 2021: Higher ▲ Lower ▼

Significant difference between 2021 sub-group and overall: Higher ● Lower ●

***Figure 19**: Question: To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: I have done outreach activities to share my research findings with the wider public (e.g. non-expert summaries, speaking at schools, media appearance) Source: Researcher surveys 2020 and 2021. Base: All researchers 2020 (n=1066); 2021 (n=1173). Chart excludes don't know answers*

"I seek out and am highly involved in outreach activities. This is important to me as I'm from a socioeconomically disadvantaged background and a female in STEM, so I want others to see examples of what possible things are out there to study."

Neuroscience, US, aged 26-35

Looking at activity by specialty, researchers working in Earth & Environment and Social Sciences are the most active in outreach activities, as was also the case in 2020, though their level of activity fell in 2021, to 63 percent from 74 percent in 2020 for Social Science and from 71 percent to 65 percent for Earth & Environmental Science. Outreach by Computer Science researchers grew strongly in 2021, to 56 percent from 38 percent a year earlier.

For those who do take part in outreach activities, key motivators include complying with institution and funder mandates, as well as a desire to encourage the public and policy makers to act on their findings. Raising the profile of research in the field and attracting a new generation of scientists also play a role, as does justifying public funding.

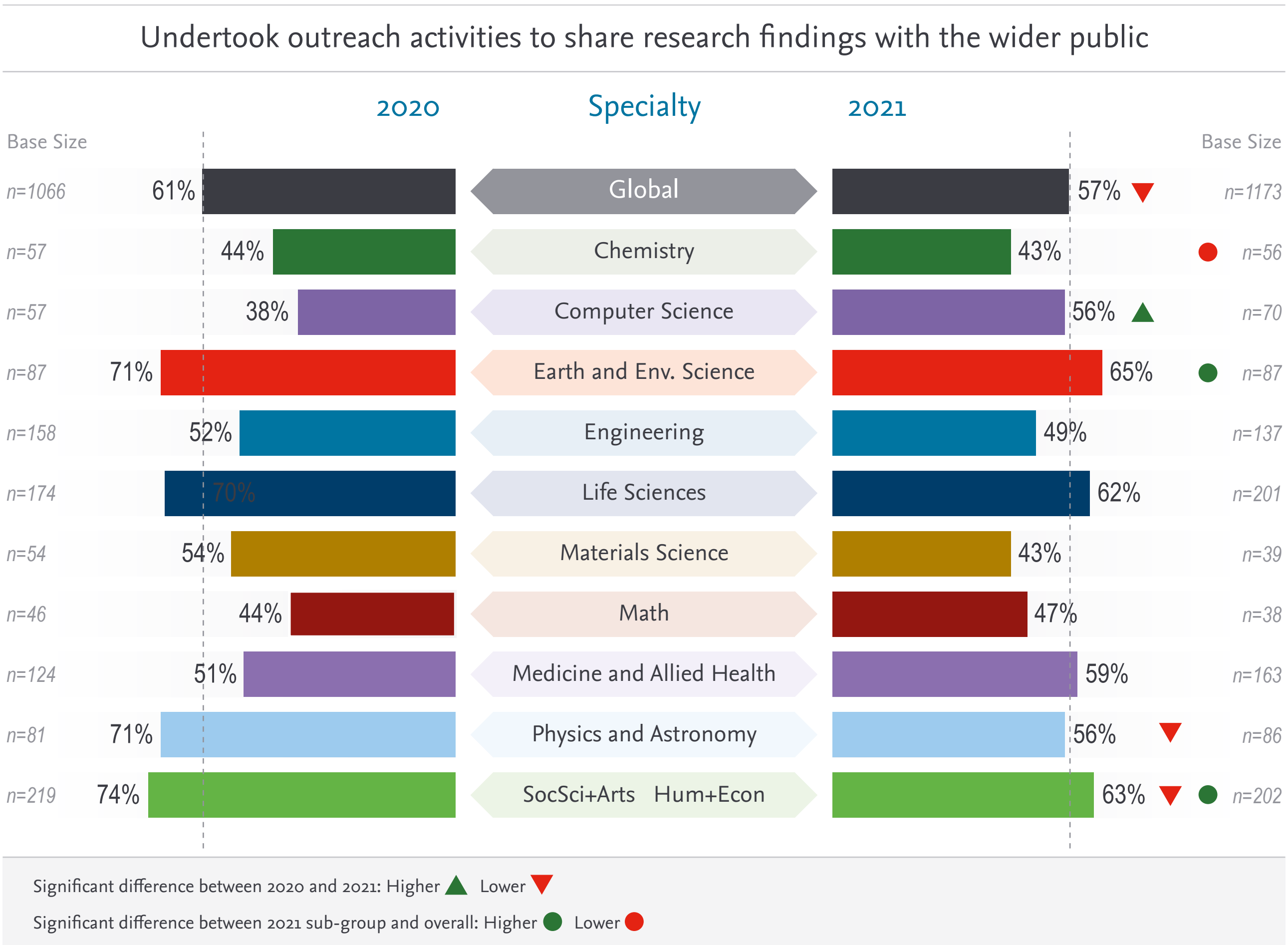


***Figure 20**: Question: " To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: I have done outreach activities to share my research findings with the wider public (e.g. non-expert summaries, speaking at schools, media appearance) ." Source: Researcher surveys 2020 and 2021 Base: All researchers 2020 (n=1066); 2021 (n=1173). Chart excludes don't know answers*

"It is a duty of scientists who are paid by society (via taxes) to share their knowledge with other people. And I like it."

Biological Sciences, Poland, aged 65+

"The more the general public understands, the more they are willing to fund research through their taxes and donations."

(Biochemistry, Genetics and Molecular Biology, USA, aged 46-55)

"Science literacy is poor in general, and my area is no exception."

(Medicine and Allied Health, Canada, aged 36-45)

The role of technology

The engine driving many of the open science responses to COVID-19, and the growth of open science in general, is technology. The past years have seen researchers and organizations leveraging the many possibilities offered by algorithms, machine learning and AI to advance and share knowledge. For example, a group of scientists created a coronavirus version of their existing knowledge base that brings together data from multiple disciplines and applies machine learning to "freely and openly" deliver predictions useful for drug discovery and translational research. [27] Others have joined forces to launch openVirus, a digital knowledge-based project that aims to use natural language processing (NLP) and text mining to better classify, mine and understand data related to viruses and viral epidemics.[28]

> *"The information technology shall aid us to share and review the result of research quickly. For example, in the field of AI, the latest research is made public with the complete set of program which anybody can use, try and improve."*
>
> Physics, Japan, aged 46-55

The pandemic has played a part in hastening a move to digital formats as budgets for education, research and library budgets have come under pressure. Online teaching has also pushed the move to online formats. According to the latest report from STM—the Association of Scientific, Technical and Medical Publishers—digital is the dominant format worldwide, accounting for up to 89 percent of the scientific and technical market in 2020, a 10 percent increase on 2019, when it accounted for 77 percent of that market. [12]

COVID-19 has also prompted a rise in open data that can be freely accessed and used, something many see as a critical step on the path to achieving truly open science. The power of open data to drive discovery was never more evident than in the early days of the pandemic, as Xin Xu, based at the University of Oxford, noted on The Conversation.com in February 2020. In the same month, Yong-Zhen Zhang and his colleagues from Fudan University in Shanghai first sequenced the DNA of the novel coronavirus and "placed the gene sequence in GenBank, an open access data repository. Researchers around the world immediately started analyzing it to develop diagnostics." [19]

Tackling the research integrity issue

COVID-19 has also reignited discussion around a long-running challenge for the research communit – the accuracy and integrity of studies and their findings. 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".[29] In practice, that means publishing reproducible research, disseminating negative results, following ethical standards, applying best practice, and abiding by confidentially requirements, among other things.

Long before the pandemic, there was a strong drive to improve research integrity, particularly reproducibility. This was sparked by the results of several studies, including a 2016 Nature survey which found that 70 percent of respondents had failed to reproduce another scientist's experiment. [30] The researcher survey we conducted for our original *Research Futures* report suggested the situation was not quite so bleak – 37 percent of those who had tried to reproduce a study were successful, nearly two thirds were partially successful, while only six percent indicated they were unsuccessful. [30A]

> *"The number of wrong results is increasing, hence openness is becoming crucial to keep science reliable."*
>
> Physics, Italy, aged 36-45

Some believe the rush to publish during the pandemic has exacerbated existing issues around research integrity. In a Journal of Medical Ethics paper, ethicist Katrina Bramstedt stated that by 31 July 2020, 19 published articles and 14 preprints about COVID-19 had either been retracted, withdrawn, or an expression of concern had been issued. She noted: "During the pandemic there is the potential for the race of research to occur with fewer reflective and rest periods.

Less reflection can facilitate missed opportunities for quality checks such as robust reviews of study applications by research ethics committees (RECs) and quality checks by researchers and their supervisors." In addition, she highlighted the danger of mistakes and errors of judgement creeping in when researchers are fatigued. [31] For forensic scientist Ricardo Jorge Dinis-Oliveira, it's crucial to strike the right balance between rapid access to new scientific data and the threat of incorrect clinical decisions based on mistakes or misconduct. "The truth is that the "scientific research has changed the world" but now, and more than ever, "it needs to change itself". [32]

"The need for speed (to publish or go to market) will continue to undermine the ability to properly test and review findings.

Computer Sciences / IT, US, aged 56-65

The European Network of Research Integrity Offices (ENRIO) was moved to publish a reminder to researchers about the importance of research ethics in the time of a pandemic, amid fears researchers might be induced to ignore ethics and biosafety standards and protocols, or cut corners.[33]

In Science and Engineering, China's research output grew at almost twice the rate of the world's annual average between 2009 and 2019, according to the STM report, which based its finding on research by the National Science Foundation. Over the same period, output from the United States and the European Union increased at less than half the world's annual growth rate. However, the report notes that according to a 2017 report in Quartz magazine, "more than 50 percent of all articles retracted by scientific journals worldwide for fake peer reviews were submitted by Chinese authors." [34] China has been attempting to deal with the problem of research integrity. In October 2021, Nature reported that two major research funders in the country investigated the use of paper mills and punished at least 23 scientists for misconduct including buying data. [35]

A July 2021 study in the Netherlands found cases of "outright fraud" in 8 percent of cases. The Dutch National Survey on Research Integrity was the largest of its kind, with 6,800 responses. The survey found that pressure to publish was the most cited reason for behavior that included fraud, hiding flaws in research design or selectively citing literature.[36]

For many, open science, including the rising number of data platforms and policies mandating the sharing of data, will help to combat research integrity and reproducibility issues, benefitting not only science, but society, with more open sharing supporting the hunt for solutions to today's pressing issues.

"[Open science] will increase in reproducibility of research. It will allow for new research problems to be addressed."

Social Sciences, Chile, aged 36-45

So, what's holding back open science?

As the previous paragraphs show, support for open science is probably at an all-time high. It's desired by funders and governments, and also by many of those responsible for conducting studies.

"....the majority all researchers wish that the research process has to be open."

Pharmacology, Italy, aged 65+

Others view it as an unstoppable force.

"...it appears to be the way we are moving and it all should be open and transparent."

Medicine, US, aged 65+

Yet, uptake continues to remain lower than anticipated. For example, in the case of open access, Piwowar, Priem and Orr have calculated that in 2019, just 31 percent of all journal articles were made available as OA in some form and received 52 percent of total article views. In a preprint published on bioRxiv prior to the pandemic, they predicted that, by 2025, those figures will rise to 44 percent and 70 percent, respectively. [37]

Bridging the geographic divide

One stumbling block is that global alignment on open science and open access remains elusive.

In Europe, support for the open science movement and gold open access publishing has traditionally been strong. For the European Commission, open science is a "policy priority" and beneficiaries of EC funding must publish open access and, wherever possible, share their data. [38] That strong support has led to the launch of the European Open Science Cloud, a "trusted, virtual, federated environment that cuts across borders and scientific disciplines to store, share, process and reuse research digital objects (like publications, data, and software)." [39] January 2021 marked the launch of the EC's new research and innovation funding program – Horizon Europe. It continues the focus on open science and aims to tackle some of the long-standing challenges that lie in its path, including the need for new indicators to evaluate open research and reward researchers (see "Recognizing and rewarding an open approach" in this essay). Importantly, one of the key goals of Horizon Europe is to realize the development of an open access publishing platform to host the publications of grant beneficiaries [39] – the contract for development of the platform was awarded in March 2020. [39]

In the USA, the newly appointed director of the White House Office of Science and Technology Policy (OSTP) mathematician and geneticist Eric Lander announced his full support of open access. "I'm a very big supporter of open access, and I'd love to see the time be as short as possible," he said, in a reference to the US policy that typically allows journals to retain access to articles behind a paywall for up to one year before making them freely available. "Because once research is available, other people can pick it up and do more research, and we can speed that cycle of discovery." [40]

In 2016, when the then-Vice President Biden spearheaded the country's Cancer Moonshot program following the death of his son Beau from brain cancer, he expressed his support for making "all that we know open to everyone so that the world can join the global campaign to end cancer in our lifetimes." [41] The US' National Cancer Institute (NCI) went on to mandate immediate open access to the peer-reviewed publications it funded, in contrast to the green open access position of the NIH, NCI's parent agency. NIH's policy remains in line with the general approach of federal agencies in the US, which stipuates that researchers should make their publications available within a year of publication. [41] Together with the NCI, Biden also launched a first-of-its kind, open access cancer database - The Genomic Data Commons – containing raw genomic and clinical data for patients. [42]

In China, while the Chinese Academy of Sciences (CAS) primarily encourages green OA publishing, the support of CAS and other Chinese funders for gold OA is growing. Increasingly, funding is being made available for payment of the article publishing charges (APCs) associated with gold OA. In a 2019 interview, Xiaolin Zhang of China's National Science Library said the country was watching Plan S developments with interest. He pointed out that the National Science Library, the China National Science and Technology Digital Library and a further 12+ Chinese libraries had already signed the OA2020 Expression of Interest, supporting the OA transformation of scholarly journals. [42A] And he stated: "I think that in 10 years' time we will see the realization of almost complete and immediate open access to publicly funded research, especially for journal articles, because of the push for innovation-driven development for the Chinese economy and society." Zhang added: "Just as open access is taking off, I think that open science will see a gradual and then a really fast acceleration..." [42A]

With China's research output poised to overtake that of the USA (see **"Funding the future"** essay in this report), many believe that adoption of open science in China may prove a tipping point. As Robert Kiley, Head of Open Research at the UK's Wellcome Trust noted in our original *Research Futures* report: "If China goes for open science then it could all happen very quickly as they would mandate it and it would actually happen." [30A] While the likelihood that this will come to pass is still uncertain, more recently, China has reiterated its support for open access publishing and its commitment to actively pursue it. At the 43rd annual meeting of the Society for Scholarly Publishing held in late May 2021, Dr Zhaoping Lyu, Executive Secretary of the China Association for Science and Technology (CAST), said: "China has always focused on the global progress of open science and has actively participated in it. The Excellence Action Plan, led by CAST, has an OA ratio of 81 per cent for new journals, which shows that Chinese STM journals are becoming an important force in the open access landscape."

Dr Lyu said China would make "positive contributions" to the United Nations' promotion of open science, and added: "We welcome the cooperation between professional platforms, technological service providers, and Chinese academic and publishing institutions. While cooperating with foreign publishers, domestic publishers are also actively exploring a more autonomous development model." [42B]

Until recently, China's academic culture had tended to favor prestigious journals with high Impact Factors; often subscription journals. However, in 2020, the Chinese government released two documents advocating a move away from using research papers published in the Science Citation Index (SCI) to determine funding and career advancement,[43] potentially opening the door to more open access publishing [43] The same documents, however, floated a threshold of 20,000 RMB for APCs, less than US$3,000. Often, charges for fully open access titles are higher.

India has the second highest number of STEM graduates, at 2.6 million in 2016. [12] For India, green open access remains the favored route with its plan to make publicly funded authors archive their accepted manuscripts in public open repositories.

At the same time, the country of 1.3 billion announced plans to pursue a "one nation, one subscription" option, which would see the government negotiate with information providers for subscriptions allowing everyone in the country to freely access scholarly publications. [44]

As the United Nations agency responsible for science, in 2019, 193 of UNESCO's member states tasked the organization with developing an international standard-setting instrument on open science. In 2020, the first draft of that instrument – the UNESCO Recommendation on Open Science – was published.[45] It contains a series of goals and objectives that aim to "provide an international framework for Open Science policy and practice that recognizes regional differences in Open Science perspectives, takes into account, in particular, the specific challenges of scientists and other Open Science actors in developing countries, and contributes to reducing the digital, technological and knowledge divides existing between and within countries." [46] The draft recommendation was adopted on 15 November 2021. For some, at least, the UNESCO document provides a "promising start" to resolving these geographic differences. [47]

Getting the right tools in place

While researchers may desire more transparency and sharing, many are frustrated by the limitations of the current infrastructure on offer. As we explored in our previous report, technological tools to support open dissemination have been gradually increasing in scope and number. Many cater for open access publishing – including dedicated platforms launched by funders and policy makers, such as the one recently commissioned by the European Commission. Others are focused on open data sharing and open peer review, while some incorporate all three. In 2020, there were 220 new entries in the Registry of Open Access Repositories (ROAR), which tracks the growth and status of repositories worldwide. [48]

Figures suggest COVID-19 has also prompted institutions to make greater use of their open digital repositories; for example, uploads to Elsevier's Digital Commons institutional repositories in the first and second quarters of 2020 exceeded 2019 figures by 84 percent. [49]

But "Invest in Open Infrastructure", an initiative dedicated to improving funding and resourcing for open technologies and systems supporting research and scholarship, has found that achieving open science brings its own challenges. In preparation for an upcoming report on the *Future of Open Scholarship*, it conducted a series of stakeholder interviews with representatives of institutions, scholarly societies, and supporting organizations. It found that a key tension point/balancing act was the "demand for increased levels of service, more robust and immediate access to research, data and educational materials, while also managing budget cuts and financial instability." For interviewees, the layoffs, furloughs and hiring freezes prompted by the pandemic had impacted "open infrastructure development, maintenance, and innovation". There was particular concern in the USA. [50]

Covering the costs

Finding the funds to pay for the cost of publishing open access can be difficult. In fully open access journals and hybrid journals, the costs of publishing a gold open access article are covered by an APC (article publishing charge), usually paid for by the author, their funder or their institution. In many parts of the world, some publishers waive, or reduce APC fees for authors in developing countries.

"While Senior Management want open access publications they are unwilling to allocate extra funds for them. This means the decision is made at a project/team level to re-allocate funds (e.g., spend less on travel to fund open access). Often, the decision is to concentrate on the project running costs rather than reallocate to open access."

Environmental Sciences, Australia, aged 56-65

For some of our survey respondents, another downside of APCs is that they open the door to "predatory" journals; titles that charge researchers for publication while offering poor or no peer review.

With the rise in transformative agreements that cover the costs of publishing open access, these issues may be resolved in the years ahead. In addition, a transformative agreement toolkit launched to help publishers align with Plan S lists 27 business models and strategies for transitioning to OA, only three of which rely on author payments to fund article publishing. [51]

"Such requirements mean that papers are published because the authors have funds, not that the paper is worth publishing."

Medicine and Allied Health, US, aged 65+

Recognizing and rewarding an open approach

Many feel that as long as the "publish or perish" phenomenon persists (see the **How researchers work: change ahead** essay), researchers' career and funding opportunities will be influenced by the number – and impact – of the articles they've published, leaving few incentives to strive for more openness. And with many of the highest impact journals subscription titles, open access publishing is not always an attractive route.

This appears to be borne out by the results of a 2019 survey conducted by the European University Association (EUA). It found that for most universities, open science practices remain of low importance when it comes to evaluating researchers. [52]

Wheels are in motion that could see this change in the years ahead. Initiatives such as the Declaration on Research Assessment (DORA) have been seeking to improve the ways in which researchers and the outputs of scholarly research are evaluated. [53] And more recently, cOAlition S funders confirmed that when "assessing research outputs during funding decisions they will value the intrinsic merit of the work and not consider the publication channel, its impact factor (or other journal metrics), or the publisher." [54]

In its open science policy, the European Commission lists eight ambitions, three of which touch directly on the creation of new measures and metrics to recognize open science. [38] And as we've seen, China, which for many years rewarded researchers for articles published in Web of Science indexed journals, [55] is moving away from focusing on the quantity of papers published or the Impact Factor of the journals they appear in as a measure of performance or research ability. [43]

Scenario match

In the scenario Brave open world, we suggested that funders would collaborate to create guiding principles for new metrics of assessment, such as societal impact, data dissemination, peer review and the success of collaborations.

However, hurdles remain for researchers. The environment they operate in is becoming increasingly competitive. Finding time to meet the transparency goals of open science by preparing and publishing all aspects of the research process, let alone communicating their findings in a manner that makes them easy to understand, is proving challenging for many. It will be crucial for their institutions to support them in this process.

As we explored in the previous *Research futures report*, open science has helped to fuel a new generation of metrics, moving beyond the traditional citation counts to embrace alternative metrics. These 'altmetrics' map online activity around research outputs, from mentions on certain social media platforms, news outlets and blogs, to citations in clinical summaries and policy documents. Importantly, they also draw on other data such as usage and views. For researchers, that could be good news – an increasing number of studies suggest open access papers receive more views than articles published via the subscription route. [37] (See the "**How researchers work: change ahead"** essay). As we noted back in 2019, for many, altmetrics, and indeed traditional metrics, have yet to answer some of the key problems of measuring impact; for example, establishing whether attention is positive or negative; critical when an article has received that attention for the wrong reasons.

This proved to be the case with a preprint published on 2 February 2020, which claimed to show 'insertons' in the coronavirus' DNA that showed an "uncanny similarity" to regions found in HIV DNA." [19] Despite the authors withdrawing the work following criticism, by 19 February 2020, it was the most discussed study in online news and social media. [19]

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 some, these must include measures that incentivize researchers to perform activities that benefit science; for example publish and share their negative results. For others, the key will be finding ways to demonstrate 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 **Funding the future** essay).

Dealing with data

The definition of open data varies, ranging from figures to sound recordings, and primary sources to secondary sources. There are also varying levels of openness. As we've seen, whatever form it takes, for many it's a critical strand of the open science story and one that is increasingly being mandated by funders, publishers and journals. At the same time, new repositories and platforms are emerging to host and preserve it and increase its discoverability.

However, for some, one of the major roadblocks on the road to open data success is the incredible volume of data now being generated and shared. For those creating it, considerations include adding suitable metadata and making it usable; in fact, some funders now require grant applications to include a detailed data management plan.

For those accessing open data, there are challenges around locating, managing and manipulating it.

"Research data need to fit into a standardized format to be made public. In practice, data are messy. They need a 'free repository' in which all kinds of data in all kinds of structures can be stored and accessed."

Social Sciences, Belgium, aged 46-55

"In the age of the digital media, nothing can be hidden for long. The only issue may be that the sheer volume of information will drown specific instances."

Arts and Humanities, Israel, aged 46-55

Initiatives like the FAIR Guiding Principles for scientific data management and stewardship (Findability, Accessibility, Interoperability, and Reuse) are improving the quality of open data shared but concerns remain the scale of data being generated, and the technology required to interrogate it, (see our **Technology: revolution or evolution** essay).

Another hesitation for some of the researchers we surveyed for this report lies in ownership of the data once it has been openly shared, particularly given the hyper-competitive environment they are operating in.

"Having the research process fully open will increase the risk that research will be stolen by trolls, competing organizations, and colleagues."

Computer Science, US, aged 56-65

Data repositories such as Mendeley Data and Figshare now provide DOIs (digital object identifiers) for published data, which could help to allay some of these fears. However, for others, issues of ownership and openness are more pressing when corporate partners are involved.

"So much research is industry-funded and industry wants to make a profit, so not all stages of a process will ever be transparent."

Earth and Planetary Sciences, Australia, over 65

As with many other aspects of open science, for open data to truly take off it, incentivization may prove crucial, with the effort researchers invest in sharing it, recognized and rewarded. In our essay "**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.

References

1 cOAlition S – Plan S Principles. https://www.coalition-s.org/plan_s_principles/

2 Open access 2020 (OA2020). Executive Summary. n/d. https://oa2020.org/wp-content/uploads/pdfs/Open-Access-2020-Executive-Summary.pd

3 Hinchliffe, L. J. Transformative Agreements: A Primer. The Scholarly Kitchen. 23 April 2019. https://scholarlykitchen.sspnet.org/2019/04/23/transformative-agreements/

4 Timeline of open research at Springer Nature. Springer Nature. n/d. https://www.springernature.com/gp/open-research/about/timeline

5 Dutch research institutions and Elsevier reach framework agreement. VSNU. 19 December 2019. https://www.vsnu.nl/en_GB/news-items/nieuwsbericht/552-dutch-research-institutions-and-elsevier-reach-framework-agreement.html

6 Open Access Journals 11th April 2022 https://www.elsevier.com/open-access/open-access-journals

7 Springer.com. n/d https://www.springer.com/gp/open-accesshttps://www.springer.com/gp/open-access

8 Springer Nature continues to drive OA with launch of brand new OA journal series. Springer Nature Group. 23 June 2020. https://group.springernature.com/gb/group/media/press-releases/springer-nature-discover-journal/18109908

9 Wiley Announces the Acquisition of Hindawi. Businesswire. 5 January 2021. https://www.businesswire.com/news/home/20210105005201/en/Wiley-Announces-the-Acquisition-of-Hindawi

10 Maastricht University news. 26 October 2021. https://library.maastrichtuniversity.nl/news/new-open-access-journal-browser/

11 Banks M. Physics world.com 22 October 2021. https://physicsworld.com/a/celebrating-open-access-week-2021-new-environmental-open-access-journals/

12 STM Global Brief 2021 Economics and Market Size. October 2021. https://www.stm-assoc.org/2021_10_19_STM_Global_Brief_2021_Economics_and_Market_Size.pdf

13 Pollock, D. News & Views: Open access market sizing update 2020. Delta Think. 19 October 2020. https://deltathink.com/news-views-open-access-market-sizing-update-2020/

14 INFO – Price G. Delta Think Shares New Open Access Journals Market Data. 19 October 2021. https://www.infodocket.com/2021/10/19/delta-think-shares-new-open-access-journals-market-data/

15 Zubascu F. Science Business. 7 September 2021. https://sciencebusiness.net/news/81-horizon-2020-papers-were-published-open-access

16 RORI: Waltman L et al. Research on Research Institute. Scholarly Communication in Times of Crisis: The response of the scholarly communication system to the COVID-19 pandemic. December 2021.https://rori.figshare.com/articles/report/Scholarly_communication_in_times_of_crisis_The_response_of_the_scholarly_communication_system_to_the_COVID-19_pandemic/17125394

17 Kiley, R. Three lessons COVID-19 has taught us about Open Access publishing. LSE. 6 October 2020. https://blogs.lse.ac.uk/impactofsocialsciences/2020/10/06/39677/

18 Publishing industry response to COVID-19. Publishers Association. n/d. https://www.publishers.org.uk/covid-19-publishing-industry-response/

19 Xu, X. The Conversation.com 24 February 2020. https://theconversation.com/the-hunt-for-a-coronavirus-cure-is-showing-how-science-can-change-for-the-better-132130

19A.Editorial. Nature.com 4 February 2020 https://www.nature.com/articles/d41586-020-00307-x

20 COVID-19 Open Research Dataset Challenge (CORD-19): An AI challenge with AI2, CZI, MSR, Georgetown, NIH & The White House. Kaggle. Accessed 6 January 2020. https://www.kaggle.com/allen-institute-for-ai/CORD-19-research-challenge

21 Kadakia K. et al. Leveraging Open Science to Accelerate Research. The New England Journal of Medicine. 29 April 2021. https://www.nejm.org/doi/full/10.1056/NEJMp2034518https://www.nejm.org/doi/full/10.1056/NEJMp2034518

22 NWO (Dutch Research Council) report 2020. June 2021. https://www.nwo.nl/sites/nwo/files/media-files/Annual%20report_2020_11-10-2021.pdf

23 OECD Science, Technology and Innovation Outlook 2021: Times of Crisis and Opportunity, OECD Publishing. 2021. https://doi.org/10.1787/75f79015-en

24 UNESCO, WHO and the UN High Commissioner for Human Rights call for "open science". UNESCO. 27 October 2020. https://en.unesco.org/news/unesco-who-and-high-commissioner-human-rights-call-open-science

25 Wolfram, D. et al. Open peer review: promoting transparency in open science. Scientometrics 125, 1033–1051. 2020. https://doi.org/10.1007/s11192-020-03488-4

26 European Data Portal. 02 June 2020. https://www.europeandataportal.eu/en/news/rise-ai-and-open-data

27 Coronavirus Discovery resource. Coronavirus canSAR. n/d. https://corona.cansar.icr.ac.uk/

28 openVirus. GitHub. Last update 7 November 2020. https://github.com/petermr/openVirus/blob/master/README.md

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

30 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

30A Research futures: Drivers and scenarios for the next decade. Elsevier. February 2019. https://www.elsevier.com/connect/elsevier-research-futures-report

31 Bramstedt, K. A. The carnage of substandard research during the COVID-19 pandemic: a call for quality. Journal of Medical Ethics 46:803-807. 2020. https://jme.bmj.com/content/46/12/803.abstract

32 Dinis-Oliveira, R. J. COVID-19 research: pandemic versus "paperdemic", integrity, values and risks of the "speed science". Forensic Sciences Research, 5:2, 174-187. 2020. DOI: 10.1080/20961790.2020.1767754

https://www.tandfonline.com/doi/full/10.1080/20961790.2020.1767754

33 ENRIO Statement: Research integrity even more important for research during a pandemic. n/d. http://www.enrio.eu/enrio-statement-research-integrity-even-more-important-for-research-during-a-pandemic/

34 Huang E. 9 May 2017. Quartz.com https://qz.com/978037/china-publishes-more-science-research-with-fabricated-peer-review-than-everyone-else-put-together/

35 Else, H. China's clampdown on fake-paper factories picks up speed. Nature. 1 October 2021. https://www.nature.com/articles/d41586-021-02587-3

36 De Vrieze, Jop. Science.org. 21 July 2021. https://www.science.org/content/article/landmark-research-integrity-survey-finds-questionable-practices-are-surprisingly-common

37 Piwowar, H., Priem, J. & Orr, R. The Future of OA: A large-scale analysis projecting Open Access publication and readership. bioRxiv 795310. 9 October 2019. https://doi.org/10.1101/795310

38 Ec.europa.eu. European Commission. n/d. https://ec.europa.eu/info/research-and-innovation/strategy/goals-research-and-innovation-policy/open-science_en

39 European Commission. 20 March 2020. https://ec.europa.eu/info/news/european-commission-awards-contract-setting-open-access-publishing-platform-2020-mar-20_en

40 https://www.science.org/content/article/biden-s-new-science-adviser-shares-views-foreign-influence-research-budgets-and-more

41 Kaiser, J. In departure for NIH, Cancer Moonshot requires grantees to make papers immediately free. Science. 14 August 2019. https://www.sciencemag.org/news/2019/08/departure-nih-cancer-moonshot-requires-grantees-make-papers-immediately-free

42A Open Access in China: Interview with Xiaolin Zhang of the National Science Library. International Science Council. 25 February 2019. https://council.science/current/blog/open-access-in-china-interview-with-xiaolin-zhang-of-the-national-science-library/

42B China 'pursuing national open science strategy'. Researchinformation.info 3 June 2021. https://www.researchinformation.info/news/china-pursuing-national-open-science-strategy

42 McGinley, L. Biden unveils launch of major, open-access database to advance cancer research. The Washington Post. 6 June 2016. https://www.washingtonpost.com/national/health-science/biden-to-unveil-launch-of-major-open-access-database-to-advance-cancer-research/2016/06/05/8918c442-2b30-11e6-9de3-6e6e7a14000c_story.html

43 Tao, T. New Chinese Policy Could Reshape Global STM Publishing. The Scholarly Kitchen. 27 February 2020. https://scholarlykitchen.sspnet.org/2020/02/27/new-chinese-policy-could-reshape-global-stm-publishing/

44 Mallapatty S. Nature.com 30 September 2020. India pushes bold 'one nation, one subscription' journal-access plan https://www.nature.com/articles/d41586-020-02708-4

45 Open Science. UNESCO. n/d. https://en.unesco.org/science-sustainable-future/open-science/

46 First draft of the UNESCO Recommendation on Open Science. UNESCO. 2020. https://unesdoc.unesco.org/ark:/48223/pf0000374837

47 Saenen, B. European University Association. 19 October 2020.

https://eua.eu/resources/expert-voices/196-shifting-global-opportunities-and-challenges-for-the-transition-to-open-science.html

48 Registry of Open Access Repositories (ROAR). Accessed 7 January 2021. http://roar.eprints.org/

49 Digital Commons White Paper: Accelerating online support for students and researchers. January 2021. https://www.elsevier.com/solutions/digital-commons/essential-ir/more-essential-ir-resources

50 Thaney, K. & Goudarzi, S. Future of Open Scholarship project: Preliminary Findings. Invest in Open Infrastructure. Interviews conducted 29 June to 24 August 2020. https://docs.google.com/document/d/1IOOWFOT7_Il117wY4WuT5f3E-jcZiB3Q2IijhZ26iQ4/edit#

51 Independent report and transformative agreement toolkit launched to support Learned Society publishers transition to immediate Open Access and align with Plan S. Information Power. 12 September 2019. https://www.informationpower.co.uk/press-release-spaops-report-toolkit

52 Spichtinger, D. Not yet the default setting – in 2020 open research remains a work in progress. LSE. 17 January 2020. https://blogs.lse.ac.uk/impactofsocialsciences/2020/01/17/not-yet-the-default-setting-in-2020-open-research-remains-a-work-in-progress/

53 What is DORA? DORA website. n/d. https://sfdora.org/ The rise of AI and open data.

54 How does DORA fit with Plan S? cOAlition S. n/d. https://www.coalition-s.org/faq/how-does-dora-fit-with-plan-s/

55 Quan, W., Chen, B. and Shu, F. Publish or impoverish: An investigation of the monetary reward system of science in China (1999-2016). Aslib Journal of Information Management, Vol. 69 No. 5, pp. 486-502. (2017). https://doi.org/10.1108/AJIM-01-2017-0014

How researchers work: change ahead

A quick glance back...

In our original report, we identified three key areas of change – these are featured in the blue boxes below. Each of these is accompanied by a bulleted breakdown of the shifts we anticipated would occur as that change unfolded.

Taken from ***Research futures 2019***

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 idea-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 hypercompetitive 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 challenges, especially as older and 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 hypercompetitive future.

Now, three years into the 10-year window and with COVID-19 impacting every element of our lives, how are those predictions standing up?

We have used a traffic light system to give an indication: red for no progress, amber for some progress, and green for a reasonable amount of progress.

Read the original **"How researchers work: change ahead"** essay in *Research futures*
www.elsevier.com/research-intelligence/resource-library/research-futures

The current situation

Key findings

- The pandemic affected work-life balance for most researchers, but women (62 percent) more than men (50 percent).
- Researchers are collaborating markedly more than before the pandemic (63 percent agree), with interdisciplinary collaboration still the most prevalent form.
- Higher levels of competition between countries are showing signs of affecting academic collaboration.
- The unprecedented volume of new data sparked by the pandemic has increased the urgency for researchers to develop data-related skills.
- The pandemic has increased future expectations of more collaboration across different disciplines,with women's expectations notably higher (60 percent) than men's (51 percent).
- The need for speed has boosted researchers' use of technology, including AI, and supported the growth of preprints.
- COVID-19 has exacerbated job insecurities for younger researchers, which may accelerate the rate at which they leave academia.
- Border closures and travel bans changed the nature of events and conferences. These changes are likely to outlive the pandemic. Future conferences are likely to blend virtual and in-person events.
- There will be a greater emphasis on the societal impact of research going forward. Overall 54 percent think there will be more focus, this is higher among women (62 percent) than men (52 percent).
- Researcher mobility is increasing; more researchers are willing to relocate to another country than before the pandemic (27% in 2019 versus 34% in 2021).

When we sat down with experts and researchers in 2019 for our original study, we had already envisaged the possibility of a pandemic. In our Brave Open World scenario, we predicted international collaboration would work to end it, and that the rapid growth of preprints would speed up the process. However, none of us fully anticipated the level of global disruption that COVID-19 would bring when it appeared in December 2019, or its power to disrupt every aspect of the researcher workflow.

Two years later, we can see that many of the indicators that drive our Tech Titans scenario are also coming to pass: in particular the acceleration of AI and the rise of big data are increasingly changing how researchers work. Pressure on younger researchers has grown, and they are increasingly developing the data skills most in demand from large tech companies. Collaboration across disciplines continues to increase, while geopolitical tensions are showing signs of impacting the growth of collaboration across borders. As we discuss further in this essay, the war in Ukraine has implications for the future of researchers' work and projects, though many aspects of the situation remain fluid at present.

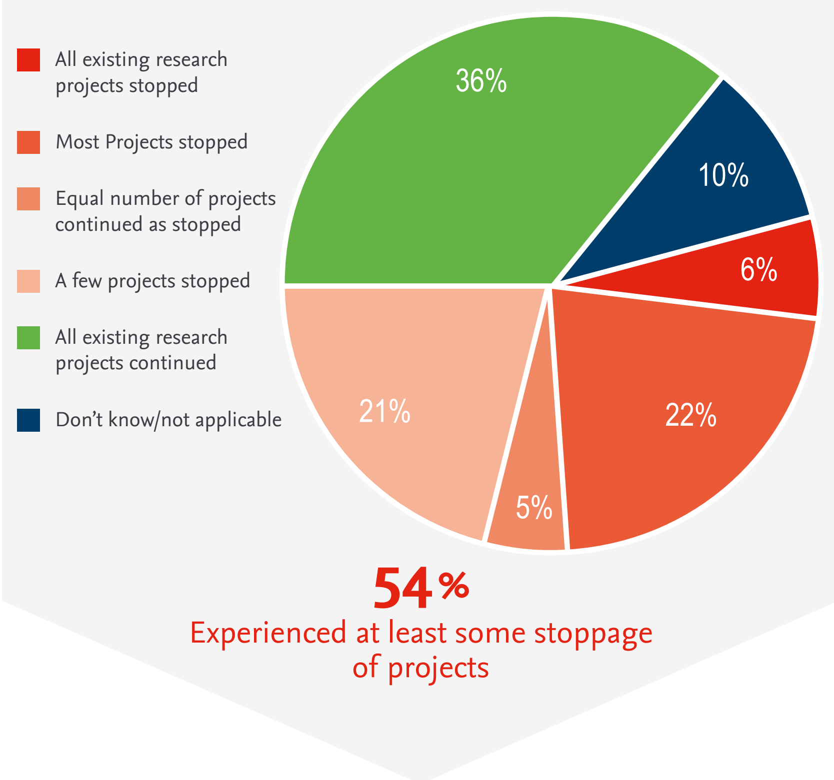
Long before the pandemic, researchers found themselves operating in an increasingly hypercompetitive environment. As we noted in our original report, they were juggling tasks such as applying for funding, competing for laboratory resources, balancing research activities with teaching, and attempting to be the first to uncover new findings. Then there were the challenges of getting published, seen and read, while trying to advance in their careers (or simply secure a permanent position). [1] The pandemic has added to the burden on researchers while also changing the way they work, with notable increases in levels of collaboration and the use of technology.

Disruptions to research and resources

When we conducted the survey for this study in July and August 2021, cases of COVID-19 were continuing to rise around the globe. At the time of going to press in 2022, the global death toll had surpassed 6 million and the number of confirmed cases worldwide was more than 497 million. [2]

Efforts to curtail the pandemic had a direct impact on researchers' ability to do their work. Of the researchers we surveyed in summer 2020, 54 percent had seen work on at least some of their projects grind to a halt. These interruptions were largely related to logistical reasons, such as closure of their institution (50 percent) or inability to travel to work (36 percent).

Research experience during the pandemic.
To what extent have you experienced the following since the start of the COVID-19 pandemic?



Why did all/some of your research projects stop

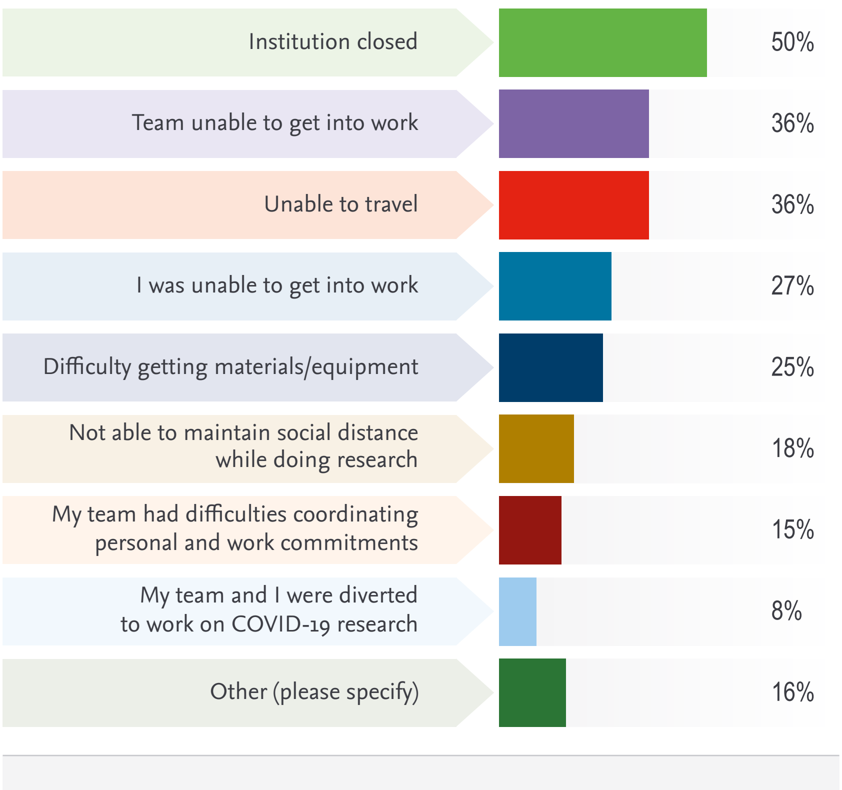


Figure 21: *Question: "To what extent have you experienced the following since the start of the COVID-19 pandemic? Base =1,066 Question: "Why did all/some of your research projects stop? Base researchers that experienced stoppage=573. Source: Researcher survey 2020.*

At that stage in mid-2020, many countries had experienced a lockdown, although others, especially in APAC, had not. We explore the impact of these measures on national economies and R&D funding in our **"Funding the future"** essay in this report.

The impact upon respondents from fields that require access to labs and heavy equipment were more likely than the global average (54 percent) to have had projects postponed or cancelled. For example, Materials Scientists (73 percent), Life Scientists (64 percent), and particularly those working in Medicine and Health (76 percent)—a field which saw researchers, practitioners and resources diverted to combat the virus. Subjects where the bulk of the work can be completed behind a computer terminal, making it easier to work from home or observe social distancing—for example, Math (27 percent) and Computer Science (38 percent)—were less likely to be affected, although our results show no discipline escaped unscathed.

Research experience during the pandemic

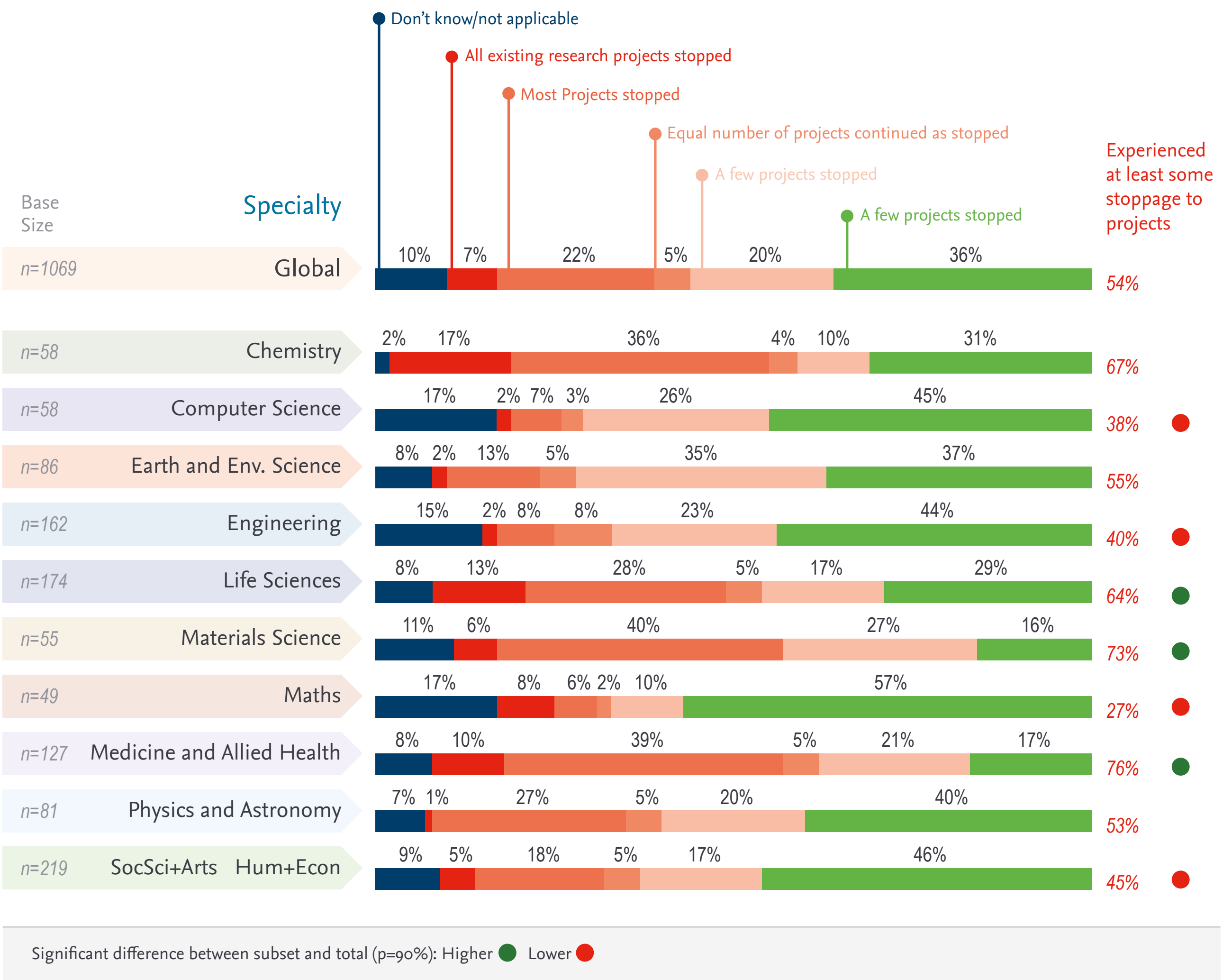


Figure 22: *Question: "To what extent have you experienced the following since the start of the COVID-19 pandemic?"*
Source: Researcher survey 2020. Base =1,066.

More research projects stopped in developing regions such as Africa (78 percent) and Latin America (70 percent); Eastern and Western Europe were less affected (44 percent and 54 percent, respectively). This may be related to the difficulties many workers in developing countries face when trying to work from home, such as lack of access to broadband internet or a personal computer, although researchers and other highly educated workers are at less of a disadvantage than other workers. [3] If we look at the general impact of COVID-19 by region, there are some striking variations. Latin America was hard hit generally, not only in terms of disrupted projects, but by institution closures (71 percent), teams unable to get into work (54 percent) and difficulty accessing materials and equipment (39 percent). Our survey results from mid-2020 show that researchers working in Eastern European countries faced many of the same challenges as their Latin American counterparts, including high numbers of institution closures (71 percent in both regions).
In contrast to developing countries, our research shows that those working in North America and Western Europe were less likely than average to experience problems sourcing materials and equipment. There were also fewer reports of difficulties getting into work.

Research experience during the pandemic, why projects stopped by region.
Why did all/some of your research project stop?

Figure 23: *Question: "Why did all/some of your research projects stop?" Source: Researcher survey 2020. Base=573.*

In a global survey of more than 25,000 members of the academic community conducted in May/June 2020, open access publisher Frontiers found that the working processes of only 10 percent of researchers were unaffected by the pandemic. One major impact on projects was the decision by many institutions to shift research teams and labs to studies (or testing) for COVID-19. [4]

However, just as with R&D funding (see "**Funding the Future**" essay), some in the research community have expressed concerns about the potential long-term impact that this increased focus on pandemic-related activities might have on other research areas. [4]

Digging deeper into the demographics

As we explored in our original report, a diverse and inclusive research community is a healthy one. It's also crucial if we want to reflect the society that research serves and operates in; for example, studies have long reported on the dangers of a lack of diversity in clinical trials. For many, a more inclusive approach simply leads to higher-quality research. [5]

Unequal impacts

In our previous report, we also touched upon the existing lack of job security for researchers. Many, including both early- and mid-career researchers, face years of 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 skills and experience that would help them secure a permanent role. There were already clear signs that pressure on researcher roles would continue to rise in the years ahead, with funding shortages, senior staff remaining in roles longer, a growing researcher population, and tasks being taken over by tech all adding to the mix. As one Canadian funder observed: "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." [1]

Equality and job security in research remain elusive, and studies suggest that the pandemic is exacerbating existing issues for women researchers as well as younger researchers. In our latest survey for this report, for example, 62 percent of female researchers reported finding it difficult to achieve a work-life balance during the pandemic, versus 50 percent of male researchers (see figure 26).

A survey conducted by *Nature* in April 2020 found that time devoted to research suffered more impact than other areas of scientific work, such as fundraising and teaching. The time spent on research by all respondents fell by 24 percent during those early days of the pandemic. For women, the impact was greater: the survey found that female scientists, and in particular those with young children, reported the greatest impact on the time they could devote to research. When all other circumstances were equal, such as grade and availability of research facilities, female scientists reported a 5 percent decrease in the time they could spend on research. For female researchers with at least one child aged five or younger, the loss of research time rose to 17 percent. "Our survey results overall indicate that at least some of the gender discrepancy can be attributed to female scientists being more likely to have young children as dependents," the report finds. [6]

A study of the impact of the first lockdown in the Netherlands, which took place from March to June 2020, found that at Dutch universities, women researchers with young children faced the biggest problems in trying to reconcile work and childcare responsibilities. These researchers also reported the highest stress levels of any group about their research progress and their career future. Compared to male researchers with young children, female researchers tended to be at an earlier stage in their careers and were more likely to have a temporary work contract. [7]

Research experience during the pandemic - views

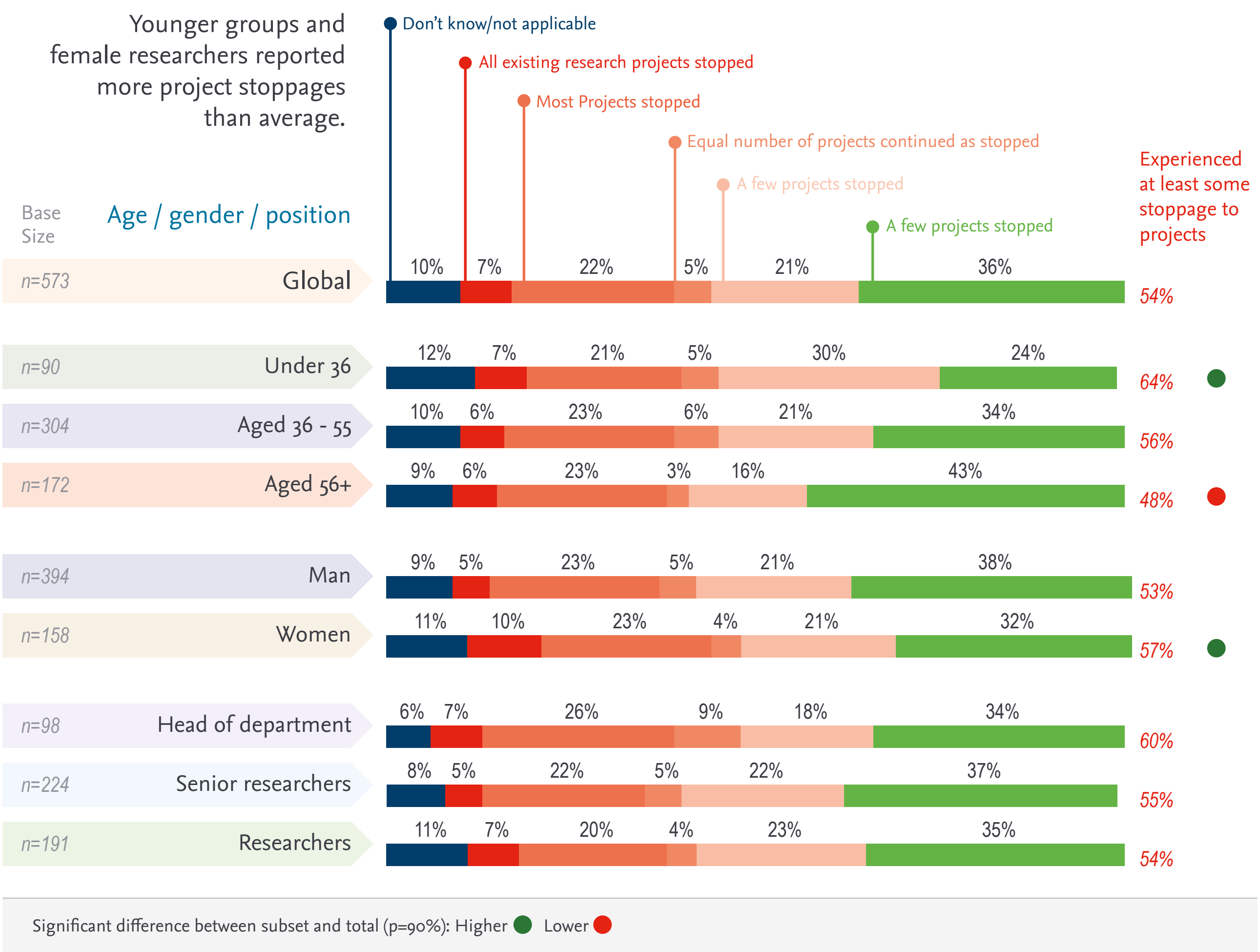


Figure 24: *Question: "To what extent have you experienced the following since the start of the COVID-19 pandemic?"*

Source: Researcher survey 2020. Base=573.

In our 2020 researcher survey for this report, female researchers (57 percent) and those aged 36 years and under (64 percent) reported a higher rate of project stoppages than the global average of 54 percent, while researchers aged 56 years and over were the least impacted (48 percent), perhaps due to being more established in their careers. Although we do not have a chart showing the reasons why research projects stopped in this report, we observed that younger researchers were also disproportionately impacted by challenges around getting into work and accessing materials and equipment.

A November 2020 report by SpringerNature also found that early career researchers were among those disproportionately impacted by the pandemic. [8] In addition, the report noted that the undermining of the career prospects and financial stability of many researchers may result in "a reduction in the talent pool, with a lasting impact on future research production." [8]

Findings like these suggest that our 2019 prediction about early career researchers will prove true – it is likely that the number of young researchers leaving academic research will only accelerate as they seek job security/ opportunities elsewhere; particularly among research-focused tech companies, which have been actively recruiting from academia. These younger researchers are likely to be ideal candidates: in our most recent survey, younger researchers – those aged under 36—are significantly more likely than other age groups to be heavy users of AI in their research, making them a good match for tech companies seeking these skills. Almost double the proportion of female researchers are using AI extensively in their own research compared to a year ago, rising from 7 percent to 13 percent. We explore the use of AI in research further in our **"Technology: evolution or revolution"** essay in this report.

Proportion using artificial intelligence extensively in research

Response on a five-point scale where 5 is extensively and 1 is not at all. % using AI (4 or 5)

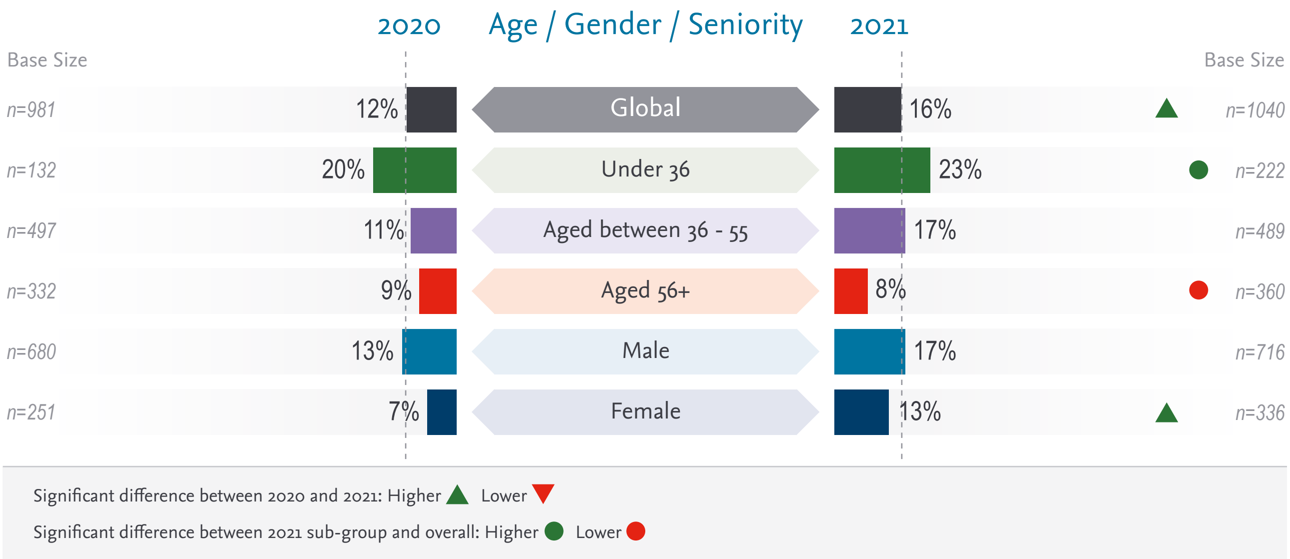


***Figure 25**: Question: To what extent do you use Artificial Intelligence (AI) in your research? Please indicate your response on a five-point scale where 5 is extensively and 1 is not at all. Source: Researcher survey 2021. Base =1173.*

Moves are underway to combat this brain drain. In the USA, Congress is being asked to consider the Supporting Early-Career Researchers Act, which aims to "to forestall the loss of research talent by establishing a temporary early career research fellowship program." [9] Individual universities are also taking steps – introducing tenure and promotion clock extensions for younger researchers. [4]

Several studies and industry commentators have zeroed in on the effect of the pandemic on female researchers in particular, with one describing it as an "existential threat" to gender equality in academia. [10] Another found that the pandemic has created a cumulative advantage for men, with women submitting proportionally fewer manuscripts during the COVID-19 lockdown months. [11] A *Nature* study of Elsevier journals established that this disparity in submissions proved true whatever the discipline or career stage. [12]

According to Megan Frederickson, Associate Professor of Ecology and Evolutionary Biology at Canada's University of Toronto, it is crucial that universities take into account the pandemic's gendered effects on research when making key decisions, for example, around hiring, tenure, promotion and merit pay. [13]

It's a sentiment echoed by the authors of a study involving principal investigators (i.e., named leads on externally funded research grants). Their findings suggest that female scientists, those in the "bench sciences" (i.e., scientists who do experiments in a laboratory) and, especially, scientists with young children, experienced a substantial decline in time devoted to research. "This could have important short- and longer-term effects on their careers, which institution leaders and funders need to address carefully."[14]

Yet, as the World Economic Forum 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 wellbeing of both businesses and countries". [15]

The pandemic has also, not surprisingly, affected researchers' mental health as well as their future work plans. A US study found that the rate of major depression among postgraduate students has more than doubled during the pandemic, with doctoral researchers displaying the highest rates of major depressive disorder (43 percent) and generalized anxiety disorder (36 percent). "Both disorders were more common among women, caregivers, students of color, non-binary and LGBTQ students, and those from a low-income background." [16]

In our own survey results, we found that gender differences are also apparent in researchers' thinking about the impact of COVID-19. Overall, 54 percent of researchers found ensuring they have a good work-life balance has been difficult during pandemic, but women were more likely to agree at 62 percent, versus 50 percent for men.

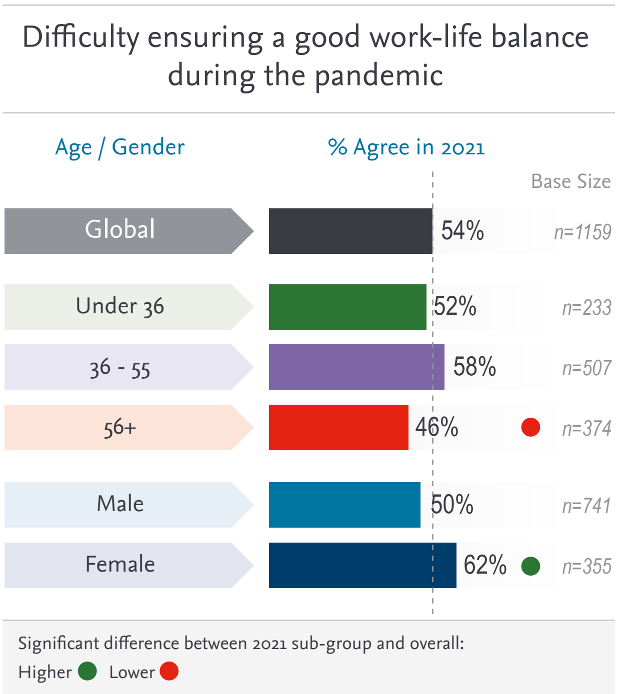


***Figure 26**: Question: "To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: Ensuring I have a good work-life balance has been difficult during Covid. Source: Researcher survey 2021. Base=1159. Chart excludes "don't know" answers.*

Of the 26 percent that disagreed that finding a good work-life balance has been difficult, some said working from home allowed them to adopt flexible working, and the lack of need to commute left them with more time. For others, working at home allowed more choice of when to focus on work or family.

The rise of collaborative research

In our previous report, we explored the growing influence of collaborative science, with increasing numbers of institutions either joining forces with counterparts in other areas of the country, seeking international partners, forging new bonds with industry, or blurring traditional disciplinary borders in the form of interdisciplinary and multidisciplinary research.

At that stage, collaborative research was clearly on the rise. Since the onset of COVID-19, the appetite for these partnerships has increased strongly. In 2021, 63 percent of researchers agree that there is now more collaboration on their projects than previously, a rise from 48 percent in 2020 (see figure 12 in the essay **"Pathways to open science"**). The increase in collaboration is being pushed by the ease of collaborating across borders, the nature of the research, encouragement or requirements of funders, and the accessibility of online communication methods.

The impact of funding on collaboration

As we've seen, collaboration can take many forms, including cross-institution, cross-border and academic/corporate. The first COVID-19 vaccine to receive approval in the UK was the result of a collaboration between corporate and corporate – Pfizer and BioNTech. Funders, policy makers, institutions and others cite the benefits, including an increased funding pot and spread of funding risk, and an opportunity to pool knowledge, accelerate progress and increase citation impact: the list goes on… With the scale of global challenges we now face, many also view these forms of cooperation as our best hope of finding solutions. Large-scale collaborations also make good sense financially in some fields, given the technology and equipment required to conduct science and handle the large volumes of data generated. Mega-science projects such as the Square Kilometre Array (SKA) and the Large Hadron Collider (LHC) are only possible to fund and maintain due to the large numbers of countries involved.

Scenario Match

The growing trend of collaboration is a driver of our **Brave Open World** scenario, which envisages greater demand for cross-disciplinary work.

New funding requirements are one of the reasons for the increase in collaboration. In our most recent survey in 2021, of the researchers who said there were more funding requirements compared to two to three years ago, evidence of both interdisciplinary collaboration (39 percent) and international collaboration (31 percent) were among the most common new requirements for funding. Evidence of interdisciplinary collaboration is most likely to be required in Medicine (50 percent) and international collaboration is most likely to be required in Earth & Environmental Science (45 percent). (See figures 7 and 8 in the **"Funding the future"** essay).

In terms of growing collaboration, in some cases COVID-19 has proven to be a force for good, by transcending political differences and speeding up discovery. Collaborations to better understand the coronavirus and to find a vaccine have generated "scientific research collaboration at levels that have never before been seen," conducted at a far more rapid pace than is the norm. [4] This is one way the pandemic has accelerated a move towards a more open and connected research ecosystem – another driver of our Brave Open World scenario. For some, one of the benefits of the virus is that it has created a "growing sense of mission taking priority over individual credit, and the spreading realization of ways in which one field can benefit another."[17]

"There will be much less room for individualism, and more emphasis of functioning as part of a large research team."

Neuroscience, USA, aged 26-35

Digging deeper into collaboration issues

While, generally, the will to collaborate remains strong among researchers, there have been some subtle changes in collaboration since the pandemic, according to a *Times Higher Education (THE)* article, which analyzed three recent studies on the topic. [18] Although research ties between the USA and China strengthened in recent years, the Scopus database of indexed research shows that the increase in USA-China publications slowed markedly in 2020 and may have fallen in 2021, although not all research for the year had been indexed by early 2022. According to *THE*, the share of research from mainland China that showed any international collaboration also appears to be levelling off. [18] This collaboration grew from about 14 percent in 2010 to 23 percent in 2018, remaining at this level until 2020. Current data for 2021 shows an international collaboration level of 22 percent. Changes in the relationship between the two countries as well as travel restrictions limiting contact were mentioned as possible reasons for the slowing increase in collaboration. [18] These changes may also be related to increased competition between countries, which we noted in our original report and which is a driver of our Brave Open World scenario. These findings will ring true for Prof David Bogle, Pro-Vice-Provost of the Doctoral School at University College London, who has found that at his university, "existing international collaborations are working well, but new ones are perhaps not being developed and developing world collaborations have been hit hardest." [19]

Scenario Match

In our **Brave Open World** scenario, we anticipated that rising tensions between competing countries would impact academic collaboration

War in Ukraine

Russia's invasion of Ukraine in February 2022 has had an immediate impact on the way nation states, and in turn researchers, work and will likely have lasting consequences.

On 4 March 2022, the European Commission announced an end to cooperation with Russia in research, science and innovation, and will not make any new contracts or agreements with Russia in the framework of Horizon Europe. [20] In mid-March, the European Space Agency suspended its planned launch of the ExoMars Rover, Europe's first planetary rover – a collaboration between the ESA and the Russian space agency, Roscosmos. [21, 22] Following a request from Ukranian scientists, the member states of CERN—the Geneva-based European nuclear research body—suspended Russia's observer status and all collaboration with Russia. [23]

The Alliance of Science Organisations in Germany, a group of Germany's largest research funders, which includes the German Research Foundation, froze all scientific cooperation with Russia. Denmark announced an end to cooperation on research and innovation with institutions in Russia and Belarus, [24] as did Sweden. [25]

On 25 February, the Massachusetts Institute of Technology in the USA announced the end of its relationship with the Skolkovo Foundation, a Moscow-based non-profit organization that focuses on innovation. [26]

The speed and scale of the severing of these collaborations has been a concern for many. In an open letter published in in the journal *Science*, several professors from renowned universities including Harvard have called on "science and technology communities to avoid shunning all Russian scientists for the actions of the Russian government." They believe severing ties "would be a serious setback to a variety of Western and global interests and values." [27]

A closer look at collaboration

While the situation in Ukraine remains fluid and its longer-term impact unclear, we know from our study that collaboration has been on the rise. Most disciplines report an increase in collaboration levels compared to 2020. Researchers in Computer Science have seen the biggest rise in collaboration, with 76 percent agreeing that there is more collaboration involved in their projects than previously, a substantial increase compared to the 41 percent who agreed in 2020.

Collaboration in Medicine has also risen, with 70 percent reporting an increase up from 53 percent a year ago. An increase in working with other researchers in their own department is the primary reason for the rise year-on-year. Of those who experienced an increase in collaboration, the proportion who attribute this to working with other institutions abroad has fallen substantially, from 73 percent in 2020 to 42 percent in 2021. Similarly, fewer are attributing the rise to working with other institutions in their home country, at 57 percent in 2021 compared to 73 percent in 2020.

As we found in our survey last year, interdisciplinary research remains the most common form of increased collaboration (62 percent agree). Several studies suggest that COVID-19 has accelerated the growth of interdisciplinary research,largely because of the complexity of the issue and its impact on so many aspects of our daily lives, from physical and mental health, to economics and tourism. [28, 29, 30]

Proportions that believe collaboration has increased and ways it has increased - view by specialty

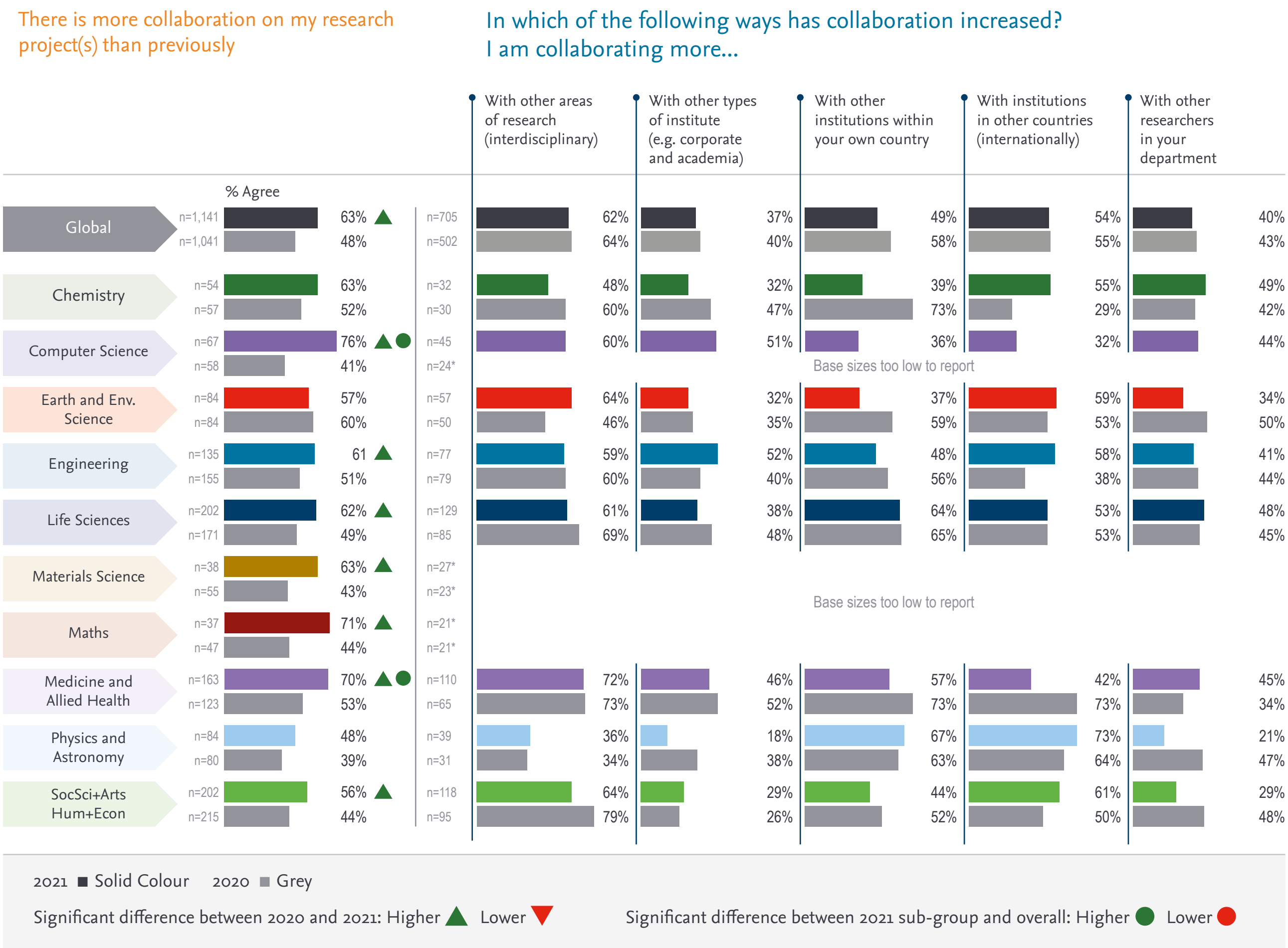


Figure 27: Question: "To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: 'There is more collaboration on my research project(s) than previously.' Source: Researcher survey 2021 base=1,141 and researcher survey 2020 base=1,041.

All regions reported an increase in collaboration levels in 2021, i.e., more agree there has been an increase in collaboration than disagree, and mostly more strongly than last year, except for those in Latin America. APAC has seen a large rise in those reporting an increase in collaboration levels, up 19 percent on 2020. No one collaboration type stands out as the driver of this year-on-year rise.

Proportions that believe collaboration has increased and ways it has increased - view by region

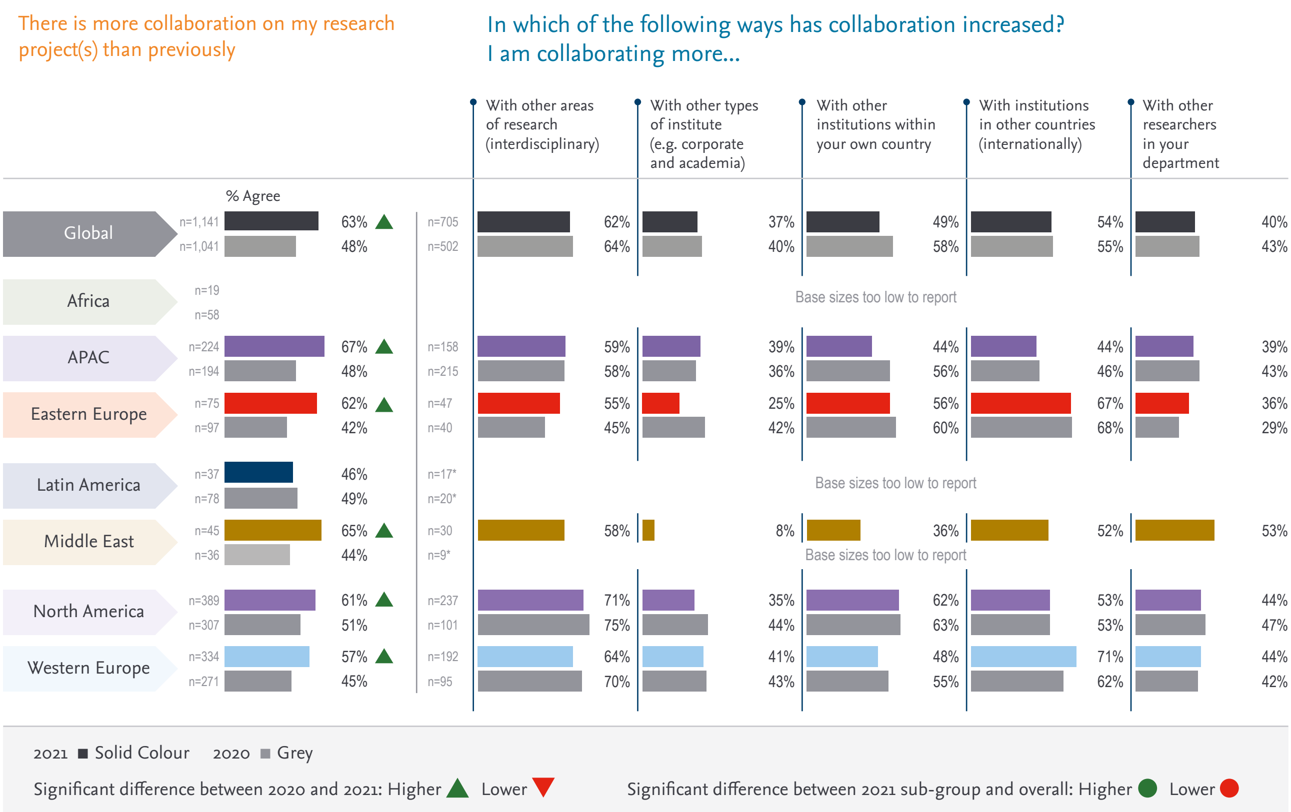


***Figure 28**: Question: "To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: 'There is more collaboration on my research project(s) than previously.' Source: Researcher survey 2021 base=1,141 and researcher survey 2020 base=1,041.*

> *"The trend towards consortiums and program grants will continue. Conditions for public data availability will become more stringent. Perhaps even methods will have to be published in advance for public comment/peer review. This process will increase efficiency and pace of research, but will increase the gap between small research labs at smaller institutions."*
>
> Neuroscience, US, aged 26-35

> *"...research study [is] more sophisticated, involving experts of more disciplines working together."*
>
> Pharmacology, Italy, aged 65+

We also looked at collaboration through the lens of age, gender and seniority. Younger researchers (75 percent) and heads of department (70 percent) are the most likely to report increased levels of collaboration. That is a jump compared to 2020, when only half (52 percent) of researchers in both categories agreed. Younger researchers show the biggest rise in those citing interdisciplinary work as the cause, at 65 percent, up from 50 percent in 2020. For heads of department,, interdisciplinary work is also the biggest growth area, but those citing collaboration with institutions in other countries as the cause of their increased collaboration has fallen notably to 47 percent in 2021, from 71 percent a year earlier.

Both men and women report similar growth in levels of collaboration compared to last year: 62 percent of men this year report more collaboration compared to 47 percent in 2020, while 65 percent of women report it in 2021, up from 51 percent a year earlier.

Proportions that believe collaboration has increased and ways it has increased - view by age, gender and position

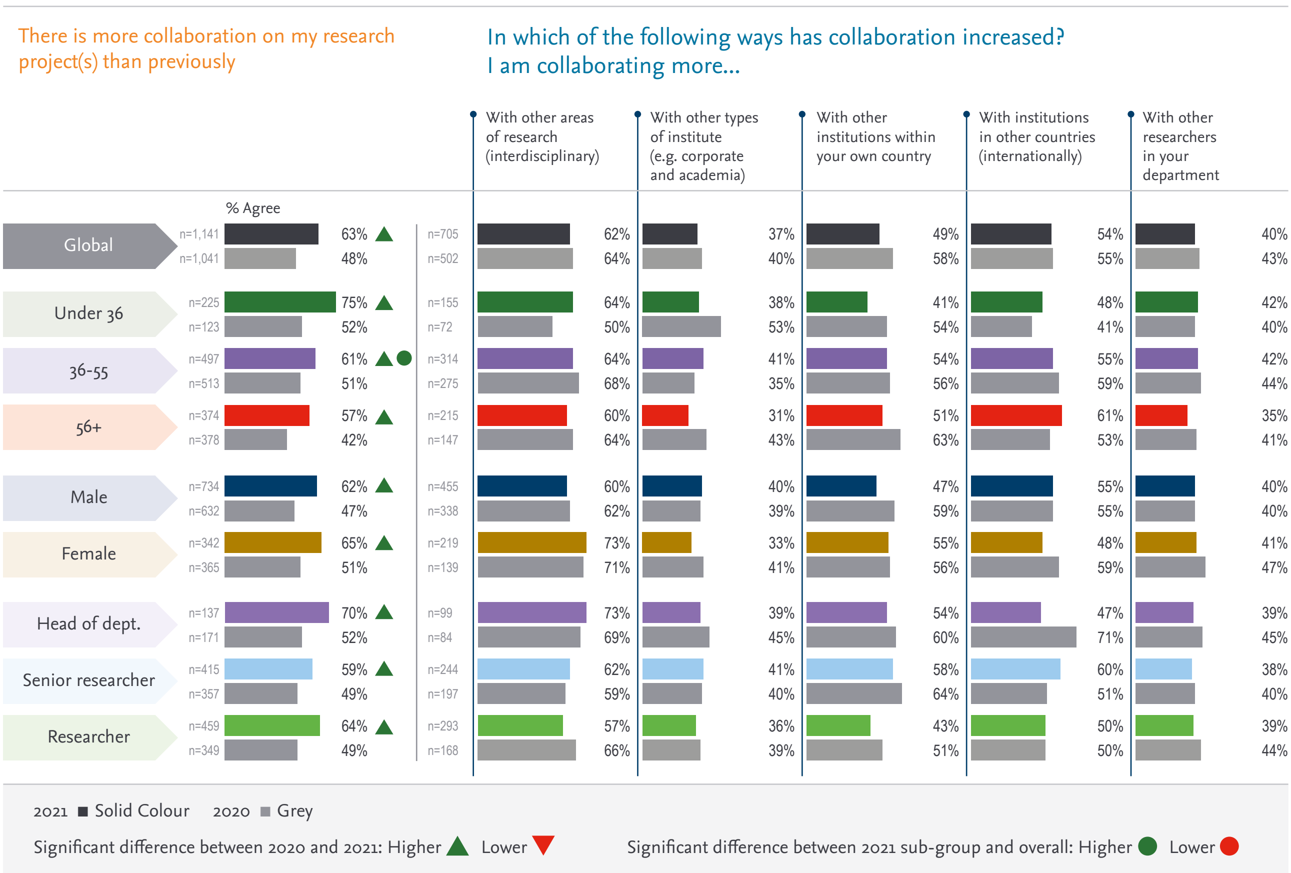


Figure 29: *Question: "To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: 'There is more collaboration on my research project(s) than previously.' Source: Researcher survey 2021 base=1,141 and researcher survey 2020 base=1,041.*

The protracted duration of the pandemic and its heavy impact on travel has undoubtedly impacted collaboration opportunities. The pandemic has now entered its third year, far longer than many anticipated at the onset. It has had a heavy toll on airlines and travel as countries open and close their borders and impose different entry restrictions, making travel difficult to plan.

In the case of corporate/academia collaborations, some researchers believe that companies' concern over their economic future is holding them back from forming new partnerships.

"The industry does not know where they will be in one year. So they stopped the collaboration with scientists."

Medicine, Germany, aged 46-55

Technology and online activity

In our previous report, we looked at how advances taking place in technology were proving to be a researcher's closest ally in their quest to get ahead in the increasingly competitive landscape. We looked at some of the many tools and platforms they were using to support their workflow from conducting research to reading, writing, collaborating and communicating. We discussed their desire for these tools to display many of the characteristics they experience in other sectors – integration; vendor neutrality; intuition; easy, quick and timely discovery; and personalization.

This trend has continued, with one of the most visible impacts of COVID-19 being the growth of online activity. All types of online activity increased during the pandemic. Our research shows that the use of sharing sites and apps has increased most significantly, with 46 percent saying their usage has increased since the pandemic started.

Use of social media and academic community platforms also increased substantially, with 42 percent and 38 percent of researchers, respectively, saying that they use them more often than before the pandemic. When we examine by specialty we see that those working in Medicine were most likely to have increased their use of publisher websites and government portals than other disciplines, at 47 percent and 39 percent, respectively. Computer Science (58 percent) and Physics and Astronomy (51 percent) researchers showed the highest increased usage of sharing sites. (Please note, a chart showing results by specialty is available in the accompanying "Full data analyses of research results".)

Impact of COVID-19 on use of platforms

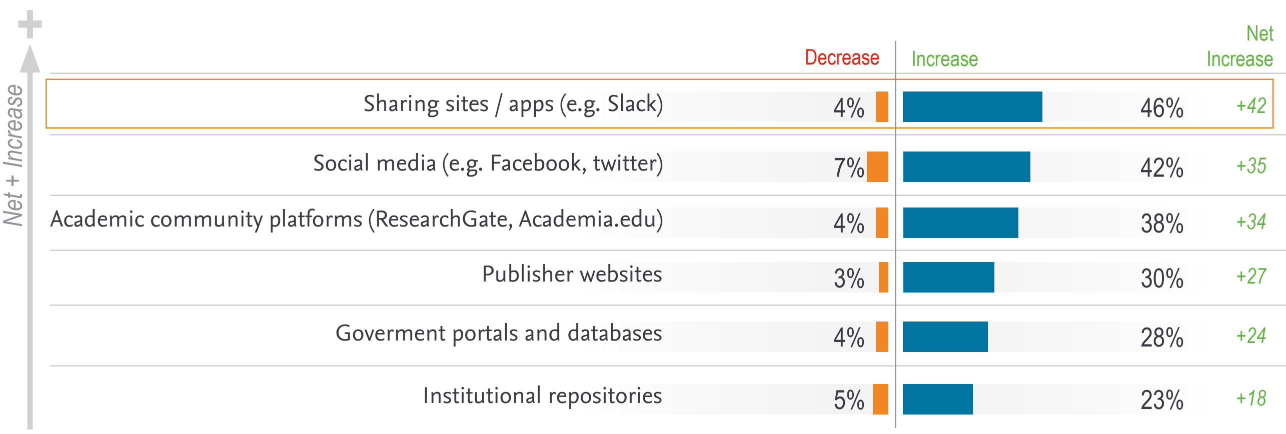


***Figure 30**: Question: Since the start of the Covid-19 pandemic (approx. 18 months) has your use of the following in relation to your research increased, stayed the same or decreased. Scale was 'Increased' 'Stayed the same' 'Decreased'. Figure shown far right is Net increase: % increase score - % decrease score. Source: Researcher survey 2021. Base varies from 861 to 1077 because respondents were offered a 'not applicable' option and these responses are not reported*

As well as increasing the connection channels between researchers, the greater use of online platforms has helped the public become more aware of researchers' work and the role of science in the community. This is expected to be a trend that will outlast the pandemic. [31]

As Odile Hologne, a delegate for French institute INRA (now INRAE), remarked in relation to electronic notebooks: "[They] 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." [1] More than three-quarters (76 percent) of the researchers we interviewed back then said integrated, end-to-end research workflow tools were high on their wish list.

The past couple of years have seen information providers, start-ups and companies outside the research sector work hard to meet that need. In some cases, the tools are new; for example, computer scientists at Northwestern University in the USA have developed CAVIDOTS, which draws on AI to search scientific literature, predicting the most useful results for the user and generating short, easy-to-skim summaries of each paper. [32]

"[It's a] massive influence on research and publishing: semi-automated systematic reviews (including automatic translations), automatic structured generation of text, semi-automated peer review (comparing 'what's known' and 'what's new')."

Social Sciences, Belgium, aged 46-55

Many of our respondents expect technology to continue to fuel the already growing pace of research.

"There will be a big acceleration in the research process at all steps (e.g. how the research is conceived, conducted and communicated) due to huge amounts of data, efficient analytical tools from machine learning, and communication speed."

Biological Sciences, Poland, aged 46-55

Researchers increasingly expect to use AI in their work. Globally, 47 percent of researchers in our latest survey expect to have a greater dependency on technology in their work than they did in 2020, when 44 percent agreed. For women researchers, the expectation is 53 percent, up from 43 percent a year earlier. Younger researchers are more likely than any other group to expect to use more technology, with 55 percent agreeing, up from 50 percent in 2020 (see figure 32). As we noted earlier in this essay, younger researchers are already the heaviest users of AI (see figure 25). While some welcome this, believing it will improve research efficiency and reduce the burden on researchers, others are concerned it will only exacerbate the existing pressure to publish. For some, technology-enabled speed could negatively impact the quality of the research produced, with work shared more quickly and with fewer quality checks.

"[It could] lower the quality because it detracts from focusing on the problem and emphasizes applying technologies without understanding the actual need/issue."

Medicine, USA, aged 65+

And, for many of our respondents, there are also ethical issues to consider, particularly around the use of AI. We explore these challenges – and researchers' current adoption rates of AI – in our **"Technology: revolution or evolution"** essay.

For at least one of our respondents, these new ways of working will accelerate the anticipated shift from basic to applied science we explore in our **"Funding the future"** essay.

"Yes, the researchers will change from fundamental research to practical research. The most important issue may [be the] change to technology."

Chemistry, China, aged 36-45

Prior to the pandemic, technology was helping fuel the growth of collaboration via tools such as web annotation services and collaborative writing tools. In terms of interdisciplinary research, social media and other networking tools were bringing researchers in contact with scientists beyond their own fields and exposing them to new ideas and perspectives. At the same time, recommender and search tools were helping them locate relevant studies outside their own disciplines. In recent months, the role of technology has proven ever more valuable, supporting remote video and online meetings via platforms such as Zoom and Microsoft Teams.

These online platforms have been particularly important in enabling virtual conferences, so long the lifeblood of information exchange and the birthplace of many academic collaborations.

"… research collaboration [has been] affected by COVID-19 despite the existing online means that may help in remote collaboration….most of research meetings, conferences and symposiums are cancelled or delayed. Researchers couldn't meet and share ideas, refresh the relationships, build new committees, etc."

Engineering and Technology, Japan, aged 26-35

However, despite fears that the move from physical to virtual may negatively impact attendance, some US-based scholarly societies have found that moving their face-to-face meetings online may actually have increased participation, [4] a view also held by others. According to a survey published in *Nature* in March 2021, 74 percent of scientists hope that virtual access to conferences will remain available even after in-person events resume. [33] The easy access to attendance from anywhere in the world is the main attraction (49 percent), next to lower carbon footprints and costs. However, in the same survey 69 percent see the loss of opportunities for networking and in-person information exchange as an important consideration, with more voices calling for conferences that blend virtual and in-person options. One respondent commented that "virtual platforms suck the soul from true science collaboration."

The OECD identifies several positive and negative factors around the use of virtual communication and conferencing tools. Virtual conferences can encourage bigger and more diverse audiences and reduce the cost of attendance, but they cannot replace the important experience of meeting colleagues and networking in person at conferences. This has consequences for future collaboration opportunities, "as building trusted relations for future research collaborations is harder." [34]

Publishing papers

In terms of numbers of papers published, the impact of COVID-19 has been immense, with estimates that around 4 percent of the world's research output was devoted to the coronavirus in 2020. [12] Some have labelled it one of "the biggest explosions of scientific literature ever." [35] As a study of Elsevier journals revealed, submissions to health and medical journals during the pandemic increased by 92 percent compared to the same period in 2019 (from 114,377 submissions in February-May 2019 to 219,552 in 2020). Health wasn't the only field impacted though – submissions to all Elsevier journals over the same period increased by 58 percent (from 466,846 submissions to 738,705). [11]

Some conjecture that the general rise in submissions is down to the fact that many researchers were forced to work remotely, giving them more time to focus on writing up the papers on their "to do" lists. [12] However, as we noted earlier in this essay, that was not the case for all researchers. Female researchers, especially those with small children, found they had less time to work on their research during the pandemic.

The pandemic changed researchers' output: some produced more papers while others' work was disrupted by lack of access to labs or a heavier burden of care while working from home. In the coming 12 months, the volume of research papers, 29 percent expect to publish less than they did before the pandemic, while 38 percent disagree that they will publish less.

Expectation for the amount of research papers written to be less than prior to the pandemic

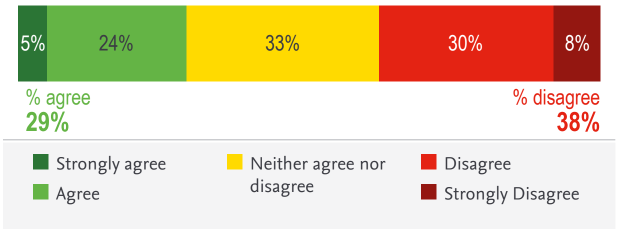


***Figure 31**: Question: "To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: Over the next 12 months I expect the amount of research papers I write to be less than prior to the pandemic."*
Source: Researcher survey 2021. Base=1,173. Respondents were offered a 'not applicable' option and these responses are not reported.

It is generally accepted that the unprecedented increase in publications at the height of the pandemic was likely to diminish post-pandemic, with submission numbers returning to their usual year-on-year growth rate. However, some were concerned that the pressure placed on the community in the interim to write, review and publish "these astonishing volumes" resulted in errors. [36] Others fear more, lower-quality papers being published. We explore these concerns and the rise of preprints in our essay Building the future research information system.

For some, researchers' plans to reuse existing data to create new content are raising red flags. One survey found that with the ability to generate new data hampered during lockdown, 64 percent of researchers reused their own data, while 51 percent expect to reuse someone else's.[37] Some concerns were raised around 'salami slicing' (the 'slicing' of research that would divide one meaningful paper into several different papers) or inaccurate claims that the data used is new. For others, the survey responses may just indicate that: "Many scientists are sitting on quite a lot of data that they just haven't had time to explore properly." [38] We examine the impact of the pandemic on data sharing and research integrity in our essay **"Pathways to open science".**

Identifying trends for the future

As mentioned earlier, several changes brought by the pandemic are expected to persist into the longer-term across a number of different areas (see figures 32 and 33). The area most agree will be affected is flexible working with 77 percent agreeing in 2021, up from 72 percent in 2020, reflecting increased acceptance over the past year that working from home has become part of the new normal.

As also mentioned earlier in this essay, collaboration has increased as we have progressed through the pandemic. Most researchers (54 percent) believe this will continue to increase, compared to 40 percent in 2020. We saw some gender differences: Though both men and women expect an increase in cross-discipline working, women researchers (64 percent) expect that to happen compared to men (51 percent). More women also believe there will be an increase in collaboration with international colleagues.

Our respondents believe cross-disciplinary research yields different benefits.

"Interdisciplinarity will be rewarded."

Arts and Humanities, USA, aged 36-45

"I hope to see more open and collaborative research in the future, minimizing the waste of resources."

Immunology and Microbiology, USA, aged 46-55

While in the longer term, the general view of the respondents to our 2021 researcher survey is that collaborations will grow, some anticipate that their form will likely change, with large, multidisciplinary groups dominating.

Some are concerned that collaboration with industry will lead to the closure of laboratories. This could lead to larger institutions securing the lion's share of funding, with consequences for smaller labs and teams, who will need to be more resourceful in securing funding.

"I can't imagine that federal research funding will keep up with the demands of the new trend toward "big science". The only real options I can see are a reduction/ consolidation of research labs and possibly more collaborative efforts with industry."

Biochemistry, USA, aged 56-65

The increased use of technology such as AI in their research will also persist, and women (53 percent) are more likely to believe there will be greater dependency on technology when doing research than men (46 percent). We also saw that more women were optimistic that the longer-term impact of COVID-19 will mean that there will be more research in new areas (60 percent versus 50 percent for men).

Many researchers who teach have had to transition to online classes, but fewer than before see that as a long-term situation. In 2020, 65 percent thought it would continue, whereas 56 percent now expect that to be the case.

The downward trend is generally welcomed, with nearly half (46 percent) of researchers disagreeing that online teaching is a positive thing for teachers. They say it is not as effective and not a substitute for direct contact. It also increases the burden of preparation for teachers and can't provide field and lab experiences. However, 29 percent think the benefits of online classes are positive for teachers, as they can enable a wider audience to be reached, save time, be more efficient and allow for better one-on-one contact with students. When it comes to the benefits of online teaching for students, 53 percent do not think the shift to online is positive for students while 21 percent think it is a positive shift. We explore these results further in our essay "**The Academy and Beyond"**.

A good work-life balance has been difficult during the pandemic, as we noted earlier in the report - 54 percent agree (see figure 26 earlier in this essay). This may become difficult in the future as reasons given included the blurring of home and work-life, difficulties in working from home, and disconnect from students when teaching online. These issues are likely to persist as most researchers (77 percent) believe there will be more flexible working, and 56 percent think there will be more teaching online in the next 2 to 5 years.

Longer-term impact of COVID-19 (1 of 3) - view by age and gender

Figure 32: *Question: Do you think the longer term (next 2-5 years) impact of COVID-19 will lead to... scale was '+' 'no change' '-'*
Source: Research survey 2020 and 2021. Base varies from 1,035 to 1,139 both years. Don't know/not applicable not included.

In our previous report, we mentioned that many believe we will 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. In some ways, the pandemic has accelerated that trend, with the need to share knowledge swiftly and openly leading to virus-related data sets appearing online within just days or weeks of discovery. We saw in our 2021 survey that 43 percent of researchers believe there will be more research data being shared in the next 2 to 3 years and more focus on the societal impact of research (54 percent).

Longer-term impact of COVID-19 (2 of 3) - view by age and gender

Figure 33: *Question: Do you think the longer term (next 2-5 years) impact of COVID-19 will lead to... scale was '+' 'no change' '-'*
Source: Research survey 2020 and 2021. Base varies from 1,035 to 1,139 both years. Don't know/not applicable not included.

Researchers also believe that in the future there will likely be less practical experiments/ fieldwork, a net decrease of 3 percent (22% believe there will be 'more' versus 25% believe there will be 'less' in the future).

Longer-term impact of COVID-19 (3 of 3) - view by age and gender

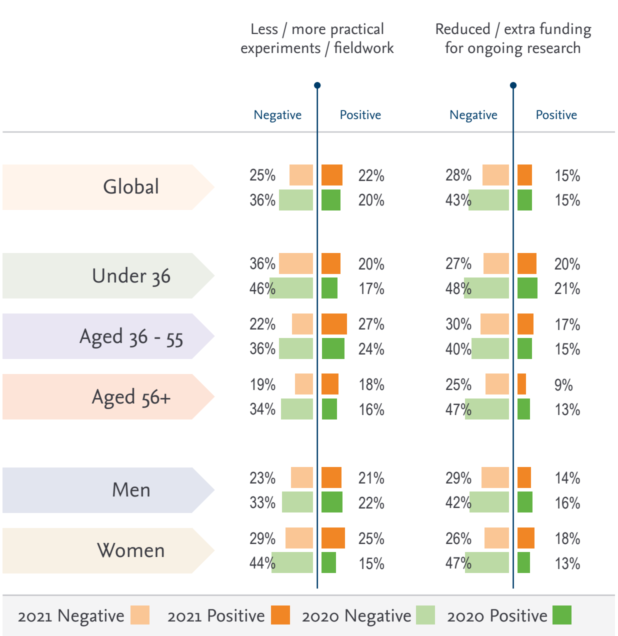


Figure 34: Question: Do you think the longer term (next 2-5 years) impact of COVID-19 will lead to... scale was '+' 'no change' '-'
Source: Research survey 2020 and 2021. Base varies from 1,035 to 1,139 both years. Don't know/not applicable not included.

Exploring new horizons

Appetite among researchers for a change of scene has increased since 2020. Now 34 percent of researchers say they would consider a move in the next two years for career reasons, up from 28 percent who said this in 2020. The increase in the numbers who 'strongly agree' has grown by the biggest margin, to from 9 percent in 2020 to 14 percent in 2021. Better facilities or equipment for research is the top reason given for considering a move; it is also the motivator with the biggest increase from last year, with 56 percent now giving this as their main reason, up from 40 percent in 2020.

The search for better working hours and a better work-life balance was the top reason for moving in 2020, but this fell to the fourth most important factor in 2021, with 47 percent citing this as a main reason, down from 53 percent a year earlier. This may be a result of researchers adapting to the work from home experience as it extended into a second year for many.

The wish for more funding and higher salaries are the second and third most cited reasons for considering a move abroad. Researchers are also motivated by a growing belief that more job opportunities exist abroad, with double the proportion of researchers saying this is a main factor compared to last year (24 percent versus 12 percent in 2020).

Considering moving to another country in the next two years and reasons.

Figure 35: Question 1: "I would consider moving to another country to further my career in research (in the next 2 years)." Question 2: "What are the main reasons you would consider relocating to another country." Source: Researcher survey 2020, 2021. Q1 Base 2020=1,031, base 2021=1,127. Q2 Base 2020 =284, base 2021=355

The number of those who are not considering a move cite family commitments, satisfaction with their current position or conditions, and the ability to carry out their work from where they currently are located as reasons for staying put.

Female researchers have become much more likely than they were in 2020 to look for better research facilities, more funding and a higher salary when considering a move abroad. These are also the top three considerations for younger researchers, for whom a better work-life balance has also become more important. As we noted earlier in this essay, younger researchers are increasingly likely to leave academia as they look for better opportunities and job security. Their potential departure from research is one of the drivers of our Tech Titans scenario, which envisages changes to the profile of researchers as younger researchers abandon academia for better opportunities with tech companies.

Mid-career researchers (aged 36 to 55) are most motivated by better research facilities, more funding and higher salaries, while for older researchers (56+), more funding and better research facilities are the main reasons for considering a move.

The most popular countries for researchers considering a move abroad remain the similar year on year. The USA is the most popular destination in 2021: 14 percent of those who would relocate would consider it, up from 8 percent a year earlier. Next is the UK at 13 percent, up from 9 percent in 2020. Preference for Canada is growing, with double the number of researcher (12 percent) in 2021 saying they would choose Canada compared to 2020, when 6 percent said they would consider it.

Within the EU, Germany has increased its lead as the top choice at 11 percent, up from 9 percent in 2020. China does not yet show signs of attracting large numbers of researchers, with 2 percent considering it in 2021, up from 1 percent a year earlier.

It is difficult to gauge yet to what extent pandemic-imposed travel constraints and quarantine requirements may have impacted these changes.

For those working in North America, the search for a better work-life balance is the biggest factor in their mobility decision. For those in Western Europe, the top three reasons given by about half of researchers are better research facilities, more funding and better salaries.

Where researchers would locate

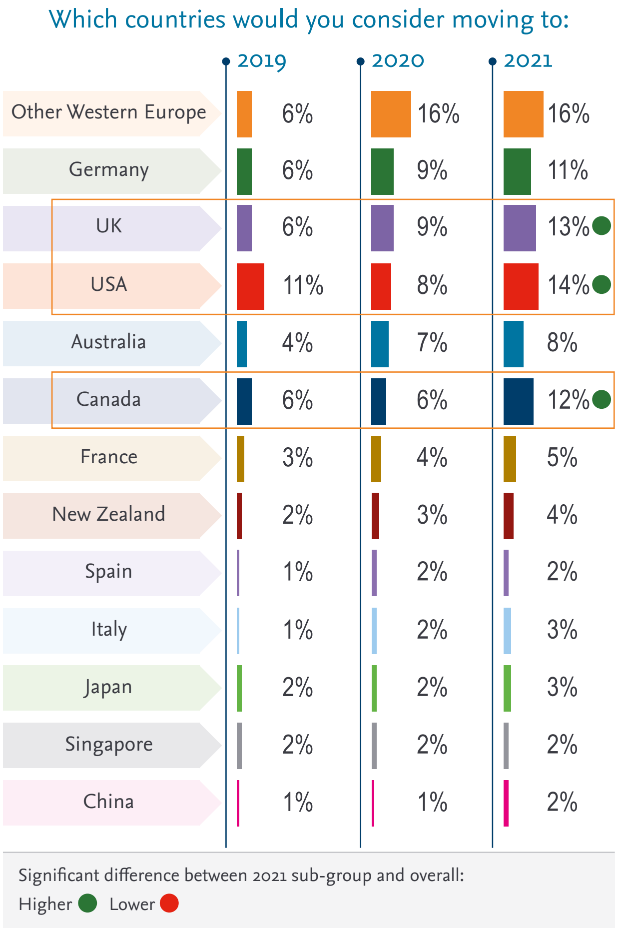


***Figure 36**: Question: "Which countries would you consider moving to: Source: Researcher survey 2019, 2020, 2021. Base 2019=1,450, base 2020=1,031, base 2021 =1,127.*

> *"I am unhappy with the political climate towards higher education in the US."*
>
> (Social Science, USA, aged 36-45)

> *"Despite loving France, I think other countries have more to offer in terms of scientific excellence."*
>
> (Biochemistry/ Genetics/ Molecular Biology, France, aged 36-45)

Developing data skills

In our previous report, we identified the need for researchers to master new data science skills. We noted these were necessary not only to manage the rising volume of data being generated by developments such as the Internet of Things (see Technology: revolution or evolution essay), but to meet the growing dependency of many fields on data, and the corresponding shift toward data-driven hypothesis development.

> *"It seems to me that research will be increasingly relying on big data analyses and machine learning processes."*
>
> Biochemistry, Genetics, and Molecular Biology, UK, aged 36-45

As with so many of the trends identified in that study, progress has been accelerated by the current pandemic. Data have proven the cornerstone of COVID-19 research – as we explore in our essays **"Pathways to open science"** and **"Technology: revolution or evolution,"** the pandemic has prompted an unprecedented outpouring of (often open) data and sparked new platforms to host and connect it. At the same time, researchers have been mining data sets on existing therapeutics to identify potential treatments, analyzing data on previous pandemics to enhance our understanding of this one, or initiating new studies that build on the data being shared.

The OECD noted in its 2021 report: "The crisis has highlighted the importance of data-intensive science… digital tools and open-data infrastructures [have] allowed many scientists to continue to function effectively outside their usual laboratory or field environments during lockdowns… they have also massively accelerated data-driven discovery and knowledge dissemination." [39]

The OECD report goes on to echo the findings of our original *Research futures* study around the consequences of this shift for researchers' careers: "Investment in research data infrastructures needs to be matched by long-term investment in human resources, including data stewards, software engineers and data analysts." [39] In some cases, researchers, librarians and people in other institution roles are retraining to learn these skills; in other cases, experts in data are being recruited by universities, who face fierce competition from the marketplace. Some of these roles are directly involved in research, and others are research support roles. [39] The demand is also driving the move toward large teams with people with niche expertise or support.

> *"[Researchers] will be forced to work with big data information in multidisciplinary topics."*
>
> Materials Science, Czech Republic, aged 36-45

And just as with other aspects of the changing researcher workflow, this change has implications for how the impact of researchers is measured. Current bibliometric scores unsuitable for assessing or recognizing many of these new data skill sets. [39]

But the OECD fears the "scale and immediacy of the challenge of building digital capacity for data-intensive research, which is at the forefront of the scientific response to COVID-19" is widely underestimated, despite several initiatives already underway. For the OECD, both national governments and institutions have an important role to play in training more digitally skilled scientists and research support professionals, and developing "attractive and supportive academic research environments so that they do not all leave to take up better paid jobs in industry." [39]

Ensuring research is accessible and accountable

Measuring impact

Central to so many of the topics discussed in both our *Research futures* reports is the "publish or perish" spiral that has ensnared researchers for many years now. It describes the pressure on them to publish research articles early in their career (preferably in leading journals) and then continue to publish high-impact papers at regular intervals.

This has been seen as crucial for a researcher to progress, with both funders and institutions considering the publishing history of an applicant when making key funding and recruitment decisions, respectively. As a result, it has shaped the way researchers approach research projects, open science, the publishing process and many other aspects of their work.

At the time of our original report in 2019, the majority of the researchers we surveyed (73 percent) felt that this pressure was likely to increase over the coming 10 years. The experts we spoke with agreed – as Sarah Pritchard, Dean of Libraries at the US' Northwestern University, observed: "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?'" [1] However, since 2019, we've seen moves by China to step away from assessing and rewarding researchers based on the number of their published articles and the Impact Factor of the journal in which those articles were published. We've also seen the growing number of funders participating in cOAlition S pledge to focus on the intrinsic merit of the work, rather than the publication channel. Tools such as Altmetrics and Plum Analytics provide a variety of alternative metrics to measure impact, including downloads, usage, and news and social media mentions. In addition, there are multiple initiatives afoot to find new ways to recognize the work of researchers, particularly their contribution to society and data sharing, and the pandemic's acceleration of open science has only added a new urgency to these. As the OECD notes in a 2020 report that examines the impact of COVID-19 on trends in the community: "Important scientific outputs, such as databases or software, policy reports or citizen engagement activities, which are critical for crisis response, are undervalued. New incentives and measures for evaluating and rewarding both individual and collective contributions to science are urgently required." [39]

We explore some of these shifts further in our **"Funding the future"** and **"Pathways to open science"** essays.

Interestingly, one study suggests that the focus on citations as a measure of impact may be more common among researchers (90 percent) than university research office staff (63 percent), with the latter taking a range of other factors into account. Researchers also attached more importance to some of the alternative metrics being used, such as views and social media mentions. While 38 percent of research office staff favored policy papers and regulations as a measure of success, they also acknowledged the challenges involved in assessing these, and indeed societal impact, in the short term, as well as linking them back to individual publications. [40] As mentioned earlier, we found that most researchers believe there would be more focus on the societal impact of research in the next 2–5 years (see fig 32).

Impact on society and public perception of science have been highlighted by the pandemic. As Kreps and Kriner noted in an October 2020 *ScienceAdvances* paper: "While scientific uncertainty always invites the risk of politicization and raises questions of how to communicate about science, this risk is magnified for COVID-19. The limited data and accelerated research timelines mean that some prominent models or findings inevitably will be overturned or retracted." [41] The two researchers found that while downplaying uncertainty can raise support in the short term, reversals in projections may temper those effects or even reduce scientific trust. [41]

"An increased number of non-valid studies were published and were used as scientific truth."

Medicine, Portugal, aged 56-65

Writing about the importance of the peer-review process in September 2020, *The Lancet* pointed out the vital role of science as "a powerful and positive force in society; it shapes the present, and it guides our future. Politicians and policy makers rely on published research at critical moments of crises and emergency to guide their actions." [42] But it also acknowledged that with COVID-19 prompting unprecedented discussions about science publishing, "articulating the importance of peer review—how it benefits science and society, and its achievements and its limitations—is essential to engendering trust." [42] This echoes the findings of a 2019 Elsevier and Sense about Science report, *Quality, trust & peer review: researchers' perspectives 10 years on*, which, in addition, found that few researchers believe the public understand the concept of peer review. [43] We explore these issues further in our essay **"Pathways to open science"** in this report.

References

1 Research futures: Drivers and scenarios for the next decade. Elsevier. February 2019. https://www.elsevier.com/connect/elsevier-research-futures-report

2 World Health Organization. Accessed 12th April 2022. https://covid19.who.int/

3 Economics Observatory. 1 December 2020. https://www.economicsobservatory.com/how-feasible-working-home-developing-countries

4 Radecki, J. & Schonfeld, R. C. The Impacts of COVID-19 on the Research Enterprise: A Landscape Review. Ithaka S+R. 26 October 2020. https://doi.org/10.18665/sr.314247

5 Editorial: Science benefits from diversity. Nature. 6 June 2018. https://www.nature.com/articles/d41586-018-05326-3

6 Remmel A. Scientists want virtual meetings to stay after the COVID pandemic. 2 March 2021. https://www.nature.com/articles/d41586-021-00513-1

7 The Royal Netherlands Academy of Arts and Sciences.Report on impact of COVID-19 pandemic on researchers. 30 November 2021. https://www.knaw.nl/en/news/news/report-on-impact-of-covid-19-pandemic-on-researchers

8 Fosci, M. et al. Emerging from uncertainty: International perspectives on the impact of COVID-19 on university research. Prepared on behalf of Springer Nature. November 2020. https://resource-cms.springernature.com/springer-cms/rest/v1/content/18537754/data/v6

9 Supporting Early-Career Researchers Act - H.R.144. FYI: Science Policy News from AIP. American Institute of Physics. Accessed 13 January 2020. https://www.aip.org/fyi/federal-science-bill-tracker/117th/supporting-early-career-researchers-act

10 Bothwell, E. V-c: pandemic 'existential threat' to gender equality in academia. Times Higher Education. 23 October 2020. https://www.timeshighereducation.com/news/v-c-pandemic-existential-threat-togender-equality-inacademia

11 Squazzoni, F. et al. No Tickets for Women in the COVID-19 Race? A Study on Manuscript Submissions and Reviews in 2347 Elsevier Journals during the Pandemic. SSRN. 16 October 2020. http://dx.doi.org/10.2139/ssrn.3712813

12 Else, H. How a torrent of COVID science changed research publishing — in seven charts. Nature. 16 December 2020. https://www.nature.com/articles/d41586-020-03564-y

13 Matthews, D. Pandemic lockdown holding back female academics, data show. Times Higher Education. 25 June 2020. https://www.timeshighereducation.com/news/pandemic-lockdown-holding-back-female-academics-data-show

14 Myers, K. R. et al. Unequal effects of the COVID-19 pandemic on scientists. Nature Human Behaviour 4, 880–883. 2020. https://doi.org/10.1038/s41562-020-0921-y

15 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/

16 COVID-19 research update: How many pandemic papers have been published? Nature Index. 28 August 2020. https://www.natureindex.com/news-blog/how-coronavirus-is-changing-research-practices-and-publishing

17 Basken, P. From Crisis, US Researchers See Prospect of Durable Gains. Times Higher Education. 23 April 2020. https://www.timeshighereducation.com/news/crisis-us-researchers-see-prospect-durable-gains.

18 Baker S. THE. 2 February 2022. https://www.timeshighereducation.com/news/us-china-research-collaboration-waning

19 Bogle D. University World News. 5 September 2020. https://www.universityworldnews.com/post.php?story=20200904133393595

20 Press release. Europa.eu. 4 March 2022. https://ec.europa.eu/commission/presscorner/detail/en/IP_22_1544

21 Pultarova T. Space.com 18 March 2022. https://www.space.com/exomars-mars-rover-europe-russia-ukraine-delays

22 Hunt K. CNN. 17 March 2022

https://edition.cnn.com/2022/03/17/world/exomars-suspended-european-space-agency-russia-scn/index.html

23 Euronews.com & AFP. 8 March 2022. https://www.euronews.com/next/2022/03/08/ukraine-war-cern-suspends-russia-s-observer-status-and-all-future-collaboration-over-invas

24 Matthews D. Sciencebusiness.net. 1 March 2022 https://sciencebusiness.net/news/denmark-tells-universities-suspend-all-cooperation-russia

25 FOF: Davour A. Forskning & Framsteg. 3 March 2022. https://fof.se/artikel/sa-ar-laget-for-forskare-i-ryssland/

26 Gaind N and Else H. Nature.com 1 March 2022. https://www.nature.com/articles/d41586-022-00601-w

27 Matthews D. Sciencebusiness.net 22 March 2022 https://sciencebusiness.net/news/anti-war-russian-scientists-ambivalent-over-scientific-sanctions-against-them

28 Bontempi E, Vergalli S, Squazzoni F. Understanding COVID-19 diffusion requires an interdisciplinary, multi-dimensional approach. Environ Research. 2020;188:109814. doi:10.1016/j.envres.2020.109814

29 Baxter R et al. COVID-19: Opportunities for interdisciplinary research to improve care for older people in Sweden. Scandinavian Journal of Public Health. November 2020. doi:10.1177/1403494820969544

30 Wen, J, et al. Many brains are better than one: the importance of interdisciplinary studies on COVID-19 in and beyond tourism. Tourism Recreation Research. 2020. https://doi.org/10.1080/02508281.2020.1761120

31 Benchekroun S. Industry at a strategic crossroads. 19 October 2021. https://www.researchinformation.info/analysis-opinion/industry-strategic-crossroads

32 Morris, A. New A.I. tool is a potential timesaver for COVID-19 researchers. Northwestern University. 18 June 2020. https://news.northwestern.edu/stories/2020/06/new-a-i-tool-is-a-potential-timesaver-for-covid-19-researchers/

33 Remmel A. Scientists want virtual meetings to stay after the COVID pandemic 2 March 2021. https://www.nature.com/articles/d41586-021-00513-1

34 Policy responses to coronavirus (COVID-19). OECD. 23 June 2021. https://www.oecd.org/coronavirus/policy-responses/how-will-covid-19-reshape-science-technology-and-innovation-2332334d/

35 Brainard, J. Scientists are drowning in COVID-19 papers. Can new tools keep them afloat? Science. 13 May 2020. https://www.sciencemag.org/news/2020/05/scientists-are-drowning-covid-19-papers-can-new-tools-keep-them-afloat

36 Teixeira da Silva, J. A., Tsigaris, P. & Erfanmanesh, M. Publishing volumes in major databases related to Covid-19. Scientometrics. 2020. https://doi.org/10.1007/s11192-020-03675-3

37 Baynes, G. & Hahnel, M. Research Practices in the wake of COVID-19: Busting open the myths around open data. Springer Nature. 07 August 2020. https://www.springernature.com/gp/advancing-discovery/blog/blogposts/research-practices-in-the-wake-of-covid/18256280

38 Grove J. THE. 20 August 2020.
https://www.timeshighereducation.com/news/spike-research-misconduct-feared-after-covid-disruption

39 Science, Technology and Innovation Outlook 2021: Times of Crisis and Opportunity. OECD Publishing. 2021. https://doi.org/10.1787/75f79015-en

40 Supporting Academic Research: Understanding the Challenges. Alterline. Ex Libris 2020.
https://page.exlibrisgroup.com/research-office-challenges-2020-report

41 Kreps S & Kriner D. Model uncertainty, political contestation, and public trust in science: Evidence from the COVID-19 pandemic. 21 October 2020. https://www.science.org/doi/10.1126/sciadv.abd4563

42 Editorial: COVID-19 in Latin America: a humanitarian crisis. The Lancet. 7 November 2020. https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(20)32328-X/fulltext

43 Elsevier & Sense About Science. Quality Trust & Peer review: Researchers' perspectives 10 years on. 2019. https://www.elsevier.com/research-intelligence/resource-library/trust-in-research-report

Technology: revolution or evolution

A quick glance back...

In our original report, we identified four key areas of change – these are featured in the blue boxes below. Each of these is accompanied by a bulleted breakdown of the shifts we anticipated would occur as that change unfolded.

Taken from ***Research futures 2019***

1

Big data is fast becoming the lifeblood of nearly all research

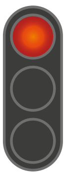
- Big data can be (and is) used throughout the research cycle; for example to understand research processes, analyze and share data sets, link interactive articles to data sets and create efficiencies.
- With the volume of research data increasing, the skills that many researchers require are continuing 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 institutions

- 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.

Now, three years into the 10-year window and with COVID-19 impacting every element of our lives, how are those predictions standing up?

We have used a traffic light system to give an indication: red for no progress, amber for some progress, and green for a reasonable amount of progress.

Read the original **"Technology: revolution or evolution"** essay in *Research futures*
www.elsevier.com/research-intelligence/resource-library/research-futures

The current situation

Key findings

- Technologies such as the Internet of Things (responsible for much of the digital information generated), big data, artificial intelligence (AI) and robots (also explored in our original essay) have powered the response to the pandemic, while also accelerating development in these areas.
- Issues around data security and inherent bias have become more apparent due to the pandemic.
- Researcher dependency on technology including artificial intelligence will increase - 52 percent think they will become more dependent on it over the next two to five years – a lasting legacy of the pandemic.
- Of those that use AI in their research, a portion of those researchers (17%) are using AI to generate hypotheses.
- AR and VR have played a role in delivering healthcare during the pandemic, and the pandemic will drive further adoption of AR and VR in health and education

For some, one of the few bright points in the COVID-19 story is that the virus emerged into a world that has largely embraced digital technology. In our public health response to the virus, we've been able to leverage "billions of mobile phones, large online datasets, connected devices, relatively low-cost computing resources and advances in machine learning and natural language processing." [1] These resources and technologies have not only powered the identification of new cases, contact tracing, monitoring of public compliance, statistical mapping, and medical research and interventions, they have also proved invaluable in areas such as remote learning and working and international collaboration.

Connectivity: the highs and lows

In our previous report, we explored the seemingly unstoppable rise of big data – a term generally agreed to describe data sets too large and complex to be processed by traditional database management tools. The general consensus was, and remains, that the volume of data in the digital universe could rise to 175 zettabytes by 2025. To put that into perspective, 1 zettabyte (ZB) is equivalent to 1 sextillion bytes; downloading 175 ZB would take one person 1.8 billion years at the current average internet connection speed. [2]

As we explore in our essay **"Pathways to open science,"** we have since seen a corresponding rise in the launch of new repositories to manage, preserve and disseminate this data, many of them open access. Data, and technology in general is driving changes in researchers' workflows and relationships: fueling collaboration and new ways of thinking, driving a need to learn new skills and powering remote teaching, as we discover in our essays **"How researchers work: change ahead"** and **"The academy and beyond."**

"A lot of research will be based on bioinformatic analyses of public datasets. To facilitate this, public datasets will be published in repositories immediately or in parallel with collection prior to any interpretation or analysis of the data."

Life Sciences, US, aged 26-35

The rise of big data

Only weeks into the pandemic, it was clear that COVID-19 was accelerating the growth of big data. According to a post in the Harvard Business Review, the pandemic "created a tidal wave of data" that governments, public health bodies, tech corporations and data aggregators are using to understand, track and respond to the virus.[3] In our most recent survey in 2021 we saw that 52 percent thought that data sharing had increased compared to two to three years ago (see figure 14 in the essay Pathways to open science). That has long-term implications – for example, an OECD report found that the unprecedented use of new data and digital tools during the crisis may be innovating policy making; real-time granular health data has been used to inform policy decisions, while new data sources, such as job portals, have increased understanding of the economic impact. [4]

However, as the *Harvard Business Review* article authors note, data can vary in quality and it's not always easy to tell the good from the bad. Another potential issue is that "…because technology and telecom companies have greater access to mobile device data, enormous financial resources, and larger teams of data scientists, than academic researchers do, their data products are being rolled out at a higher volume than high quality studies."

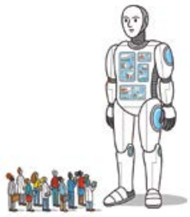
Much of the digital information being generated is only possible because of the Internet of Things (IoT) – the growing network of physical and digital elements connected and exchanging data. According to the International Data Corporation (IDC), in 2020, connectedness and connectivity became the "glue that enables the modern digital world" as people were forced to work and learn at home. [5] For some researchers, the ability the IoT offers to remotely monitor and adjust experiments proved a lifeline during pandemic lockdowns. On the healthcare front, it was already playing an increasingly important role; for example, by allowing physicians to use smart devices to monitor outpatients with conditions such as diabetes and asthma. Since the arrival of COVID-19, the importance of IoT has escalated: we've seen it powering virus contact-tracing programs around the globe, and allowing hospital networks to monitor bed capacity. IoT has also supported the vaccine rollout; for example, countries have been able to track the location, temperature and stock levels of vaccine supplies.[6]

Some believe that the gradual introduction of 5G technology is "almost certain to lead to explosive growth in IoT". [7] 5G can connect more devices than 4G and at higher speeds. Growth in the number, and computing power, of IoT devices will, in turn, create "unprecedented volumes of data." [8] Together, these developments are likely to accelerate the use of edge computing, which sees data processed close to its source; for example on an IoT device or local server, producing faster response times. This will pave the way for further exploration of large, interconnected data sets and greater insights, advancing discovery and development.

As the volume of interconnected data sets increase so to do concerns about privacy, particularly when the data being shared is personal, financial or health-related. While certain regions already had measures in place to regulate this, such as Europe's data protection regulation GDPR, a number of developing economies have yet to address this issue, which may slow down their adoption of IoT. The Council of Europe is just one of the organizations concerned about the potential loss of personal rights in the wake of the pandemic. It notes on its website: "Emergency measures using technological solutions, including AI, should…be assessed at the end of the crisis. Those that infringe on individual freedoms should not be trivialized on the pretext of a better protection of the population." [9]

Data Security

COVID-19 has also reignited concerns about the security of the digital information we generate. In December 2020, it was announced that documents linked to the development of the Pfizer/BioNTech COVID-19 vaccine were stolen during a cyber attack on the European Medicines Agency (EMA) and were later leaked online. [10] In the same month, it emerged that a number of US government organizations, including the National Institutes of Health (NIH), had fallen victim to a "massive cyber breach", [11] while a 2020 study found that criminals could use malware to trick scientists into making dangerous toxins or viruses.[12]



Scenario Match

In the scenario **Tech Titans**, we envisaged growing awareness of the risk of data security.

Hackers can also impact the effectiveness of individual government's measures to stem the spread of the virus, and in turn make the public less confident about the safety of using health-related apps. In Australia, data breaches in the healthcare sector accounted for the highest proportion of breaches in the first six months of 2021. [13] In July 2021, a security breach in a Dutch provider of COVID-19 tests allowed online users to access the company records and create fake negative test certificates for use on the country's CoronaCheck app. The personal data of more than 60,000 people who had taken a test with the company was also compromised. [14] As we note in the *New jobs, new skills* section of this essay, incidents such as these have led to a rise in demand for information security analysts, alongside a growing requirement for other data and technology-related specialist roles.

A new type of intelligence to the rescue?

In recent years, many fields have been exploring the possibilities offered by artificial intelligence (AI) and machine learning; for example, how it can be used to predict the progress of Alzheimer's disease [15], develop personalized medication plans for cancer patients, [16] or reduce the time taken to conduct complex data analyses from weeks to just seconds. [17] In our **"Pathways to Open Science"** essay, we take a look at how AI and other technologies are accelerating the open science movement.

In our 2021 survey, more researchers agree that one of the longer term impacts of COVID-19 will be a greater dependency on technology when doing research than anticipated a year ago, an increase of 3 percentage points but a net increase of 7 percentage points (% positive score minus % negative score).

“The ability to easily manipulate huge amounts of data has already drastically changed our approaches to biological questions since the turn of the century. Now, the addition of artificial intelligence to these analyses is just beginning what I’m certain will be another big step up in our approaches over the next decade.”

Biochemistry, Genetics, and Molecular Biology, US, aged 56-65

Understanding the tech terminology

Algorithm:

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

Artificial intelligence (AI):

An interdisciplinary branch of computer science that builds intelligent machines, especially computer programs, which perform tasks that would normally require human intelligence. AI imitates the constant processes occurring in human brains and nervous systems, but while our thinking is fed by our senses, AI systems rely on algorithms or machine learning.

Deep learning:

An artificial neural network that attempts to mimic human thinking.

Machine learning:

Computer programs that can access data and use it to learn for themselves.

Natural language processing (NLP):

A branch of artificial intelligence that helps computers understand, interpret and manipulate human language.

Quantum computers:

These draw on quantum mechanical phenomena to solve complex problems we are otherwise unable to tackle.

Anticipated longer term impact of COVID-19

Dependency on technology when doing research (e.g. AI)

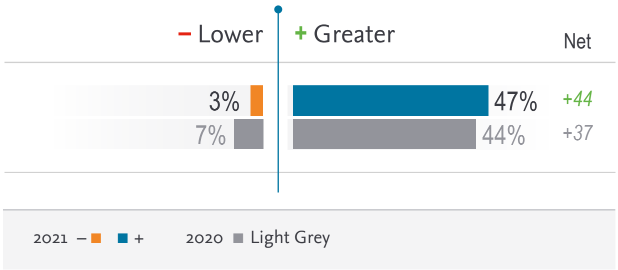


***Figure 37**: Question: Do you think the longer term (next 2-5 years) impact of COVID-19 will lead to... scale was ‘- lower’ ‘no change’ ‘+ Greater’ Lower. The Net figures shown in chart is % positive score minus % negative score. Source: Research survey 2020 and 2021 Base varies from 1035 to 1139 both years, respondents were offered a ‘not applicable‘ option these responses are not part of % reported*

COVID-19 has been credited with accelerating adoption of AI in pharmaceutics and has been used, among other things, to develop and repurpose existing drugs to counter the pandemic. A survey of pharmaceutical professionals in a report released in January 2021 by GlobalData predicted that AI will be behind the most important technological transformation in the pharmaceutical industry in 2021. [18] We already saw its impact from the earliest days of the pandemic when industry watchers labelled AI and machine learning as two of the most promising avenues for resolving the health crisis. [19] In fact, Canadian start-up BlueDot is widely credited with being the first to detect the virus – its AI platform picked up a cluster of “unusual pneumonia cases” in Wuhan, China, days before the World Health Organization issued its official alert.[20]

Late 2020 marked probably the most exciting AI-related development to date, when AI developed by DeepMind, a subsidiary of Google, made a “gigantic leap” in solving protein structures. [21] Known as the ‘protein folding problem’, it has stood as an unsolved biology grand challenge for half a century. Many believe that this AI-powered discovery has the potential to transform Life Sciences and Medicine, empowering faster and more effective drug development.

Since COVID-19’s arrival, governments, organizations, industry and academia have been drawing on algorithms, data analytics and natural language processing (NLP) to power a range of disease-combating initiatives, from modeling the spread of the virus, to identifying potential therapeutics among existing treatments.

AI has also played a key role in the development of testing kits, diagnosis procedures and even vaccines. [22]

"AI has been shown to outperform humans in many tasks."

Medicine, US, aged 36-45

In our latest survey, almost two-thirds of researchers are collaborating more on their projects (see figure 27 in our essay **"How researchers work: change ahead"**).

The pandemic has also prompted more AI-related collaborations as experts from all sectors seek to pool knowledge, resources and computing power. For example, the COVID-19 Open Research Dataset Challenge (CORD-19) initiative we explore in the **"Pathways to open science"** essay involves a host of organizations. These range from the Allen Institute for AI and the Chan Zuckerberg Initiative, to IBM and the Georgetown University's Center for Security and Emerging Technology, all in collaboration with The White House Office of Science and Technology Policy. [23]

AI – the good, the bad, and the challenges

In 2019, we predicted that advances in AI and machine learning would transform the work of research. As we will see in this essay, this data-driven transformation has accelerated during the pandemic and is a key driver of our **"Tech Titans"** scenario. We noted in our previous report that as the use of AI increased, so too would concerns about its uses and potential for bias and data manipulation. In the intervening two years, those concerns seem to have become widespread. After a two-year consultation with a panel of international experts, the WHO released a report in June 2021 on the use of AI in health and setting out guiding principles for its design and use. [24] As well as noting the ability of AI to help bridge the gap in access to healthcare between countries, the report lists risks to AI use including the potential unethical collection and use of health data and biases built into algorithms. Mitigating those risks requires careful design of AI systems to reflect the diversity of socio-economic and healthcare settings, as well as training healthcare workers in digital skills to help them deal with the challenges of working with AI.

In some cases, the urgency around responding to the virus has resulted in AI developments being rolled out with undue speed. For example, in the US, a number of hospitals introduced an AI system designed to predict which Covid-19 patients would become critically ill, without taking the usual "time to test the tool on hundreds of patients, refine the algorithm underlying it, and then adjust care practices to implement it in their clinics." [25] According to an editorial in The Lancet Digital Health, this "...lax regulatory landscape for COVID-19 AI algorithms has raised substantial concern among medical researchers." [26]

The editorial points to a living systematic review published in the BMJ which claims that many COVID-19 AI models are poorly reported and trialled on small or low quality datasets with high risk of bias, while September 2020 saw the launch of new guidelines designed to improve the design of and reporting on clinical trials evaluating interventions with an AI component. [27]

One of the key steps required to ensure the accuracy of AI systems is to improve the data being used to train them. For example, medical datasets often lack information on people from ethnic minority backgrounds and/or for women. If that is not addressed, there is a danger that AI could misdiagnose or under diagnose cases, or just simply increase existing healthcare disparities. [28] At least one study has found that while facial recognition software is right 99 percent of the time when the person in the photo is a white male, the darker the skin, the more inaccurate the identification – with an error rate of up to 35 percent for darker-skinned women. [29]

Algorithm bias also risks perpetuating gender inequality; for example, in 2018, Amazon had to shut down a machine learning tool used to make hiring decisions because those decisions were biased against women. The model was trained on the company's historical hiring data, suggesting the origin of the problem lay within Amazon itself. [30] Another AI feature, natural language programming (NLP) was identified as the source of the bias. [31]

"AI has already proven to be discriminatory in various ways. Programmers' blindness and bias creeps into AI, algorithms, etc., and can be manipulated."

Social Sciences, Australia, aged 36-45

Leading the AI charge

In 2019, we wrote about the rapid rise of China. Since then, China has been investing heavily in R&D funding and plans to continue to do so, despite a now-slowing economy. We explore this topic further in the **"Funding the future"** essay within this report. China is leading in AI and catching up or outpacing the US in areas including space exploration and quantum computing. These advances are strong drivers of **Eastern Ascendance** scenario. In 2017, the year that China announced its plan to become the world leader in AI by 2030, its share of AI research papers reached 27.7 percent, with 37,343 AI papers published, the highest number of any country. [32] According to the 2021 AI Index, in 2019 China published 22.4 percent of the global peer-reviewed AI papers, compared to 16.4 percent in the EU and 14.6 percent in the US. In 2020, China surpassed the US in the share of AI journal citations worldwide for the first time with 20.7 percent compared to 19.8 percent for the US.

China's AI advances have been fueled by increased resource from its largest funding agency, the National Natural Science Foundation of China (NSFC), which increased its budget for research projects to US$19.6 billion for 2016-2020, up from US$13.7 billion in 2011-2015 and US$4.6 billion in 2006-10. [33]

Quantum computing has been a particular investment priority for China, with the government spending US$10 billion on its National Laboratory for Quantum Information Sciences. [34] Quantum computers use qubits, or quantum bits, rather than the bits and bytes used by traditional computers. Qubits enables quantum computers to perform multiple calculations at the same time. China is also a world leader in quantum networking, "where data encoded using quantum mechanics is transmitted across great distances." [35]

Quantum technologies are at a nascent stage, but they offer enticing potential to provide unhackable communication channels and, at the same time, to hack the encryption that protects email and internet transactions. [36]

The National Institute of Standards and Technology, an agency of the US Department of Commerce, explains that, once built, large-scale quantum computers "will be able to break many of the public-key cryptosystems currently in use. This would seriously compromise the confidentiality and integrity of digital communications on the Internet and elsewhere." [37]

In late 2020, a team in China claimed to have launched the world's most powerful quantum computer, capable of performing at least one task 100 trillion times faster than the fastest supercomputers, operating 10 billion times faster than the Google-built machine widely believed to have been the first to achieve "quantum supremacy" just months earlier. [38] In July 2021, researchers at the University of Science and Technology in China achieved what Scientific American called "critical advances" in both quantum communication and quantum intelligence. [40] Chinese scientists say the light-based computer named "Jiuzhang 2" can perform in one millisecond a calculation that would take the world's fastest computers 30 trillion years to complete. [38]

China isn't the only country investing heavily in AI-related fields. As we explore in our **"Funding the future"** essay, US President Joe Biden's proposed increase in R&D funding has named advanced computing, which includes quantum computing, as well as semi-conductor design and manufacturing as key priorities. [39]

In 2018, the EU set up a ten-year Quantum Flagship project to boost the EU's capabilities in quantum technologies and position the EU as a leader in the field, with a budget of at least €1 billion. [40] In June 2021, Dr Thomas Monz from the University of Innsbruck in Austria, who is leading a project to develop a fully scalable quantum computer [41] built a prototype compact quantum computer that can fit in a data center, to meet common industry standards. The prototype was developed to demonstrate that quantum computers will soon be suited for use in data centers. [42]

Scenario Match

In the scenario **Eastern Ascendance**, we predicted there would be a lack of global alignment on grand challenges and governments, industry and other research funders would compete for scientific advantage.

One of the main aims of the Strategy on Artificial Intelligence is to place the EU ahead of technological developments and encourage the uptake of AI by the public and private sectors. [43] However, according to a report by the Carnegie Endowment for International Peace, when it comes to AI, "the United States and China are both in the driver's seat." Despite the EU having advantages such as a strong industrial base and leading AI research and talent, it is "punching far below its weight" says the report, largely due to "fragmentation of the EU's digital market, difficulties in attracting human capital and external investment, and the lack of commercial competitiveness." [44]

Some feel that the "image problem" AI has developed is fed by fears over jobs lost to automation (see New jobs, new skills in this essay). Others are concerned about AIs "either destroying the planet in a frenzied pursuit of their own goals or doing away with humans by accident." [45] But this negative perception may be shifting, according to Oren Etzioni, CEO of the Allen Institute for Artificial Intelligence. In a 2020 blog post, he observed: "It is ironic that the AI which has caused such consternation with facial recognition, deepfakes, and such is now at the front lines of helping scientists confront Covid-19 and future pandemics… [it] reminds us that AI is a tool, not a being, and it's up to us to employ this tool for the common good." [46]

Deep learning and health care

In our original report, we noted that we have entered the era of deep learning, which uses artificial neural networks built like the human brain to carry out the process of machine learning. Since we released the report in 2019, there have been significant developments. Deep learning excels in the processing of visual data and has already been used to examine CT scans and x-rays – including checking for signs of COVID-19 – and helping to diagnose diseases such as cancer.47 Researchers are still exploring how it can benefit other areas; for example, its ability to monitor the progression of Parkinson's disease. [48]

Moreover, researchers have been using machine learning to develop an algorithm using data from the brain scans of patients who later developed Alzheimer's. Pre-clinical tests show the algorithm can identify structural changes in brain patterns at a very early stage. In patients who had mild cognitive impairment, the algorithm was more than 80 percent accurate in predicting Alzheimer's and could also predict the speed of decline over time. [49] AI is also being used to help identify which medications already available could be used to treat the disease. Developed by Harvard Medical School and Massachusetts General Hospital, researchers hope this could prove a quick and cost-effective way to repurpose existing therapies to treat the condition as well as discovering new treatments. [50]

In the EU, the AI-Mind project, with a budget of €14 million, is undertaking a study with 1,000 participants to identify AI tools that can be used to predict who is likely to develop dementia. The program predicts that more than 80 million people will be living with dementia by 2030, up from about 50 million today. [51] In the US, researchers have been using AI to examine word usage to identify early signs of Alzheimer's. Subtle changes in word usage patterns could enable identification of the disease years before symptoms appear. [52]

This deep-learning NLP technology is also being used to improve the effectiveness of mental health care. As a result of the pandemic, demand for mental healthcare services has risen exponentially. According to the American Psychological Association, psychologists are seeing increased demand for treatment for many psychological disorders, particularly anxiety and depression. More than four-fifths (84 percent) of psychologists saw increased demand for treatment of anxiety disorders since the start of the pandemic, and 72 percent reported increased demand for treatment of depression over the same period. [53, 54]

AI and peer review

For many, peer review is the phase of the publishing process that is most ripe for change, with time-poor researchers struggling to keep up with requests to review the ever-growing number of submissions. As we discussed in our original report, new models of peer review have been trialed in recent years, as has open peer review, but these initiatives have yet to move the needle in any meaningful way. When we were conducting the study for that report, there was much speculation whether AI could prove a catalyst for change. In many cases, it was already playing an active role in the early checking of submissions; for example, by detecting plagiarism or language quality issues. StatReviewer, a product which provides "an automated review of statistical and reporting integrity for scientific manuscripts" [55] had been integrated into the widely-used submission and peer review system Editorial Manager provided by Elsevier, available to reviewers and editors. In March 2020, UNSILO announced that its AI-supported screening tools - Evaluate Technical Checks – had been fully integrated into editorial management system ScholarOne. [56]

In July 2020, open access publisher Frontiers announced that AIRA – its Artificial Intelligence Review Assistant – was being made available to all participants in the peer review process – editorial board members, reviewers and authors. [57]

Elsevier's smart Reviewer Recommender tool draws on machine learning and data science to provide editors with not only the name and contact details of a potential reviewer, but their publication history and current reviewing commitments. Elsevier has also turned to data science to support journals overwhelmed by pandemic-related submissions, using it to sort manuscripts and flag those with a COVID-19 link to editors, although the paper still undergoes the same peer review process as other submissions.

In recent years, there has been talk of AI replacing, rather than supporting human peer review, although, for some, these discussions are likely to remain "largely hypothetical" for the foreseeable future. [58] In fact, in our last report, Saul Tendler, Acting Vice-Chancellor of UK's York University, suggested that: "AI peer reviewed papers without human involvement at all is unlikely within our lifetime or our children's lifetimes." [59] There are some in the community, however, who feel that automated evaluation has the potential to not only speed up the peer review process and increase efficiency, but reduce errors and increase impartiality.

> *"Some reviewers take a long time to respond. An intelligent system would be much faster."*
>
> Chemical Engineering, Egypt, aged 46-55

To read or not to read AI reviewed articles

When we asked researchers how likely they are to read research that has been peer reviewed by AI rather than by a human, 21 percent agreed, a 5 percent increase from the 16 percent who agreed a year ago. When we asked researchers their reasons for agreeing, they believed it would reduce subjectivity and ensure consistency across reviews, a challenge some felt the current system does not do particularly well.

"Artificial intelligence (AI) is fairer than human peer review, human peer review is not a good thing because reviews are biased by the subjective view of the reviewers, reviewers are not balanced in comparison to AI."

Psychology, Germany, aged 36-45

When we asked researchers why they disagreed it was often because they valued human understanding and believed AI incapable of quality peer review.

"Peer review is very complex, and requires deep knowledge and critical thinking to assess the value and innovation of a given research work, and to identify possible confounding factors or biases. It is already very complicated for humans, and far beyond the capabilities of (current) AI systems."

(Computer Sciences / IT, France aged 36-45)

"By human peer review, I can have a very helpful communication with the reviewers who are usually the knowledgeable experts and scientists, and that surely builds a better vision and deeper understanding for me."

Electrical Engineering, China, aged 36-45

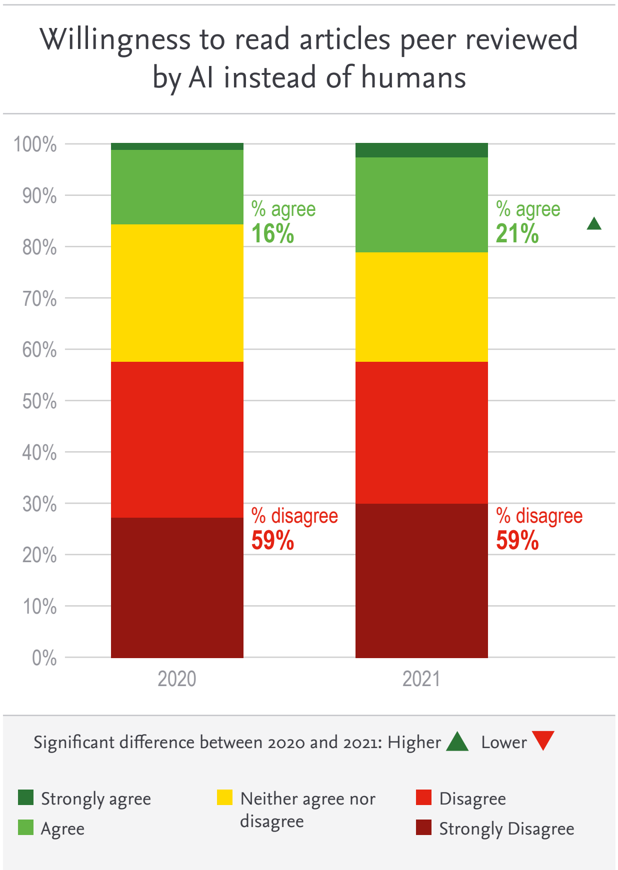


***Figure 38**: Question: "To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: I would be willing to read articles in a journal that relies on artificial intelligence (AI) instead of human peer review." Source: Researcher survey 2020 and 2021. Base 2020= 1066 and 2021 base=1173. Note: in 2020 it was not % agree BUT % likely).*

Generally, acceptance of AI-reviewed research appears to be growing, though from a low base, with all researchers more willing to read AI-reviewed articles than was the case last year. When we examine the results by gender we see almost double the proportion of female researchers would be willing to read AI-reviewed articles than was the case a year ago (19 percent now versus 10 percent in 2020). (Although not charted here the gender split and other segmentations are available in the full data analyses of research results available with this report).

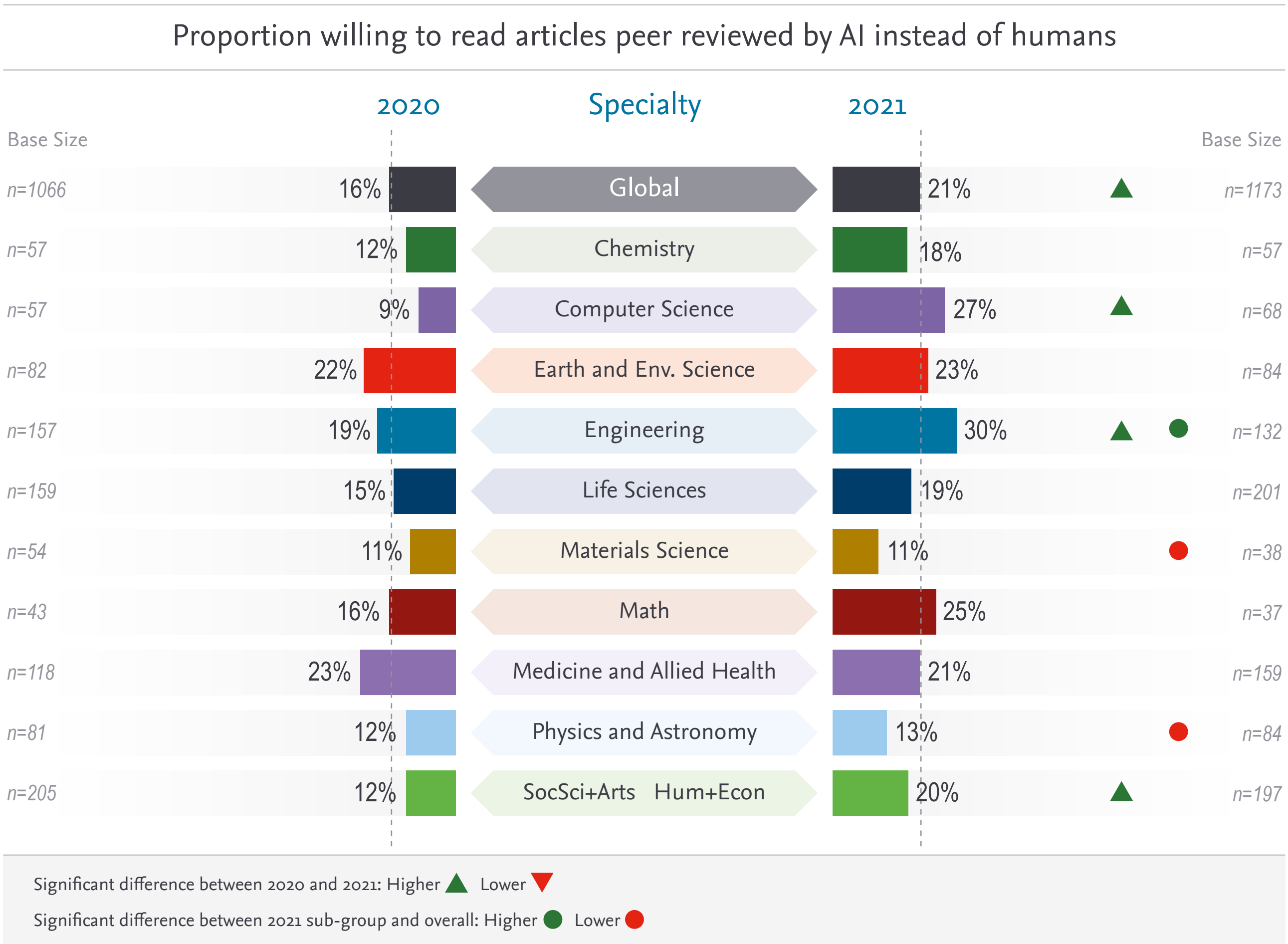


***Figure 39**: Question: "To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: I would be willing to read articles in a journal that relies on artificial intelligence (AI) instead of human peer review." Source: Researcher survey 2020 and 2021. Base 2020= 1066 and 2021 base=1173. Note: in 2020 it was not % agree BUT % likely).*

When we look at researchers' views by specialty, the fields of Engineering, Computer Science and Math are the most willing to read AI-reviewed articles, while Materials Science and Physics are the least likely. However, overall, almost two in three researchers said they would not be willing to read such articles (58 percent), a similar proportion as in 2020. Those who were willing to read AI-reviewed research cited the likely lack of bias versus research reviewed by humans, while those who disagreed were doubtful that AI's abilities were as good as a human.

Use of AI in research

When we asked researchers the extent to which they use artificial intelligence in their research, just 16 percent can be considered heavy users, a figure likely skewed by a considerably higher adoption rate in Computer Sciences (64 percent). While the majority are not heavy users, many recognize the nature of research work is likely to change in the years to come, with modeling and computer-based experiments increasing and researchers required to adopt (and adapt to) new tools and instruments.

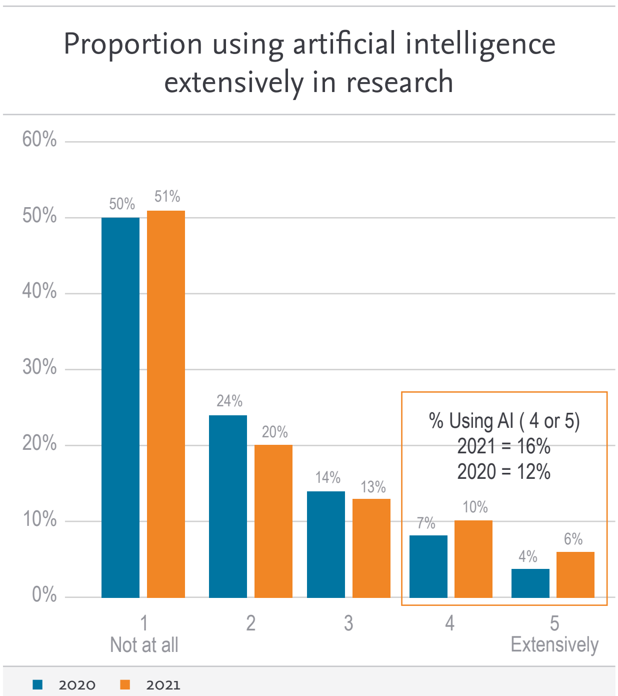


***Figure 40**: Question: "To what extent do you use Artificial Intelligence (AI) in your research? Please indicate your response on a five-point scale where 5 is extensively and 1 is not at all." Source: Researcher survey 2020 and 2021. Base 2020= 1066 and 2021 base=1173. Note: in 2020 it was not % agree BUT % likely).*

"The arrival of new computational platforms such as quantum computing has the potential to make a big revolution in scientific modelling and simulation."

Electrical / Electronic Engineering, Brazil, aged 56-65

AI has become notably used in some specialties since last year. In Materials Science, 18 percent are now likely to be heavy users of AI in their research, up from zero a year ago. In Chemistry, a similar change has taken place, with 19 percent now heavy users of AI compared with 2 percent last year. Math has risen to 13 percent from 4 percent a year ago.

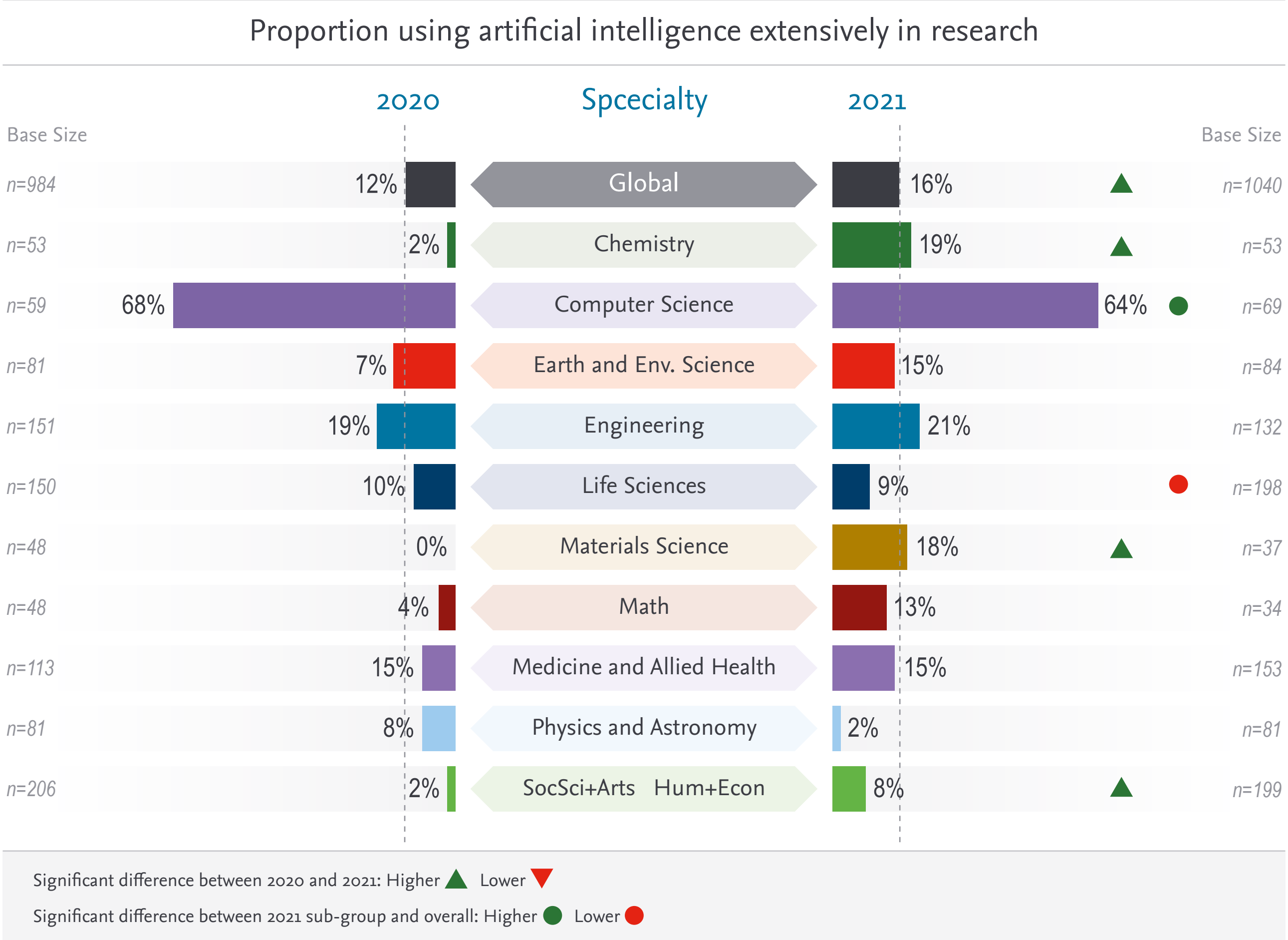


***Figure 41**: Question: "To what extent do you use Artificial Intelligence (AI) in your research? Please indicate your response on a five-point scale where 5 is extensively and 1 is not at all." Source: Researcher survey 2020 and 2021. Base 2020= 1066 and 2021 base=1173. Note in 2020 it was not % agree BUT % likely).*

Of all those who do use AI, most researchers (66 percent) use it to analyze their results. It is also used to process data sets to spot defects or issues, as well as to help with repetitive tasks. Notable, though, is the use of AI to help generate hypotheses. In our original 2019 study, we postulated that the hypotheses driving new research projects would be determined by data, not ideas.

Scenario Match

In the scenario **Brave Open World** we predicted developments in artificial intelligence (AI) would mean hypotheses can now be data-driven.

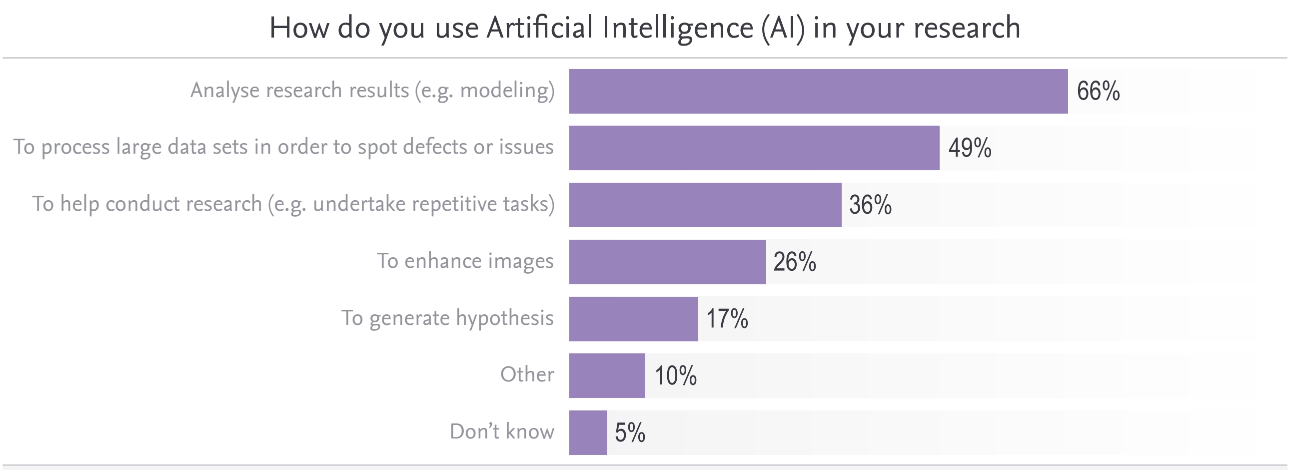


***Figure 42**: Question: "How do you use Artificial Intelligence (AI) in your research?" Source: Researcher survey 2021. Base all researchers who use AI = 479*

China's tech focus

China is investing heavily in areas that would make the country less reliant on foreign technology, with a focus on semiconductors. China is seeking to develop new chips domestically and plans to spend US$150 billion to develop its semiconductor industry by 2030. In 2020, China spent more than US$300 billion on imported chips. Some industry observers are concerned that a dual semiconductor system could result in incompatibilities and harm innovation globally.

As well as seeking technological independence, China is boosting its local talent bank. More than 10 percent of academics in Chinese universities moved there from overseas in the past three years, with the numbers accelerating since the beginning of the pandemic. The number of full-time equivalent researchers in China was 1.12 million in 2020, almost on a par with the EU's 1.13 million (after Brexit), and bigger than the 1.10 million in the US. Many of these are returning Chinese citizens who are coming home with higher degrees and research experience. Often enticed home by the offer of generous benefits, their return has coincided with a sharp rise in published research and may also be changing the collaboration landscape. According to the Nature Index, US-China collaborations grew by an average of more than 10 per cent each year from 2015 to 2019, but showed no growth in 2020.[60]

The rise of robotics

Patients' reaction to robotic care has been positive. According to a study conducted at Brigham and Women's Hospital where 41 patients agreed to be interviewed about their symptoms by a robot, more than 90 percent said that the experience was similar to interacting with a healthcare worker. [63]

According to research organization, Robotics for Infectious Diseases, as of January 2021, robots were being used to directly combat the pandemic in at least 45 nations, leading some to describe this as their "breakthrough moment."[64] A study by roboticists Murphy, Adams and Gandudi found that ground and aerial robots have played a role in almost every aspect of the COVID-19 crisis, including helping out in labs. [65]

In our original report, we also examined the rising use of robots in surgery, with their actions typically guided by an experienced – and some might say, reassuring – human hand. The use of robots – programmable machines that can carry out tasks independently, or semi-independently – has surged since the pandemic. For example, in September 2021, the EU delivered its 200th disinfection robot to a hospital in the bloc, with another 100 on the way. [61] Each robot can disinfect a standard patient room in less than 15 minutes. Furthermore, in Italy, when six doctors at a hospital in Sardinia contracted COVID-19, UVD robots were called in to disinfect the rooms using UV light, a process which destroys the DNA or RNA of microorganisms. [62] The same robots have been rolled out in Chinese hospitals.

Reported use of robots (Ground, Aerial) worldwide for COVID-19

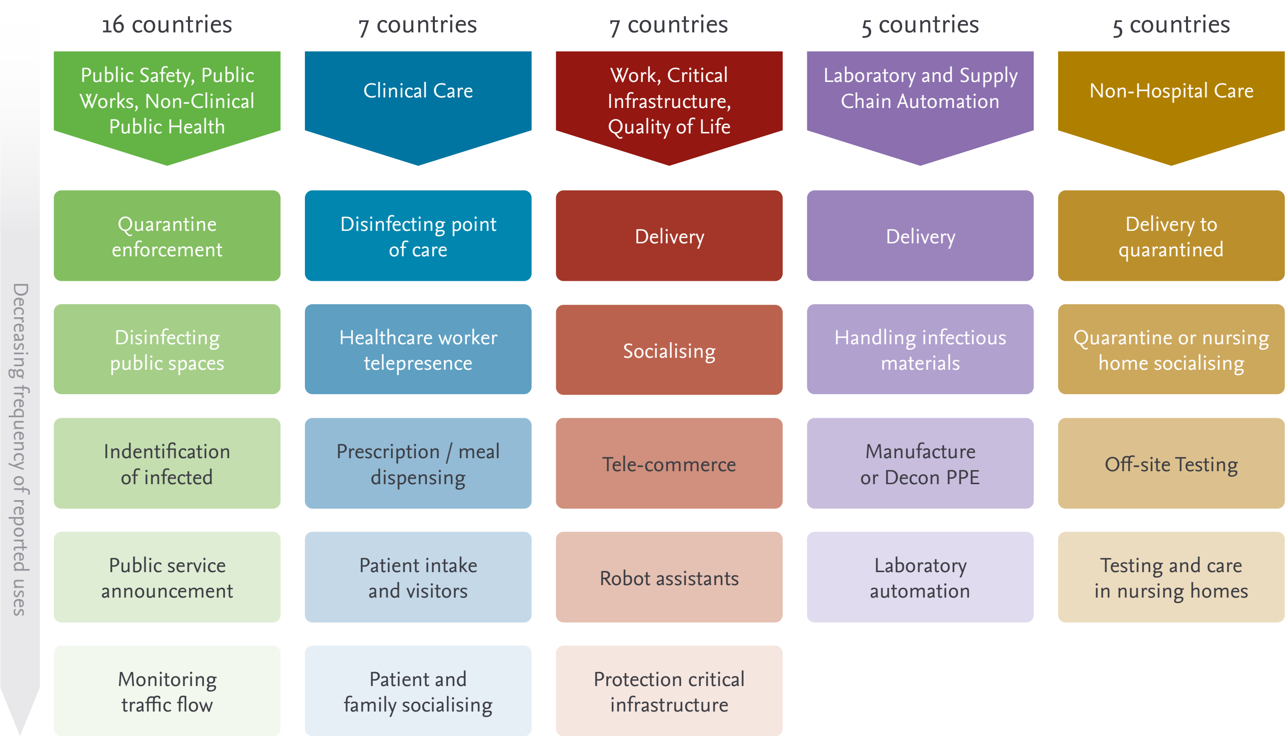


Figure 43: *Reported use of robots (ground and aerial) for COVID-19 across the globe as of 20 April 2020. Source: World Economic Forum.* [77]

Space & Astronomy

In another sign of China's ascendance, the country has been making headway in space during the pandemic. In June 2020, it put the final part of its BeiDou satellite navigation network into orbit, which may become a competitor to the US GPS system. In May 2021, its robotic rover landed on Mars, becoming the second country after the US to do so. [66] According to the vice chief of operations for the US Space Force, China is expanding its space capabilities at twice the rate of the US and could outpace the US by 2030. [67] In our original study in 2019, we identified that China would make progress in this area and by the end of the decade would be in a position to send a crewed mission to Mars.

In December 2021, NASA, in collaboration with the European Space Agency and the Canadian Space Agency, launched the James Webb Space Telescope, the successor to the Hubble Space Telescope and the "most ambitious observatory ever built", according to Scientific American. [68] JWST could look further into the past of the universe than ever before, reaching back to the 100 million years following the big bang. It will start sending data back to Earth in the summer of 2022, including a mission to look for direct evidence of the existence of planets orbiting stars other than the sun. UK scientists led the international team that developed and launched MIRI, the Mid-Infrared Instrument attached to the telescope, which is capable of seeing the light from the most distant stars and stars being born. Caroline Harper, Head of Space Science at the UK Space Agency, called the event "… a fantastic example of academic-industry partnership, showcasing the skills and expertise of our scientists and engineers." [69]

New jobs, new skills

In our last report, we predicted that as large tech and data companies become curators and distributors of knowledge, a growth in demand for data expertise, and particularly data engineers, would drive our "**Tech Titans"** scenario. We can see signs that this is now coming to pass. As we discuss in our essay **"The Academy and Beyond"**, online learners are showing growing interest in acquiring data skills. The jobs are also there: LinkedIn expects 150 million technology-related jobs to be offered over the next five years, with AI specialism the most in-demand requirement in its latest report. Machine learning engineers and researchers are also in high demand. In the US, demand for data scientists and data engineers is growing at an average annual rate of 35 percent for both roles. [70] The number of data engineering job listings in the US grew by 15 percent in the second quarter of 2021 compared to the first quarter, and had increased by 50 percent compared to 2019. [71]

Many countries have recognized the urgency to ensure future researchers are equipped with digital and data skills. For example, according to an OECD report into the impact of COVID-19 on Science, Technology and Innovation, the German Council for Scientific Information Infrastructures has charted future digital educational and training needs at both vocational and scientific research levels. In Australia, skilled workforce development and training is a key area of activity of the Australian Research Data Commons, a national initiative supporting Australian research, while the UK Arts and Humanities Research Council requires PhD students to undertake digital training and has drafted a framework against which skills are monitored. As we noted in our original report, initiatives like these will be crucial – there is currently a skills shortage in these areas, leaving academia to compete with big business for the limited pool of experts and developers available.

Blockchain

According to the Open Science Chain (OSC), blockchain is a type of distributed ledger technology that offers a secure cryptographically protected record of transactions (blocks). Blockchain's "append only" structure prevents altering or deleting previously entered data. [72]

Writing in September 2020, software developer Tarek Madany Mamlouk announced: "The blockchain hype is over. While two years ago everything was blockchain, today blockchain is what it is supposed to be: A clever solution for specific problems." He added: "The last years taught us how to build blockchains efficiently, the next years will bring maturity, scalability and interoperability." [73] His views chime with those of Gartner – blockchain featured in its 2020 list of strategic technology trends with the research company predicting it will become fully scalable by 2023. [74]

However, for some, blockchain will not reach its full potential until there is a way to navigate the roadblocks slowing down adoption. For the Blockchain Council, an international group of subject experts, there are five of them: [75]

- **Scalability**:
  Many transactions currently take too long for existing networks.
- **Interoperability**:
  Most blockchains work in silos and do not communicate with peer networks.
- **Energy consumption**:
  A high volume of computational power is required to process, verify and secure the network.
- **Lack of talent**:
  There is an acute shortage of blockchain experts and developers. At the same time, demand is rising - in 2019, global vacancies for blockchain engineers rose 517 percent compared to 2018.
- **Lack of standardization**:
  There is no universal standard network.

Blockchain terminology

"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." [85]

Some companies have been leveraging blockchain to help during the pandemic; for example, to ensure the quality and origin of COVID-19 medical equipment, or to support COVID-19 contact tracing applications. [76] One such project is IBM's blockchain-based Digital Health Pass application, which can be used to verify a person's COVID-19 test and their temperature and allows the user to set different criteria, for example a positive vaccination status. In the pharmaceuticals sector, Novartis, Merck and the Polytechnic University of Madrid have developed a blockchain-powered app called PharmaLedger that can scan medicine packages and request updated information from manufacturers as well as allowing patients to access the information. The team is now looking at other uses of blockchain including countering fake or black market medication. [77]

One of the most promising aspects of blockchain for research is its potential to support and facilitate open science, and 2019 saw the launch of the US National Science Foundation-funded Open Science Chain (OSR). A cyberinfrastructure platform built using blockchain technologies, the OSR "securely stores metadata and verification information about research data and tracks changes to that data in an auditable manner in order to address issues related to reproducibility and accountability in scientific research."[78] In August 2021, the project was awarded a $500,000 National Science Foundation grant that will allow the team to develop their Open Science Chain – Integrity Services (OSC-IS). "Our goal with OSC-IS is to ensure that sharing is conducted in a secure environment with considerations of confidentiality for private data assets which may extend to fields in metadata." said Principal Investigator Subhashini Sivagnanam. [79]

A December 2020 report by the OECD described the progress in the use of blockchain in the health sector as "still immature…The most promising applications of blockchain in the health care sector are for identity management, dynamic patient consent, and management of supply chains for medical supplies and pharmaceuticals...". [80] According to International Data Cooperation (IDC), although blockchain retains its potential to be disruptive and investment continues to grow, adoption remains in its early stages with most projects still at the pilot or proof of concept phase. [81]

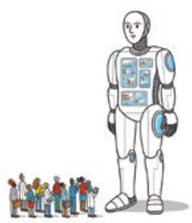
Virtual reality (VR) and augmented reality (AR)

In our previous report, we described virtual reality and augmented reality as two potential game changers. We highlighted their ability to transform how society learns, collaborates and communicates. In the case of augmented reality (AR), that prediction is unfolding. AR, which overlays virtual information on top of our existing natural environment, saw unprecedented growth in 2020. And while use of virtual reality (VR) is also on the rise, its growth rate continues to lag behind that of AR, largely because users typically require special – and, currently, expensive – headsets or goggles to enter VR's computer-generated recreations of real-life environments and situations.

The technology has been particularly useful in healthcare during COVID-19. For example, Microsoft's HoloLens Mixed Reality headsets were used by frontline medical staff at Imperial College Healthcare NHS Trust to provide remote care during the early days of the pandemic. Clinicians visited their patients in high-risk wards while wearing full PPE and a HoloLens. They were able to feed live footage to their colleagues in low-risk areas using the technology. It allows a reduction in time staff need to spend in high-risk areas and also reduces the need for PPE.

Imperial College Healthcare NHS trust reports that using HoloLens has cut time spent in high-risk areas by up to 83 percent and saves up to 700 items of PPE per ward, per week. [82]

COVID has helped to highlight the potential for the use of VR in healthcare. In the Netherlands, VR is being used to treat patients with long COVID-19 symptoms. Radboud University Medical Center has provided patients with a VR headset that includes games for physical rehabilitation, relaxation, mindfulness and cognitive training. The set is provided for six weeks' use at home or with a physical therapist. [83] In the University Medical Center in Groningen in the Netherlands, VR has been found to be an effective and easy-to-use method of quickly reducing the perceived stress levels of nurses working in intensive care units. [84]



Scenario Match:

In our **Tech Titans** scenario, we envisaged the increased uptake of AI-enabled technology across industry and healthcare.

AR has also been supporting telework (working from home using the internet, email, and the telephone), with new initiatives emerging to meet the growing need for remote support. For example, Spatial is a start-up that enables people to meet in virtual spaces through augmented or virtual reality using headsets. [85] Inspired by companies holding meetings in online virtual world Second Life, VirBela has developed a platform that lets conferences take place in custom-designed virtual worlds, while Argodesign is working on an artificial computer window that simulates working next to a real-life colleague. [86]

In China, SenseTime, an AI company focused on augmented reality and best known for its facial recognition technology, has seen its daily active user numbers reach more than 100 million since the launch of the company in 2016. [87]

References

1 Budd, J. et al. Digital technologies in the public-health response to COVID-19. Nat Med 26, 1183–1192. 2020. https://doi.org/10.1038/s41591-020-1011-4

2 Reinsel, D., Gantz, J. & Rydning, J. The Digitization of the World – From Edge to Core. IDC White Paper. November 2018. https://www.seagate.com/files/www-content/our-story/trends/files/idc-seagate-dataage-whitepaper.pdf

3 Balsari, S., Buckee, C. & Khanna, T. Which Covid-19 Data Can You Trust? Harvard Business Review. 8 May 2020. https://hbr.org/2020/05/which-covid-19-data-can-you-trust

4 OECD Science, Technology and Innovation Outlook 2021: Times of Crisis and Opportunity. OECD Publishing. 2021. https://doi.org/10.1787/75f79015-en

5 MacGillivray, C. IDC's Worldwide Future of Connectedness 2021 Predictions. IDC. 15 January 2021. https://blogs.idc.com/2021/01/15/idcs-worldwide-future-of-connectedness-2021-predictions/

6 Chebib, K. IoT applications in the fight against COVID-19. GSMA. 25 September 2020. https://www.gsma.com/mobilefordevelopment/blog/iot-applications-in-the-fight-against-covid-19/

7 Rathi, C. Demand Drivers for Edge Computing Amidst the COVID crisis. Frost & Sullivan. 15 October 2020. https://ww2.frost.com/frost-perspectives/demand-drivers-edge-computing-amidst-covid-crisis/

8 What is edge computing? IBM. Accessed on 23 January 2020. https://www.ibm.com/nl-en/cloud/what-is-edge-computing

9 AI and control of Covid-19 coronavirus: An overview. Council of Europe. Accessed on 25 January 2020. https://www.coe.int/en/web/artificial-intelligence/ai-and-control-of-covid-19-coronavirus

10 Porter, S. Pfizer COVID-19 vaccine data leaked by hackers. Healthcare IT News. 14 January 2021. https://www.healthcareitnews.com/news/emea/pfizer-covid-19-vaccine-data-leaked-hackers

11 Schneier, B. The US has suffered a massive cyberbreach. It's hard to overstate how bad it is. The Guardian. 23 December 2020. https://www.theguardian.com/commentisfree/2020/dec/23/cyber-attack-us-security-protocols

12 Ben-Gurion University of the Negev. New Cyberattack Can Trick Scientists Into Making Dangerous Toxins or Viruses. ScitechDaily. 6 December 2020. https://scitechdaily.com/new-cyberattack-can-trick-scientists-into-making-dangerous-toxins-or-viruses/

13 Ang A. 23 August 2021. https://www.healthcareitnews.com/news/anz/australia-report-shows-most-data-breaches-first-half-2021-occurred-healthcare-organisations

14 Euronews.com 19 July 2021. https://www.euronews.com/2021/07/19/dutch-authorities-defend-digital-covid-19-testing-system-despite-security-breach

15 Fisher, C. K. et al. Machine learning for comprehensive forecasting of Alzheimer's Disease progression. Sci Rep 9, 13622. 2019. https://doi.org/10.1038/s41598-019-49656-2

16 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

17 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/

18 Globaldata.com 22 January 2021. https://www.globaldata.com/artificial-intelligence-will-disruptive-technology-across-pharmaceutical-industry-2021-beyond/

19 Yakobovitch, D. How to Fight the Coronavirus with AI and Data Science. Towards Data Science. 15 February 2020. https://towardsdatascience.com/how-to-fight-the-coronavirus-with-ai-and-data-science-b3b701f8a08a

20 Stieg, C. How this Canadian start-up spotted coronavirus before everyone else knew about it. CNBC. 03 March 2020. https://www.cnbc.com/2020/03/03/bluedot-used-artificial-intelligence-to-predict-coronavirus-spread.html

21 Callaway, E. 'It will change everything': DeepMind's AI makes gigantic leap in solving protein structures. Nature. 30 November 2020. https://www.nature.com/articles/d41586-020-03348-4

22 Sharma, T. K. 5 KEY CHALLENGES FOR BLOCKCHAIN ADOPTION IN 2020. Blockchain Council. 26 March 2020. https://www.blockchain-council.org/blockchain/5-key-challenges-for-blockchain-adoption-in-2020/

23 COVID-19 Open Research Dataset Challenge (CORD-19): An AI challenge with AI2, CZI, MSR, Georgetown, NIH & The White House. Kaggle. Accessed 06 January 2020. https://www.kaggle.com/allen-institute-for-ai/CORD-19-research-challenge

24 World Healthcare Organization. 28 June 2021. https://www.who.int/news/item/28-06-2021-who-issues-first-global-report-on-ai-in-health-and-six-guiding-principles-for-its-design-and-use

25 Ross, C. Hospitals are using AI to predict the decline of Covid-19 patients — before knowing it works. Stat. 24 April 2020. https://www.statnews.com/2020/04/24/coronavirus-hospitals-use-ai-to-predict-patient-decline-before-knowing-it-works/

26 Editorial: Artificial intelligence for COVID-19: saviour or saboteur? The Lancet Digital Health. January 2021. https://www.thelancet.com/journals/landig/article/PIIS2589-7500(20)30295-8/fulltext

27 Liu, X. et al. Reporting guidelines for clinical trial reports for interventions involving artificial intelligence: the CONSORT-AI extension. Nat Med 26, 1364–1374. 2020. https://doi.org/10.1038/s41591-020-1034-x

28 Overmeyer, Z. et al. Dissecting racial bias in an algorithm used to manage the health of populations. Science Vol. 366, Issue 6464, pp. 447-453. 25 October 2019. https://doi.org/10.1126/science.aax2342

29 Buolamwini, J., & Gebru, T. Gender Shades: Intersectional Accuracy Disparities in Commercial Gender Classification. Proceedings of Machine Learning Research 81:1–15. 2018 Conference on Fairness, Accountability, and Transparency. 2018. https://www.media.mit.edu/publications/gender-shades-intersectional-accuracy-disparities-in-commercial-gender-classification/

30 Dickson, B. How deep learning can help scientific research. TechTalks. 20 April 2020. https://bdtechtalks.com/2020/04/20/deep-learning-scientific-research/

31 Kulp T. 14 April 2021. https://hrexecutive.com/ai-and-hiring-bias-why-you-need-to-teach-your-robots-well/

32 Li D et al. 18 February 2021. https://hbr.org/2021/02/is-china-emerging-as-the-global-leader-in-ai

33 O'Meara S. China's data-driven dream to overhaul healthcare. 6 October 2021. www.nature.com/articles/d41586-021-02694-1,

34 GADG: Chen S. Gadgets360.com 4 December 2020. https://gadgets360.com/laptops/news/quantum-computer-china-supremacy-google-sycamore-billion-trillion-times-faster-supercomputer-2334255

35 Letzter, R. China claims fastest quantum computer in the world. LiveScience. 7 December 2020. https://www.livescience.com/china-quantum-supremacy.html

36 Garisto D. Scientific American. China and quantum computers: 15 July 2021. https://www.scientificamerican.com/article/china-is-pulling-ahead-in-global-quantum-race-new-studies-suggest/

37 CSRC. Information Technology Laboratory. Post-Quantum cryptography. 2 December 2021. https://csrc.nist.gov/Projects/post-quantum-cryptography

38 TechHQ.com. 28 October 2021. https://techhq.com/2021/10/china-has-quantum-computers-that-are-a-million-times-more-powerful-than-googles/

39 Giles M. Forbes. 1 April 2021. https://www.forbes.com/sites/martingiles/2021/04/01/bidens-180-billion-plan-prioritizes-key-technologies/?sh=6f0b8850737dG

40 QTEU- EU Quantum Computing. Accessed January 2022. https://qt.eu/

41 Roberts J. Europa.eu. Horizon. 4 June 2019. https://ec.europa.eu/research-and-innovation/en/horizon-magazine/quantum-computers-will-soon-outperform-classical-machines

42 Flatz C. IDW. 18 June 2021. https://idw-online.de/en/news771059

43 Artificial Intelligence. European Commission. Accessed on 26 January 2020. https://ec.europa.eu/digital-single-market/en/artificial-intelligence

44 Brattberg, E., Csernatoni, R. & Rugova, V. Europe and AI: Leading, Lagging Behind, or Carving Its Own Way? Carnegie Endowment for International Peace. 9 July 2020. https://carnegieendowment.org/2020/07/09/europe-and-ai-leading-lagging-behind-or-carving-its-own-way-pub-82236

45 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/

46 O. & Decario, N. AI Can Help Scientists Find a Covid-19 Vaccine. Wired. 28 March 2020. https://www.wired.com/story/opinion-ai-can-help-find-scientists-find-a-covid-19-vaccine/

47 Dickson, B. How deep learning can help scientific research. TechTalks. 20 April 2020. https://bdtechtalks.com/2020/04/20/deep-learning-scientific-research/

48 Shahid, A. H. & Singh, M. P. A deep learning approach for prediction of Parkinson's disease progression. Biomed. Eng. Lett. 10, 227–239. 2020. https://doi.org/10.1007/s13534-020-00156-7

49 Turing. 13 April 2021. https://www.turing.ac.uk/news/ai-could-detect-dementia-after-single-brain-scan

50 Harvard Medical School. 4 March 2021. https://hms.harvard.edu/news/ai-alzheimers-disease

51 Ai-mind. Accessed December 2021. https://www.ai-mind.eu/

52 Hsu J. 22 October 2020. https://www.scientificamerican.com/article/ai-assesses-alzheimers-risk-by-analyzing-word-usage/

53 American Psychological Association. 19 October 2021. https://www.apa.org/news/press/releases/2021/10/mental-health-treatment-deman

54 Jee C and Heaven WD. MIT Technologyreview.com. 6 December 2021. https://www.technologyreview.com/2021/12/06/1041345/ai-nlp-mental-health-better-therapists-psychology-cbt/

55 StatReviewer website. Accessed 21 January 2020. http://www.statreviewer.com/

56 Rydahl, M. UNSILO and CACTUS announce full integration of Technical Checks with ScholarOne. Unsilo. 4 March 2020. https://unsilo.ai/2020/03/04/unsilo-and-cactus-announce-full-integration-of-technical-checks-with-scholarone/

57 Artificial Intelligence to help meet global demand for high-quality, objective peer-review in publishing. Frontiers Announcements. 1 July 2020. https://blog.frontiersin.org/2020/07/01/artificial-intelligence-peer-review-assistant-aira/

58 Gooch, P. Technology To Help Reviewers Keep On Top Of The Growth In Submissions. Scholarcy. 6 December 2020. https://www.scholarcy.com/how-reviewers-can-use-ai-right-now-to-make-peer-review-easier/

59 Research Futures: What will the world of research look like 10 years from now? https://www.elsevier.com/connect/elsevier-research-futures-report

60 Armitage C and Woolston C. Nature. 26 May 2021. https://www.nature.com/articles/d41586-021-01402-3

61 EC.europa.eu. 21 September 2021. https://ec.europa.eu/commission/presscorner/detail/en/mex_21_4825

62 Abano Hospital Veneto. UVD Robots. Accessed 19 January 2021. https://www.uvd-robots.com/italy

63 Berreby D. The pandemic has been good for one kind of worker: robots. National Geographic. 3 September 2020. https://www.nationalgeographic.com/science/2020/09/how-pandemic-is-good-for-robots/

64 WEF: weforum.org. Trafton A. 10 March 2021. https://www.weforum.org/agenda/2021/03/why-robots-can-be-beneficial-in-healthcare

65 Murphy, R. R., Adams, J. & Gandudi, V. B. M. Robots have demonstrated their crucial role in pandemics - and how they can help for years to come. World Economic Forum. 6 May 2020. https://www.weforum.org/agenda/2020/05/robots-coronavirus-crisis/

66 Reuters. China's recent achievements in space: 17 June 2021. https://www.reuters.com/world/china/major-milestones-chinese-space-exploration-2021-06-17/

67 Fisher K and Swire S. CNN. 4 December 2021. https://edition.cnn.com/2021/12/04/politics/american-experts-us-china-space-race/index.html

68 Panek R. Scientific American. 25 December 2021. https://www.scientificamerican.com/article/the-james-webb-space-telescope-has-launched-now-comes-the-hard-part1/

69 UK Space Agency. 25 December 2021. https://www.gov.uk/government/news/james-webb-space-telescope-launch-celebrated-by-uk

70 LinkedIn. Accessed December 2021. https://business.linkedin.com/talent-solutions/resources/talent-acquisition/jobs-on-the-rise-us

71 Dice Q2 Tech Job Report. https://marketing.dice.com/pdf/2021/Dice_Q2_Tech_Job_Report_Technologist.pdf

72 OSC: Blockchain definition https://opensciencechain.org/faq-page

73 Mamlouk, T. M. 2020 — Is Blockchain still a thing? Techblog. 10 September 2020. https://medium.com/axel-springer-tech/2020-is-blockchain-still-a-thing-2a0429430c3e

74 Panetta, K. Gartner Top 10 Strategic Technology Trends for 2020. Gartner. 21 October 2019. https://www.gartner.com/smarterwithgartner/gartner-top-10-strategic-technology-trends-for-2020/

75 Sharma, T. K. 5 key challenges for blockchain adoption in 2020. Blockchain Council. 26 March 2020. https://www.blockchain-council.org/blockchain/5-key-challenges-for-blockchain-adoption-in-2020/

76 Aarvik, P. Blockchain technology to prevent corruption in Covid-19 response: how can it help overcome risks? CMI. 2020. https://www.cmi.no/publications/7259-blockchain-technology-to-prevent-corruption-in-covid-19-response-how-can-it-help-overcome-risks

77 101blockchains.com Geroni D. 31 March 2021. https://101blockchains.com/top-blockchain-projects-ideas/#prettyPhoto

78 Sivagnanam, S. Nandigam, V. & Lin, K. Introducing the Open Science Chain: Protecting Integrity and Provenance of Research Data. In Proceedings of the Practice and Experience in Advanced Research Computing on Rise of the Machines (learning), article 18, 1–5. 2019. https://doi.org/10.1145/3332186.3332203

79 HPCwire.com 4 August 2021. https://www.hpcwire.com/off-the-wire/sdscs-open-science-chain-awarded-500000-nsf-grant/

80 OECD.org. December 2020. https://www.oecd.org/finance/Opportunities-and-Challenges-of-Blockchain-Technologies-in-Health-Care.pdf

81 Mearian, L. How Blockchain Plays into Digital Transformation. IDC. 14 December 2020. https://blogs.idc.com/2020/12/14/how-blockchain-plays-into-digital-transformation/

82 Mageit S. mobilhealthnews.com 9 June 2021. https://www.mobihealthnews.com/news/emea/himss21europe-getting-digital-innovation-ground-during-covid-19

83 Radboudumc.nl. 9 September 2021. https://www.radboudumc.nl/en/partners/collaboration-opportunities/virtual-reality-in-healthcare/news/use-of-vr-for-long-covid-discussed-in-atlas

84 Frontiersin.org. 29 September 2021. https://www.frontiersin.org/articles/10.3389/fpsyg.2021.706527/full

85 Chokkattu, J. You Can Now Attend VR Meetings—No Headset Required. Wired. 13 May 2020. https://www.wired.com/story/spatial-vr-ar-collaborative-spaces/

86 Magloff, L. TREND EXPLAINED: VIRTUAL REALITY, BEFORE AND AFTER CORONAVIRUS. Springwise. 24 June 2020. https://www.springwise.com/innovation-trends/virtual-reality-coronavirus

87 USnews.com 20 August 2021. https://www.usnews.com/news/technology/articles/2021-08-20/chinas-sensetime-says-daily-users-of-its-augmented-reality-tech-number-100-million

Building the future research information system

A quick glance back…

In our original report, we identified three key areas of change – these are featured in the blue boxes below. Each of these is accompanied by a bulleted breakdown of the shifts we anticipated would occur as that change unfolded.

Taken from ***Research futures 2019***

1

The role of the journal is transforming to meet modern needs

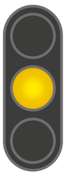
- In the future, the journal, or any new entities that emerge, will apply the same level of attention to the data and supplementary material as to the article. Most research articles will not be static, but will be updated by the author post-publication.
- As interdisciplinary collaboration, speed of 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.

Now, three years into the 10-year window and with COVID-19 impacting every element of our lives, how are those predictions standing up?

We have used a traffic light system to give an indication: red for no progress, amber for some progress, and green for a reasonable amount of progress.

Read the original **"Building the future research information system"** essay in *Research futures*
www.elsevier.com/research-intelligence/resource-library/research-futures

Key findings

- COVID-19 is accelerating some of the trends we identified in our original report, including the broader dissemination of research findings and the rising use social media in research.
  - That expansion has brought challenges for the public and researchers alike. The biggest red flag for researchers is when the source of data for the research is unclear (60 percent selected).
- Publishing moves faster, with more open knowledge. There has been a dramatic rise in the use of preprints.
  - More than two-thirds (67 percent) of researchers agree that preprints are an important way to communicate research, up from 43 percent a year ago. Support for preprints has increased across all disciplines.
  - Of those researchers that value preprints, the speed of dissemination and the ease of access are considered the greatest benefits (75 percent selected both).
  - Lack of peer review of preprint is the top concern among researchers who don't value preprints - 55 percent identified it as a disadvantage.
  - Linking preprints to the final article is key to improving the value of preprints (51% agree).
- Researchers want the public to have a greater understanding of researcher, particularly they want the public to appreciate the importance of basic research (67 percent agree).
- The United Nations' Sustainable Development Goals are having a transformative effect on research institutions and the systems they use to demonstrate their societal impact.

As one *Nature writer* noted, while the pandemic may have disrupted science, its effect on research publishing has proved nothing short of transformative. [1]
One aspect is the growth in the volume of articles published. According to an STM Global report, 2020 may have been a record year for article submissions, with an 8 percent growth in article numbers, mainly due to COVID-19. "Were it not for COVID-related papers, the growth in 2020 would have been just below 5 percent, making for a strong but unremarkable performance," the report says. [2]

We explore the surge in submitted papers in our essay **"How researchers work: change ahead"**. For example, the surge in papers has implications for journals and has increased the pressure on researchers in their reviewer and editor roles.

The good, the bad and the unknown

Hand in hand with the growth of research papers has been the sharing of research findings via various channels. As more and more research is shared, whether in data repositories, social media platforms, forums or personal websites, it is becoming increasingly difficult to discern reliable research from less reliable research.

This has implications for trust in science and for public health, among other issues. Rising awareness of the problem has helped to make fact-checking an integral part of many media and information organizations. During the pandemic, the consequences of misinformation have been highlighted, with some misinformation published online about vaccines resulting in many people in different parts of the world choosing not to get vaccinated. The term misinformation has been variously defined, with the Proceedings of the National Academy of Science (PNAS) suggesting the definition "…any piece of information that is initially processed as valid but is subsequently retracted or corrected". [3]

According to the Institute for Strategic Dialogue, much of the misinformation posted online is based on data that is genuine but which has been misappropriated, which makes it "…. sometimes more dangerous than outright false information, because it can take substantially longer to debunk by explaining how and why this is a misreading or misuse of the data." [4]

The sharing of false information and misinformation is rendered more effective and consequently more troubling by the speed of information sharing enabled by social media. Debate about whether or how to regulate, restrict or censor online misinformation is a fraught and complex topic that is unlikely to be resolved easily.

Even researchers who are best equipped to identify quality research struggle in a world where research findings are accessible through so many channels. Researchers have always looked for signals of quality, but the increases in volume, coupled with the increased pace of distribution can add a time burden to identifying quality research. Research findings being published in a peer-reviewed journal is a key requisite for most researchers, and one which helps them to navigate research, but that is not always sufficient, especially given the rise of predatory journals. [5]
The most cited red flag when deciding whether or not to engage with research findings was "Source of data is unclear" (60 percent), followed by "The journal the research appears in is perceived as low quality" (57 percent) and then "It has not been peer reviewed" (55 percent).

Red flags when engaging with research.

Figure 44: *Question: "When you encounter research findings, which of the following if any, are 'red flags' that make it unlikely you will engage with the research?" Source: Researcher survey 2021 base all researchers n=1173.*

The need for quick dissemination of research findings during the pandemic and growing pressure on researchers to share their data, along with the increase in papers, has led publishers to respond to the challenge by providing immediate access to key COVID-19 global research and data. These included Elsevier [6], Oxford University Press [7], Springer Nature [8] and Wiley [9]. (We discuss this topic in the section 'The impact of COVID-19' in the **"Pathways to Open Science"** essay within this report)

However, the demand for research information highlighted gaps in the research infrastructure. According to a Springer Nature report looking at the impact of COVID-19 on university research, while technology and the impact of the virus have accelerated the shift to digital, the "infrastructure supporting the free exchange of research information and data is still not equipped for the scale-up required." [10] Some researchers are having to work with unsuitable, or insufficiently sophisticated equipment and software. In fact, the report found that many researchers would welcome more integrated services from digital research service providers, and for institutions to develop a system that is service provider-agnostic. [10]

Globally, many governing bodies have recognized and are responding to the gaps in the research information infrastructure. For example, in the USA, the White House Office of Science and Technology Policy helped to spearhead the COVID-19 Open Research Dataset Challenge (CORD-19) initiative, which we explore in the **"Pathways to Open Science"** essay. During the pandemic, European intergovernmental organization ELIXIR has been accelerating its efforts to form a single infrastructure from life sciences resources, including databases, software tools, training materials, cloud storage, and supercomputers. At the European Future Innovation System Centre, focus on sharing the impact of research centers has grown during the pandemic. Noting the high cost of establishing these research infrastructures, the organization has been working to demonstrate the wider societal impact of these investments. [11] Meanwhile, the European Commission's European Data Portal [12] became a useful platform for sharing COVID-related information exchange and supporting research responses to the pandemic.

The pandemic has helped boost investment in research infrastructure. The Population Health Information Research Infrastructure, (PHIRI for COVID-19), funded by the European Commission, was launched as a COVID-19 health information project in November 2020. It links partners in 30 countries with the aim of helping researchers, policy makers, and organizations share and access data and expertise on its health information portal. It will also provide support for designing, analyzing, reporting and preserving data collections. [13]

Investment is also taking place at the national level. For example, the Dutch government launched a roadmap in 2021 for investing in large-scale scientific infrastructure with a budget of €200 million over five years. The roadmap was described as a "foundation for scientific progress" and will fund highly specialized equipment, such as large telescopes, as well as databases and scientific computer networks. [14]

The need for speed – the rise of preprints and rapid publication platforms

Perhaps one of the most striking shifts in publishing trends since the emergence of COVID-19 is the rapid growth in the posting of preprints, particularly in certain fields.

> *"The preprint phenomenon of recent times has to do with COVID-related research. I haven't seen any such change in reliance on peer-reviewed conference papers and journal articles in the fields I study."*
>
> Psychology, US, aged 46-55

Preprints are typically full draft research papers that are shared publicly (and quickly), prior to peer review – although, as we explore later, new services are arising to address that last point. Most preprints are citable and have their own digital object identifier (DOI).

Preprint servers are the online archives, or repositories, that have sprung up to house these early views of papers. They typically operate under a gold open access model, which means that content is immediately and freely accessible. Because there are no editorial services provided, authors aren't charged an article publishing charge (APC).

Scenario match

In the scenario **Brave open world**, we suggested that researchers would increasingly post preprints of their work to communicate research outcomes across a range of subject areas.

At the time of our original report, preprint servers arXiv, bioRxiv and SSRN were already rising in popularity. We predicted that the signs were strong their star would continue to rise, with several major funders issuing policies that supported the dissemination of results through preprint servers.

The signs are that this prediction is coming to pass. The growth of preprints has been one of the defining factors of the pandemic. According to a report in *Nature*, researchers published more than 100,000 articles about the pandemic in 2020. Of these, more than 30,000 were published as preprints, [1] with the majority published on either medRxiv, SSRN or Research Square.

"Preprints are more common and are more important in my research community now."

Medicine, Turkey, aged 36-45

Preprint servers are receiving more funding and expanding their range of services. In September, arXiv won financial support from Caltech, CERN, Georgia Institute of Technology and MIT, and in October 2021, the not-for-profit platform announced a five-fold increase in contributions from the American Physical Society and pledges of continuing support from three other leading societies. [15] In August, bioRxiv introduced B2X, a new delivery pipeline that allows authors to send manuscripts to a range of third-party services to carry out tasks such as checking for compliance with funder requirements or helping authors improve their manuscripts, and DataSeer, a service to help authors work with open data policies. [16] "arXiv has become an indispensable platform for scientific exchange in particle physics and beyond and submitting to arXiv is today a standard practice across CERN and the entire community." Joachim Mnich, CERN's Director for Research and Computing. [17]

Gregory J. Gordon, managing director of Elsevier responsible for preprint repository SSRN, said the secret to the growth of preprint servers 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. [18] Those are the very aspects that have seen them play such a key role in the response to the pandemic. On SSRN, for example, nine of the ten most downloaded papers in 2020 related to COVID-19. [19]

In fact, the first COVID-19 article appeared on the biology preprint server bioRxiv within 20 days of the Chinese government informing the World Health Organization about a new type of pneumonia in Wuhan. [20] By the end of January 2021, the open science life sciences platform Europe PMC had indexed more than 27,000 COVID-19-related preprints. [21] For comparison, in 2019, the total number of preprints deposited in bioRxiv – across all subjects – was 26,535. [20] In one study (published as a preprint), Lachapelle found that during the early stages of the pandemic, preprints represented nearly 40 percent of all English-language papers published on COVID-19 (although, by mid-August 2020, that figure had dropped to about 28 percent). [22] However, some believe the large COVID-19 preprint counts in circulation may have been inflated – possibly by more than 50 percent – due to factors such as duplicate papers. [23]

Growth of COVID-19 related articles and preprints

***Figure 45**: Cumulative growth of journal articles and preprints containing COVID-19 related search terms. Based on data extracted from Dimensions, preprint data is based on data gathered by Fraser and Kramer (2020).*

Source: "Preprinting the COVID-19 pandemic". [24]

Time-urgency during the pandemic spurred journals to speed up reviews of COVID-19 articles. According to one study, over the six months from January to June 2020, they succeeded in cutting acceptance of manuscripts from an average of
130 days to 90 days. [25]

While it is not yet clear whether levels of preprints will be sustained post-pandemic, some observers suggest that a precedent has been set and the high level of COVID-19 preprints shows their potential for what can be done in the event of a global crisis, such as climate change. [26]

"The time to actual publication is so slow as to interfere with progress in research, if it were not for preprints"

Environmental Sciences, age (prefer not to say), USA)

We have also seen growing integration of preprints into the tools that researchers rely on. For example, in July 2020, Europe PMC began indexing COVID-19-related preprints alongside peer-reviewed articles, to make them searchable, a move welcomed by the World Health Organization. [27] Elsevier's Scopus, the world's largest abstract and citation database, now includes preprints published from 2017 onwards. [28]

Although many journals will not consider papers previously published elsewhere, manuscripts that have already been shared as preprints are generally acceptable. In return, most publishers ask authors to update any pre-publication versions with a link to the final published article.

The increasing value of preprints – the researcher view

We asked the researchers participating in our 2020 survey which channel they expected to share their research on in the following 12 months. Sixteen percent chose 'preprint server' compared to only 7 percent at the time of our original report in 2019.
(see figure 11 in our essay **"Pathways to open science"**).

Support for preprints among the research community is growing apace. In our most recent survey conducted in late 2021, more than two-thirds of researchers (67 percent) agree that preprints are a valuable source of communication in research, up from 43 percent in the 2020 study. The most important benefits they cited were the increased speed of sharing research and the ease of access because the preprints are openly available. The proportion of those who didn't agree that preprints are valuable almost halved, to 12 percent, down from 21 percent in 2020.

"Since peer review in journals is where the bias of the reviewers determines adoption, we believe that preprints, which are a place where people can present their work freely, are a free place away from such bias."

(Biological Sciences, USA, age: prefer not to say)

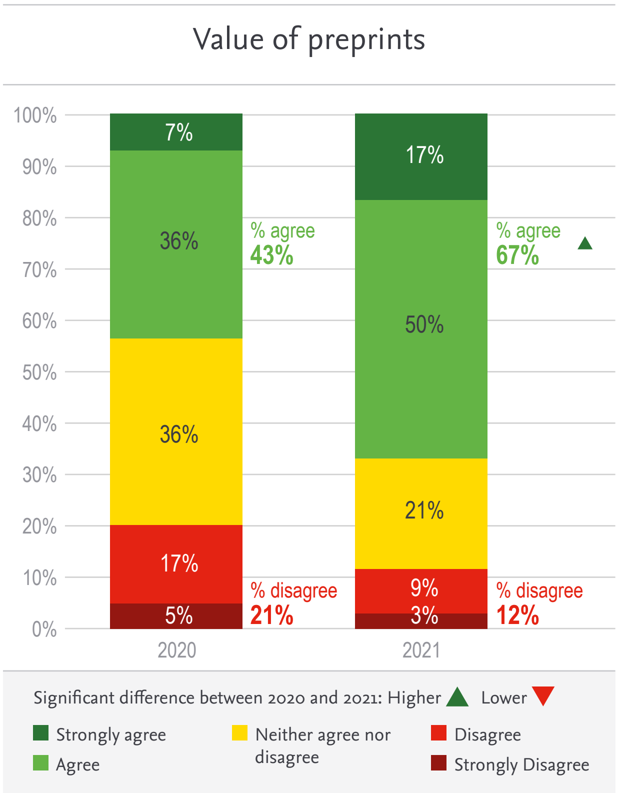


***Figure 46**: Question: "To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: Preprints are a valued source of communication in research." Source: Researcher survey 2021 base=1,141 and researcher survey 2020 base=1,041*

All disciplines increased their support for preprints compared to 2020. By specialty, support for the value of preprints was highest among researchers working in Physics & Astronomy (92 percent), Mathematics (89 percent) and Computer Scientists (81 percent). All three disciplines are served by arXiv, one of the longest running preprint servers. Somewhat surprisingly, the perceived value of preprints has greatly increased since 2020, when the figures for these disciplines were, respectively, 35 percent, 33 percent and 68 percent. Researchers working in Chemistry value preprints the least, with 36 percent agreeing they are valuable.

"I believe being incorrect is valuable. Published work is theoretically never incorrect until shown. Preprints allow an early view to work and approaches that may or may not be correct."

(Neuroscience, USA, aged over 65)

"Researchers in my field are in the same position as any reviewer to judge the quality of any paper I might publish as a preprint in the future. In fact, some of them WILL be reviewers on my papers. So why not let them know about my findings immediately after submission? That being said, I don't think preprints should be taken up by society, because laypeople generally lack the ability to judge the methods I (or any other researcher that publishes preprints) used to come to certain conclusions. This could lead to misinformation spreading to the public."

(Earth and Planetary Sciences, France, aged 26 to 35)

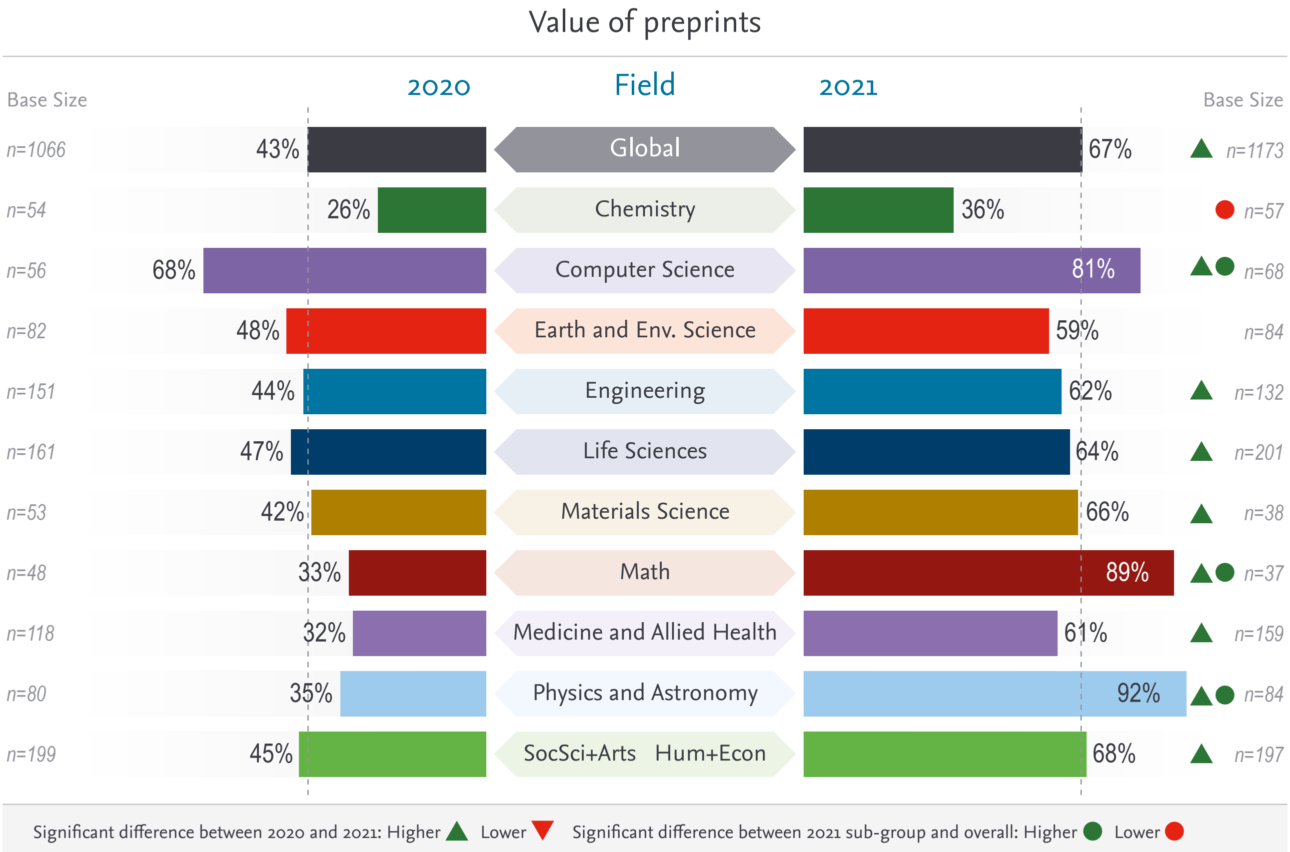


***Figure 47**: Question: "Preprints are a valued source of communication in research - % agree." Source: Researcher survey 2021 base=1,141 and researcher survey 2020 base=1,041.*

When viewed by gender, role and age, support for preprints had increased across the board compared to 2020. The biggest jump is seen in those aged 36-55, of whom 69 percent agree that preprints are valuable, up from 41 percent in 2020.

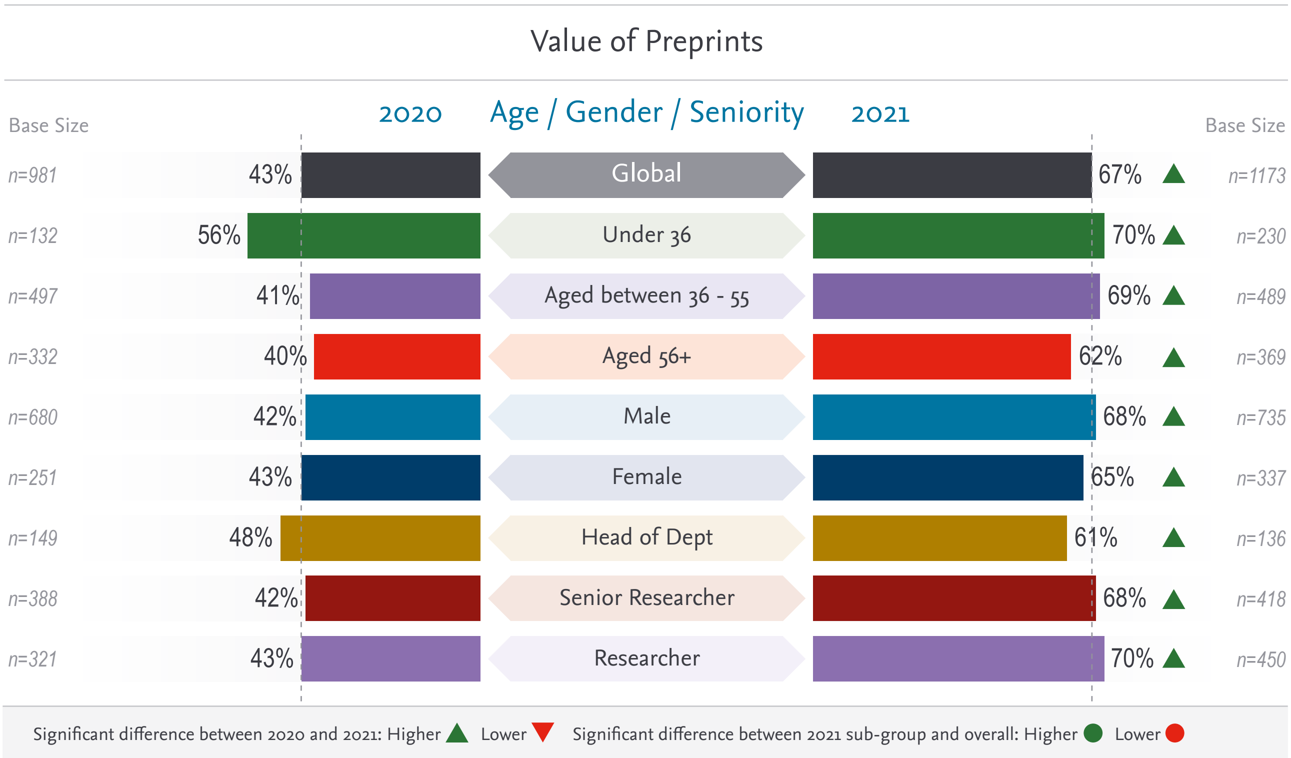


Figure48: *Question: "Preprints are a valued source of communication in research" - % agree. Source: Researcher survey 2021 base=1,141 and researcher survey 2020 base=1,041.*

Researchers were most likely to cite speed of dissemination and ease of access as the most important advantages of preprints, as seen from a reader-driven perspective. As authors, they also appreciate the opportunity to increase exposure to their work and the ability to capture early feedback.

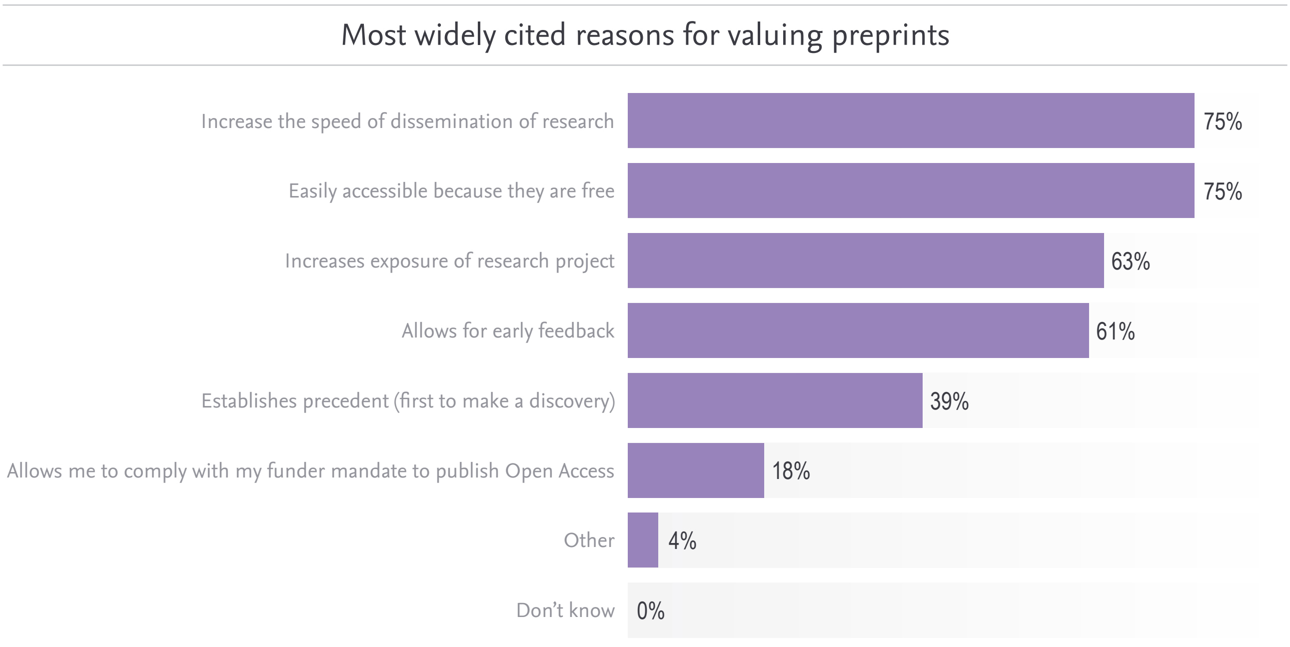


Figure 49: *Question: "You agreed with the statement 'preprints are a valued source of communication in research'. In which of the following ways are they valuable?" Source: Researcher survey base: All researchers who agreed that preprints are a valued source of communication in research. Base=746.*

The importance of validation

However, while preprints offer the benefits of freely-available content and rapid publication — which, in the case of COVID-19, have the potential to accelerate discovery and improve treatments and vaccines — for some critics there is no gain without pain. With preprints, the major pain point they cite is the lack of evaluation by others in the research community. Of the researchers who did not agree that preprints are a valued sourced of communication, the lack of peer review was the strongest reason for the lack of support (55 percent).

"I strongly believe in peer review. Most preprints do not successfully pass through the preprint stage without revision. These revisions can be important to the interpretation of the results"

Medicine and Allied Health, USA, aged 46-55

Disadvantages of preprints

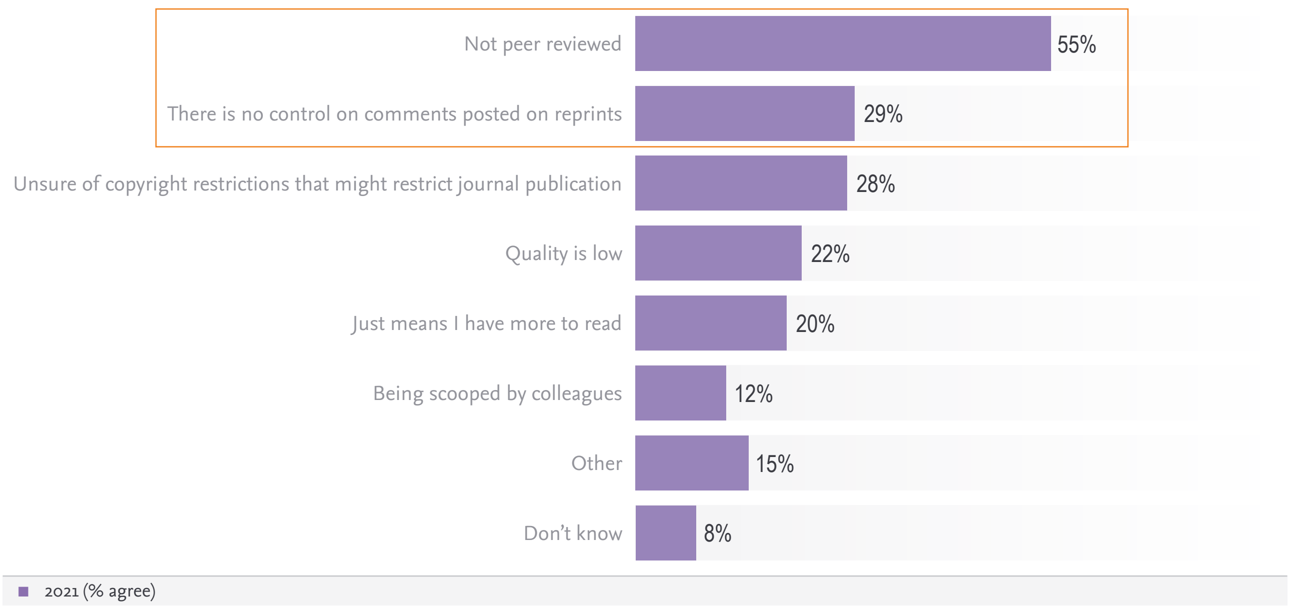


Figure 50: *Question: "You disagreed or were neutral with the statement 'preprints are a valued source of communication in research.' What do you see as some of the disadvantages of preprints?" Source: Researcher survey 2021 base =388 all researchers who disagreed or were neutral with the statement 'preprints are a valued source of communication in research'*

This was true across all specialties. In Medicine & Allied Health, that was the case for 71 percent of those who did not consider them valuable, the highest of any discipline, followed by 70 percent for those working in Earth & Environmental Sciences.

Disadvantages of preprints

By speciality:

Disadvantages of preprints:	TOTAL	Chemistry	Computer Science	Earth & Env. Science	Engineering	Life Sciences	Materials Science	Math	Medicine & Allied Health	Physics & Astronomy	SSE+Arts Hum+Econ.
Not peer reviewed	55%	52%	Base sizes too low	70%	42%	58%	Base sizes too low	Base sizes too low	71%	Base sizes too low	51%
No control on comments posted	29%	43%		23%	25%	33%			39%		23%
Unsure of copyright restrictions	28%	42%		35%	23%	25%			44%		24%
Quality is low	22%	20%		8%	23%	23%			35%		22%
I have more to read	20%	23%		33%	13%	20%			19%		13%
Being scooped by colleagues	12%	4%		22%	8%	28%			13%		10%
		n=33	n=14*	n=37	n=45	n=71	n=12*	n=7*	n=71	n=8*	n=62

*There are more funding requirements compared to 2-3 years ago. Significant difference between 2021 sub-group and overall: Higher ● Lower ●

Figure 51 *: Question: "You disagreed or were neutral with the statement 'preprints are a valued source of communication in research.' What do you see as some of the disadvantages of preprints?" Source: Researcher survey 2021 base all researchers who disagreed or were neutral with the statement 'preprints are a valued source of communication in research' base=388*

"Media outlets have begun realizing that they are oversimplifying research that includes caveats and biases that must also be presented in order to provide a complete picture. Cherry-picking results without context is becoming a bad look."

Computer Sciences / IT, US, aged 26-35

While all regions see the lack of peer review as the biggest disadvantage of preprints, there is a marked difference between APAC, where 41 percent of those who do not consider preprints valuable say the lack of peer review is a disadvantage, compared with Western Europe, where 71 percent see it as a disadvantage, and North America (61 percent).

Disadvantages of preprints

Disadvantages of preprints:	TOTAL	By region: Africa	APAC	Eastern Europe	Latin America	Middle East	North America	Western Europe
Not peer reviewed	55%	Base sizes too low	41% (Lower)	Base sizes too low	Base sizes too low	Base sizes too low	61%	71% (Higher)
No control on comments posted	29%		30%				21% (Lower)	34%
Unsure of copyright restrictions	28%		30%				26%	30%
Quality is low	22%		18%				23%	21%
I have more to read	20%		19%				26%	21%
Being scooped by colleagues	12%		10%				21% (Higher)	13%
		n=3*	n=38	n=28*	n=12*	n=16*	n=145	n=111

*There are more funding requirements compared to 2-3 years ago. Significant difference between 2021 sub-group and overall: Higher ● Lower ●

Figure 52: *Question: "You disagreed or were neutral with the statement 'preprints are a valued source of communication in research.' What do you see as some of the disadvantages of preprints?" Source: Researcher survey 2021 base all researchers who disagreed or were neutral with the statement 'preprints are a valued source of communication in research' base=388*

Science magazine's Jeffrey Brainard believes lack of peer review is the main worry "especially for findings about medical treatments that nonscientists might misinterpret, possibly at risk to their health." [29] He, and many others, believe that the coronavirus pandemic has heightened these concerns, particularly with research suggesting that COVID-19 preprints are accessed and distributed at least 15 times more than non-COVID-19 preprints. [24] In an interview with *Nature*, Richard Sever, a co-founder of bioRxiv and medRxiv, admitted: "We've seen some crazy claims and predictions about things that might treat COVID-19." [30] With much of that speculative work based on computational models, he and his team decided to bar those papers from bioRxiv. He concluded that there are just some things that "should go through peer review." [30]

Both bioRxiv and medRxiv already had a basic two-tier vetting process in place for submitted preprints, mainly designed to identify papers that might cause harm. Since the pandemic, and following the controversy that arose in the wake of a (since withdrawn) bioRxiv preprint reporting similarities between HIV and COVID-19, that process includes looking for "other types of content that need extra scrutiny — including papers that might fuel conspiracy theories." [30] Broad scope preprint server ArXiv and ChemRxiv, which publishes chemistry preprints, have also increased their screening procedures for COVID-19-related papers. [30]

In addition, medRxiv has introduced a warning in red letters on its homepage, cautioning readers that preprints have not been peer reviewed and should "not be relied on to guide clinical practice or health-related behavior" or "reported in news media as established information."[31] Similar warnings appear on the homepages of bioRxiv, arXiv, and on the coronavirus homepage of SSRN.

Similarly, opinions among researchers are varied as to the best way to improve preprints. One of the suggested ways that preprints could be improved is by linking them to the journal article (51 percent), followed closely by preprints being quality assured (45 percent). By specialty, researchers working in Physics are more likely to see the benefits of linkage than other disciplines, while the availability of metrics is seen as more beneficial by those working in Computer Science.

Improving preprints

By speciality:

Beneficial:	TOTAL	Chemistry	Computer Science	Earth & Env. Science	Engineering	Life Sciences	Materials Science	Math	Medicine & Allied Health	Physics & Astronomy	SSE+Arts Hum+Econ.
Preprints linked to article(s)	51%	54%	52%	46%	50%	46%	62%	52%	52%	66% (Higher)	46%
Preprints quality assured	45%	43%	50%	40%	43%	48%	24% (Lower)	56%	50%	45%	43%
Metrics available for preprints	37%	33%	52% (Higher)	26% (Lower)	34%	30%	31%	44%	37%	59%	35%
Readers rate pre-prints	30%	19%	46%	19%	32%	30%	26%	34%	31%	37%	27% (Lower)
Preprints display metrics	29%	24%	31%	24%	27%	31%	27%	30%	28%	47%	27%
Author's name embargoed to enable double-blind peer...	27%	32%	26%	26%	20%	26%	41%	42%	30%	16% (Lower)	33%
Pre-prints counted in metrics	25%	21%	19%	25%	22%	27%	19%	28%	26%	32%	22%
Federated search across all preprint servers	24%	28%	39% (Higher)	20%	20%	20%	12%	25%	15% (Lower)	41% (Higher)	20%
		n=57	n=70	n=87	n=137	n=204	n=39	n=39	n=165	n=86	n=207

*There are more funding requirements compared to 2-3 years ago. Significant difference between 2021 sub-group and overall: Higher ● Lower ●

***Figure 53**: Question: "Thinking about preprints and their role in research, do you believe any of the following would be beneficial?" Source: Researcher survey 2021 All researchers who disagreed or were neutral with the statement preprints are a valued source of communication in research n=388*

The changing dynamic between preprints and journals

While some in the academic community believe that we are entering "a preprint-first world," [32] in which preprints will replace traditional journal articles, others believe the two could form a symbiotic relationship. In a 2020 paper, Penfold and Polka highlighted "several tangible benefits" for journal editors and publishers in featuring preprints in their journals. [39] For example, studies suggest that preprinted papers garner more attention over time. They also allow authors to receive feedback from a broader range of scientists than the typical peer review process. Penfold and Polka also point to preprint servers as "efficient marketplace(s)" that editors can use to find interesting papers; PLOS Genetics and Proc B have already introduced initiatives along these lines. And they believe preprint servers can relieve the pressure on journals: if authors are able to share their preprints immediately, they may feel happier waiting for "high-quality, journal-organized peer review." [39] However, not all preprints will go on to be published as a final research article. One study found that by mid-September 2020, less than 50 percent of preprints uploaded in January that year had been published in peer-reviewed channels. [22] Other studies suggest a slightly higher average percentage. [24]

According to Fraser et al, "preprints have been widely adopted and used for the communication of COVID-19 research, and in turn, the pandemic has left what is likely to be a lasting imprint on the preprint and science publishing landscape." [24] How that further develops is currently difficult to predict, but it seems likely that the rise of preprints will continue.

There are other channels that share some common DNA with preprint servers in terms of rapid publication. For example, the "pre-publication" platform Research Square allows researchers to post their manuscript as a preprint and gain early feedback from the scientific community to "prepare it for peer review." [33] F1000's life sciences platform F1000Research offers rapid posting of research (in this case, within seven days of submission), prior to peer review, and with immediate open access. However, unlike preprints, F1000Research papers are considered to have been published, which means they can't be submitted elsewhere. Formal peer review takes place on the platform, and articles can go on to be indexed on bibliometric databases. The F1000 model has proved popular and research funders and institutions, including Wellcome Trust, the Bill & Melinda Gates Foundation and the Health Research Board Ireland, as well as scholarly publisher Emerald, have partnered with F1000 to launch their own branded platforms. In March 2020, it was announced that F1000 had won the contract to set up and manage a new open access publishing platform for the European Commission to host research funded by Horizon 2020 and Horizon Europe. [34]

Enhancing peer review

Peer review has long lain at the heart of scholarly communication, operated by researchers in association with academic journals and their publishers. In our original report, we suggested that the coming 10 years could see peer review become an increasingly independent activity, mediated through third-party software platforms. In the wake of the tidal wave of COVID-19 preprints, several initiatives along these lines have been launched. They include a web application, Outbreak Science Rapid PREreview. Funded by the Wellcome Trust, this collaboration is dedicated to open, rapid reviews of outbreak-related preprints. [35]

In December 2020, eLife announced it planned to refocus "editorial processes away from deciding what papers should be published" and shift to "exclusively reviewing manuscripts that have been posted as preprints." [36] While, in America, a group of 100+ researchers have urged scientists and journalists to jointly create a "rapid-review service for preprints of broad public interest" to avoid poor science making it into the news. [37]

One of the difficulties faced by editors is finding reviewers to review articles and to conduct reviews in a timely fashion. April 2020 also saw the launch of a joint "rapid review and review transfer initiative" by a group of publishers and scholarly communications organizations, supported by OASPA (Open Access Scholarly Publishing Association). [38] The calls to action contained in their open letter urged researchers to sign up to a "rapid reviewer pool" with a target turnaround of five days, or volunteer to flag important COVID-19 preprints. Meanwhile, publishers and journal editors were asked to "actively facilitate posting of COVID-19 preprints to preprint servers with the agreement of the authors." [38]

We have also seen prominent scientists leverage social media platforms, particularly Twitter, to provide informal peer review; they use it to "publicly share concerns about poor quality COVID-19 preprints or amplify high-quality preprints." [24] A survey of bioRxiv users found that more than 40 percent of authors had received feedback on their preprint through social media.

A slightly smaller proportion reported receiving private feedback through email and other correspondence with colleagues. [39] We discuss the rise of online platforms in our essay **"How Researchers Work"**.

> *"Preprints are regularly shared on social media, and there is a very active community of researchers who read and comment on preprint papers well before they ever make it into a peer-reviewed journal."*
>
> Biology, UK, aged under 36 years

Researchers have also used the comments section on a preprint's webpage to publish their praise and criticism of its findings. However, according to Fraser et al, in the case of bioRxiv, this option has been used in a limited way. They also found that few authors take advantage of the opportunity offered by preprint servers to publish improved or corrected versions of their preprints, and state "…it is clear that there is a dire need to better understand the general quality and trustworthiness of preprints compared to peer-review articles." [24] Fraser et al believe that scientists engaging more responsibly with journalists and the public will help, as will upholding high standards when sharing research. They also see the depoliticization of public health research and greater transparency in the research process as important steps. [24]

The impact of COVID-19 on peer review

According to the OECD (Organization for Economic Co-operation and Development), the rise of preprints has raised "questions as to how peer review operates, its importance and its limitations." [40]

For many, one of those limitations has long been the period of time required to complete the peer review for the average journal article. Statistics compiled by journal review site SciRev.org suggest that in nearly 20 percent of cases authors must wait more than six months to learn the fate of their submission; in some fields, it's 30 percent. [41] For journal editors, these delays can often be laid at the door of the ongoing challenges they face in sourcing knowledgeable – and, above all, willing – reviewers.

In response to the pandemic, publishers and journals have been working hard to shorten review timeframes. In some cases, that has involved launching new business models. 2020 saw The MIT Press unveil Rapid Reviews: COVID-19 (RR:C19), an open access, rapid-review overlay journal "to accelerate peer review of Covid-19-related research and deliver real-time, verified scientific information that policymakers and health leaders can use." [42]

Others have turned to technology. For example, Elsevier has been using data science to sort new submissions and flag those with a COVID-19 link to editors – although the paper still undergoes the same peer review process as other submissions. One analysis of 14 medical journals found that submission to acceptance had been reduced by an average of 45 days, and the editing stage (acceptance to publication) by 14 days, [24] despite the surge in submissions that journal editors and reviewers have been juggling with.

However, as Theodora Bloom, Executive Editor of The BMJ and a co-founder of medRxiv noted in *Nature*, "the role of the journal is to say: 'This has been fairly peer-reviewed, statistically reviewed, and can be relied on,' rather than, 'This is coming out at you as fast as it possibly can.'" [30]

Interestingly, John Inglis, co-founder of medRxiv and bioRxiv, discovered that where medRxiv preprints have gone on to appear in peer-reviewed journals, the median review time for those related to COVID-19 was 72 days – twice as fast than medRxiv preprints on other topics. [1] This prioritizing of pandemic-related papers is not without consequences: a separate study of 11 medical journals found that although they published coronavirus research faster than normal, the publication period for studies on other topics grew longer. [1]

Inglis believes the current pressure put on peer review systems by the "need for speed" will be difficult to sustain, and points to the fact that pandemic-related preprints published in the first quarter of 2020 appeared in journals more rapidly than those published later. [1] This could potentially add momentum to the two-stage publication process some industry watchers predicted in our original report, with researchers swiftly publishing initial findings before later sharing a polished and refined version. [18]

As we explore in our essay "**Technology: revolution or evolution"**, there has been much talk that AI could be used to address some of the existing concerns around peer review, including the time the review process requires. We also touch upon the AI-related initiatives that have emerged since our original report – and the ongoing caution of some researchers, driven by concerns such as algorithm biases and the potential loss of novel papers.

AI and peer review

In our 2019 report, we discussed the role of technology and its ability to enable change in articles, particularly through the use of artificial intelligence (AI). When it comes to using AI as a peer reviewing tool, as discussed in **"Technology: revolution or evolution?"** essay, researchers are more open to reading AI-reviewed articles than they were in 2020, but AI is still far from being considered an adequate replacement for human peer review. In our most recent survey, 21 percent of researchers said they would be willing to read AI-reviewed articles, up from 16 percent in 2020.

As the technology improves, it is likely to become a question of how dependent any future research information system will be on AI for peer review. When we look by various segments, there is little variation by age, gender or seniority, somewhat confounding expectations that more senior researchers would be much more conservative. We also see that women are almost twice as likely as in 2020 to be willing to read an AI reviewed article, with both women and men now at one-fifth.

Willingness to read articles peer reviewed by AI instead of humans

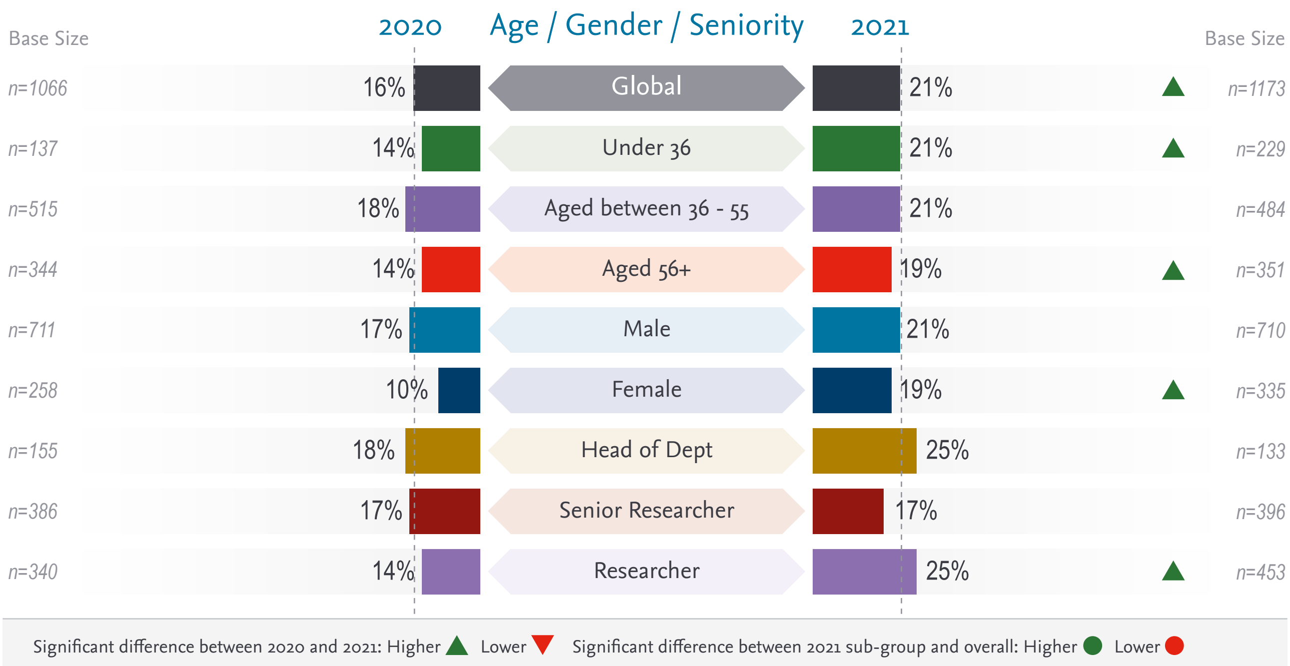


Figure 54: *Question: "I would be willing to read articles in a journal that relies on artificial intelligence (AI) instead of human peer review." % agree. Note: In 2020, it was not 'agree' but '% likely'. Source: Researcher survey 2021 base=1,141 and researcher survey 2020 base=1,041*

Engaging with research – leveraging new options

While peer-reviewed journals – and, increasingly, preprint servers – are the major channels that researchers use to disseminate their findings, they are also turning to other tools in a COVID-19 world. As we note in the essay **"How researchers work: change ahead"**, scholarly collaboration networks, for example ResearchGate, have launched services specifically designed to enable sharing and collaboration for COVID-19 researchers. [43]

As one industry watcher noted: "Not so long ago, even if researchers were willing to share their findings early, there wasn't necessarily a natural platform to do so. Now, countless initiatives have been established to facilitate this. For example, open research datasets, portals and resources are readily available. Measures are also in place to guide and moderate researchers' use of these platforms." [44]

Researchers are also making increased use of communication tools designed to serve the wider public, such as social media. In the researcher survey we conducted for this report, 42 percent of respondents said they had made increased use of social media in relation to their research since the start of the pandemic. (see figure 30 in the essay **"How Researchers work: change ahead"**)

When we examined the results by specialty, region and age, we saw that all areas reported higher use of social media for professional reasons during the pandemic (although the charts showing these various splits are not shown here, they are available in the full data analyses of research results accompanying this report). Researchers in North America were the least likely to report an increase in their use of social media, at 31 percent. Researchers aged under 36 were more likely than other age groups to have increased their use of social media (50 percent).

Increased use of social media can accelerate the sharing of preprints on platforms such as Twitter and Facebook, multiplying the reach of a preprint in seconds and reaching a more diverse audience than would otherwise be the case. In the aforementioned case of the preprint outlining similarities between COVID-19 and HIV, the paper was debunked within two weeks and then withdrawn, but in the meantime the lead author had shared his finding with more than 200,000 followers on Twitter. [45] "… what we are seeing in the context of COVID-19 is fundamentally different because we now have mechanisms that allow instantaneous dissemination of new findings to global audiences within and beyond a narrow community of like-minded scientists," says Amy Koerber of the Journal of Business and Technical Communication. [45]

Visibility and public understanding of research

As pressure increases on researchers to show the impact of their work on society, many researchers in our 2020 survey told us they believe that COVID-19 has helped scientists expand their visibility. Medical doctors and researchers have become frequent interviewees on television and social media during the pandemic and have had an opportunity to directly reach much wider audiences than before the pandemic. We explore this in our essay **"Pathways to Open Science"**.

More exposure, however, does not necessarily lead to more understanding, it seems. Researchers believe that there is broad scope for improving public understanding of the often-unseen basic research work conducted by scientists that does not appear in the news headlines. There are also gaps in society's understanding of the length of time and the amount of work that is behind much of their research. The pandemic has enabled some of this gap to be bridged, but researchers clearly feel that more needs to be done.

What researchers want the public to understand about research

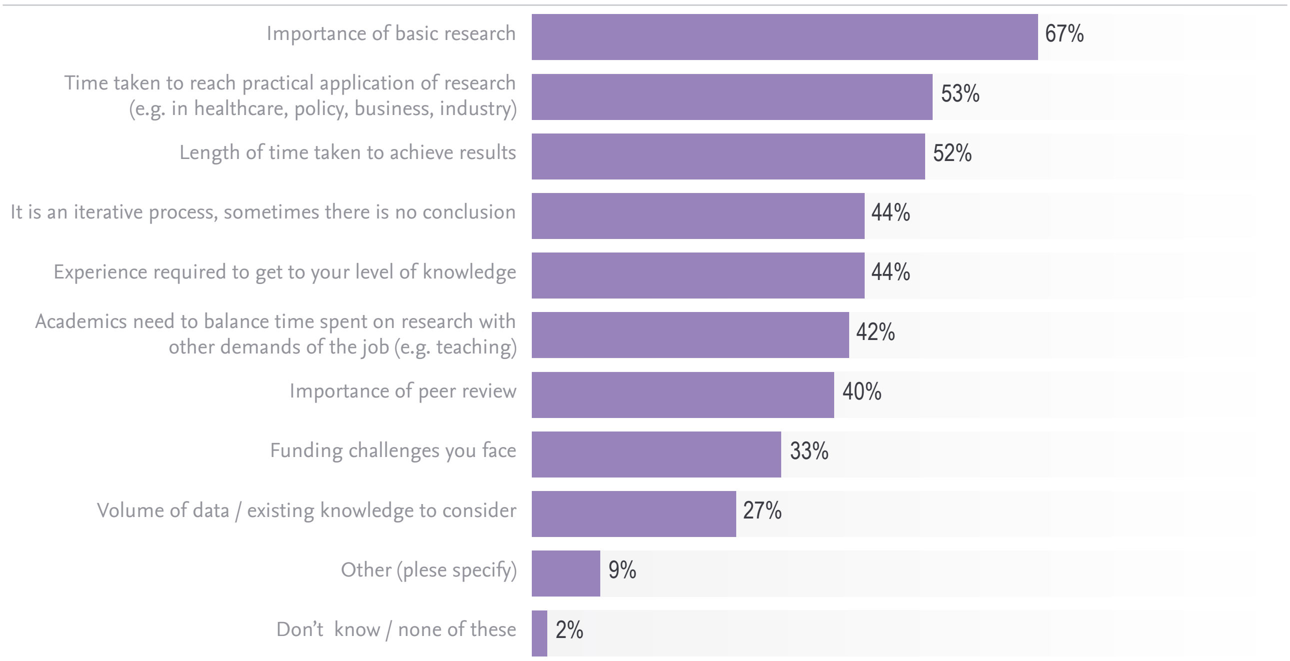


***Figure 55**: Question: "What do you think the general public needs to know to better understand research and its implications?"*
Source: Researcher survey 2021 base n=1,066

When it comes to accessing content, in our original report, we explored the desire among researchers for convenience – a seamless journal across a range of providers without the need to recall logins or be on campus.[11] Since the pandemic, with many working from home, that desire has morphed into a pressing need.

Back in 2016, the RA21 (Resource Access in the 21st Century) initiative was launched by STM and NISO, with the ultimate goal to create "seamless access to subscribed resources, from any device, from any location, from any starting point." [46] Since our original report, that project has continued to gain momentum, resulting in SeamlessAccess, a service that has built the digital authentication technology required to deliver RA.[21]

A number of publishers have adopted SeamlessAccess, including Springer Nature and Elsevier. Visitors to Elsevier's ScienceDirect now see an 'Access through your institution' button on article pages. If their institution has an authorized subscription to ScienceDirect, clicking on the button means they can use content in the same way they would on-campus, whatever their location or device.[47] And if other log-in services linked to their institutional identity have implemented SeamlessAccess, they can navigate to them without the need to log in again.

Finding and sharing data

Prior to COVID, researchers often turned to sites like Figshare and Mendeley Data to find data sets and related research outputs, or host their own data. Since the pandemic, an array of new sites have emerged, many of them open access, designed to promote sharing of data that can accelerate understanding and treatment of the virus. These include some of the platforms we highlight in the essay **"Pathways to Open Science"**, such as CORD-19 and a raft of new Open Access (OA) repositories. As we explore at the beginning of this essay, researchers are also turning to existing platforms, such as the European Commission's European Data Portal. At the same time, the international organization, Research Data Alliance, has established a COVID-19 working group to offer researchers best practice advice on data sharing. Countries outside the alliance are looking to set up similar research and guidance.[39]

In our original report, we touched on the rise of data articles, part of a wider trend of 'atomizing' the traditional research article and publishing its various components separately, from methods to software and code. Many believe these changes will help to improve the reproduction of experiments and potentially save other researchers time, and funders' money, by allowing existing knowledge to be reused. Along with increased sharing of these research elements, we have seen a corresponding rise in journals accommodating these new formats.

However, in the case of data, it's not only the pandemic that has promoted more frequent and open sharing. The academic publishing industry organization STM declared 2020 the 'STM Research Data Year' with a range of activities designed to achieve three key goals.[48]

- SHARE: Increase the number of journals with data policies and articles with data availability statements.
- LINK: Increase the number of journals that deposit data links to SCHOLIX - a high-level interoperability framework for exchanging information about the links between scholarly literature and data. [49]
- CITE: Increase the citations to datasets in line with Force 11's Joint Declaration of Data Citation Principles. [50]

At the end of the year, the program found that the average number of journals with data policies across participating publishers had risen by 80 percent (from 29 percent to 52 percent) while the number of articles that contained data availability statements had more than doubled, from 7 percent to 15 percent. [51]

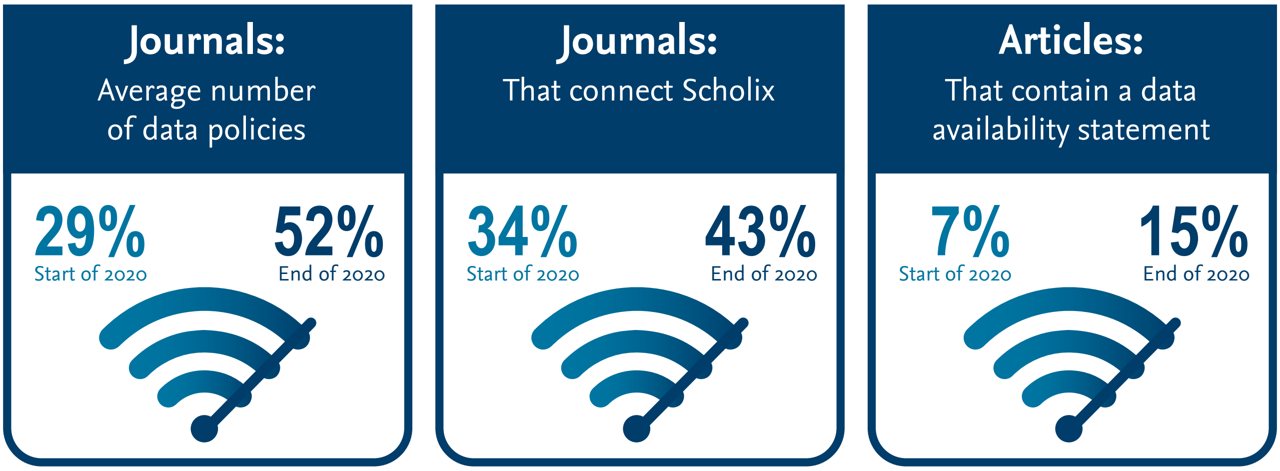


Figure 56: *STM declared 2020 the 'STM Research Data Year' with the goal of increasing sharing, linking and citing of data.*
Source: "STM 2020 Research Data Year infographic." [46]

Institutions: a society-focused approach to research

Demonstrating research impact is a key element of the researcher workflow. As we saw in the essay **"How researchers work; change ahead"**, this is expected to become more of a focus over the next two to five years (see figure 32), but it isn't only those conducting studies who are under pressure to highlight the importance and value of their findings. The institutions those researchers are associated with, and the funders who support them, are being asked to show that the projects they are linked to further knowledge and deliver true benefits, particularly to society. [18]

In our original report, we explored the performance-based research funding systems (PRFSs) introduced in some countries to measure and benchmark the impact of research institutions, including their wider societal impact. Research analytics tools such as SciVal, Dimensions, Pure and Symplectic have been helping institutions and funders track, analyze and report on some of the activities vital to these rankings and, at the time of writing in late 2018, had already begun to include new research outputs, such as patents and policy documents, to improve the measurement of societal impact. [18]

But, increasingly, demonstrating societal impact involves showing that the research conducted supports one of the United Nations' 17 Sustainable Development Goals (SDGs), which focus on areas such as health, sustainability, equality and justice.[52] Many of these goals have taken on a new resonance since the pandemic. As we explore in our essay **"Funding the future"**, regions with existing health and economic challenges have been among the worst hit by COVID-19.

Over the past year, databases such as Digital Science's Dimensions [53] and Elsevier's Scopus [54] have introduced filters and/or search queries that can help institutions track their researchers' contributions to these goals. In addition, in 2019, the Times Higher Education launched a new university ranking – the Impact Ranking – based on performance metrics designed to "capture universities' impact on society" by looking at their success in delivering the SDGs. [55] This ranking may take on a new importance as institutions face ever-tightening budgets in light of COVID-19 (see **"Funding the future"** and **"The academy and beyond"** essays). The need for governments, funders and students to understand how institutions are performing has also sparked the launch of new ranking systems; for example, the Aggregate Ranking of Top Universities (ARTU), which positions global universities based on their performance in other rankings. [56]

References

1 Else, H. How a torrent of COVID science changed research publishing — in seven charts. Nature. 16 December 2020. https://www.nature.com/articles/d41586-020-03564-y;

2 STM Global Brief 2021. Economics and Market Size. 19 October 2021. https://www.stm-assoc.org/2021_10_19_STM_Global_Brief_2021_Economics_and_Market_Size.pdf

3 Cacciatore M. Misinformation and public opinion of science and health: Approaches, findings, and future directions
Proceedings of the National Academy of Sciences. 9 April 2021. https://www.pnas.org/doi/10.1073/pnas.1912437117

4 Schraer R. BBC. Should bad science be censored on social media? 19 January 2022. https://www.bbc.com/news/technology-60036861

5 Grudniewicz, A, et al, Predatory journals: no definition, no defence. Nature, 576, 210-212. December 2019. https://www.nature.com/articles/d41586-019-03759-y

6 Elsevier's Novel Coronavirus Information Center, https://www.elsevier.com/novel-coronavirus-covid-19 available from Jan 27th 2020

7 Oxford University Press, Access to OUP resources on COVID-19, other coronaviruses https://academic.oup.com/journals/pages/coronavirus

8 SpringerNature, Coronavirus (COVID-19) Research Highlights: https://www.springernature.com/gp/researchers/campaigns/coronavirus

9 Wiley's Covid-19: Novel Coronavirus Outbreak, https://novel-coronavirus.onlinelibrary.wiley.com/

10 Fosci, M. et al. Emerging from uncertainty: International perspectives on the impact of COVID-19 on university research. Prepared on behalf of Springer Nature. November 2020. https://resource-cms.springernature.com/springer-cms/rest/v1/content/18537754/data/v6

11 European Future Innovation System Centre. 21 December 2021. https://www.efiscentre.eu/research-infrastructures-impact-assessment-shouldnt-be-a-lonely-journey/

12 https://data.europa.eu/en

13 The PHIRI project. Accessed January 2022. https://www.phiri.eu/

14 Dutch Research Council. 8 September 2021. https://www.nwo.nl/en/news/new-national-strategy-large-scale-research-infrastructure

15 ArXiv.org Blog. Cornell University. 14 October 2021. https://blog.arxiv.org/2021/10/14/academic-societies-continue-strong-support-of-arxiv/

16 BioRxiv. 16 August 2021. https://connect.biorxiv.org/news/2021/08/16/b2x

17 arXiv.org.blog. Cornell University. 30 September 2021. https://blog.arxiv.org/2021/09/30/early-adopters-arxiv-membership/

18 Research futures: Drivers and scenarios for the next decade. Elsevier. February 2019. https://www.elsevier.com/connect/elsevier-research-futures-report

19 SSRN Blog. 1 December 2021. Most downloaded papers http://ssrnblog.com/2021/01/12/top-10-papers-of-2020/

20 Kiley, R. Three lessons COVID-19 has taught us about Open Access publishing. LSE. 6 October 2020. https://blogs.lse.ac.uk/impactofsocialsciences/2020/10/06/39677/

21 Search for coronavirus preprints. Europe PMC. Accessed on 3 February 2021. https://europepmc.org/

22 Lachapelle, F. COVID-19 Preprints and Their Publishing Rate: An Improved Method. medRxiv 20188771. 4 September 2020. https://doi.org/10.1101/2020.09.04.20188771

23 Anderson, K. Covid-19 Preprint Counts Are Inflated. The Geyser. 4 January 2021. https://thegeyser.substack.com/p/covid-19-preprint-counts-are-inflated?

24 Fraser, N. et al. Preprinting the COVID-19 pandemic. bioRxiv 111294. 22 May 2020. https://doi.org/10.1101/2020.05.22.111294

25 Hook D. et al. Frontiers. 12 January 2021. https://www.frontiersin.org/articles/10.3389/frma.2020.595299/full

26 Brainard J. Science. 8 September 2021. https://www.science.org/content/article/no-revolution-covid-19-boosted-open-access-preprints-are-only-fraction-pandemic-papers

27 Preprints in Europe PMC. Europe PMC. Accessed on 3 February 2020. https://europepmc.org/Preprints#preprint-indexing

28 McCullough, R. Preprints are now in Scopus! Scopus. 28 January 2021. https://blog.scopus.com/posts/preprints-are-now-in-scopus

29 Brainard, J. Do preprints improve with peer review? A little, one study suggests. Science. 26 March 2020. https://www.sciencemag.org/news/2020/03/do-preprints-improve-peer-review-little-one-study-suggests

30 Kwon, D. How swamped preprint servers are blocking bad coronavirus research. Nature. 7 May 2020. https://www.nature.com/articles/d41586-020-01394-6

31 medRxiv: The preprint server for health sciences. Accessed on 2 March 2021. https://www.medrxiv.org/

32 Khamsi, R. Problems with Preprints: Covering Rough-Draft Manuscripts Responsibly. The OPEN Notebook. 1 June 2020. https://www.theopennotebook.com/2020/06/01/problems-with-preprints-covering-rough-draft-manuscripts-responsibly/

33 Hatch, V. Pre-publication made easy: an interview with research square. Tipbox. 24 September 2019. https://tipbox.abcam.com/pre-publication-made-easy/

34 Lawrence, R. F1000 Research Ltd wins European Commission contract to set up an open access publishing platform. F1000. 25 March 2020. https://blog.f1000.com/2020/03/25/f1000-research-ltd-wins-european-commission-contract-to-set-up-an-open-access-publishing-platform/

35 About page. Outbreak Science Rapid PREreview. https://outbreaksci.prereview.org/about

36 Eisen, M. B. et al. Peer Review: Implementing a "publish, then review" model of publishing. eLife 2020;9:e64910. 1 December 2020. https://doi.org/10.7554/eLife.64910

37 Eisen, M. B. & Tibshirani, R. How to Identify Flawed Research Before It Becomes Dangerous. The New York Times. 20 July 2020. https://www.nytimes.com/2020/07/20/opinion/coronavirus-preprints.html

38 COVID-19 Publishers Open Letter of Intent – Rapid Review. OASPA. Accessed on 11 March 2021. https://oaspa.org/covid-19-publishers-open-letter-of-intent-rapid-review/

39 Penfold, N. C. & Polka, J. K. Technical and social issues influencing the adoption of preprints in the life sciences. PLoS Genet 16(4): e1008565. (2020). https://doi.org/10.1371/journal.pgen.1008565

40 OECD Science, Technology and Innovation Outlook 2021: Times of Crisis and Opportunity. OECD Publishing. 2021. https://doi.org/10.1787/75f79015-en

41 Statistics - Total review time of accepted papers. SciRev.org. Accessed on 11 March 2021. https://scirev.org/statistics/total-duration/

42 The MIT Press and UC Berkeley launch Rapid Reviews: COVID-19. MIT News. 29 June 2020. https://news.mit.edu/2020/mit-press-and-uc-berkeley-launch-rapid-reviews-covid-19-0629

43 Radecki, J. & Schonfeld, R. C. The Impacts of COVID-19 on the Research Enterprise: A Landscape Review. Ithaka S+R. 26 October 2020. https://doi.org/10.18665/sr.314247

44 Loffreda, L. What does COVID-19 mean for scholarly communication? Four areas to consider. Research Consulting. 07 April 2020. https://www.research-consulting.com/covid-19-and-scholarly-communication/

45 Koerber A. Is it fake news or is it open science? 22 September 2020. https://journals.sagepub.com/doi/full/10.1177/1050651920958506

46 What is RA21. RA21: Resource Access for the 21st Century. Accessed on 15 March 2021. https://ra21.org/what-is-ra21/

47 ScienceDirect integrates SeamlessAccess to provide improved remote access options for researchers. Elsevier. 28 July 2020. https://www.elsevier.com/about/press-releases/science-and-technology/sciencedirect-integrates-seamlessaccess-to-provide-improved-remote-access-options-for-researchers

48 STM Research Data: Share-Link-Cite. STM. https://www.stm-researchdata.org/

49 Scholix: A Framework for Scholarly Link eXchange, SCHOLIX. http://www.scholix.org/

50 Martone, M. (ed.) Data Citation Synthesis Group: Joint Declaration of Data Citation Principles. San Diego CA: FORCE11. 2014. Accessed on 03 February 2021. https://doi.org/10.25490/a97f-egyk

51 STM Research Data: Share-Link-Cite. STM. https://www.stm-researchdata.org/

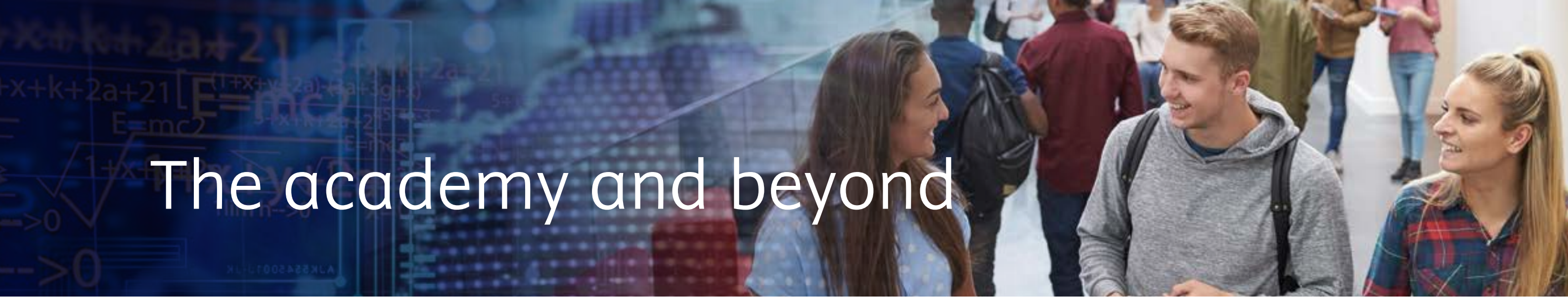
52 Sustainable Development Goals. United Nations. 2015. https://sustainabledevelopment.un.org/index.php?menu=1300

53 Jackson, A. Dimensions includes new research category filters for Sustainable Development Goals. Dimensions. 31 March 2020. https://www.dimensions.ai/blog/dimensions-includes-new-research-category-filters-for-sustainable-development-goals/

54 McCullough, R. Sustainable Development Goals (SDGs) on Scopus. Scopus. 9 December 2020. https://blog.scopus.com/posts/sustainable-development-goals-sdgs-on-scopus

55 Impact Rankings: FAQs. Times Higher Education World University Rankings. Accessed on 15 March 2021. https://www.timeshighereducation.com/world-university-rankings/impact-rankings-faqs

56 UNSW Sydney. Aggregate Ranking of Top Universities. Accessed on 15 March 2021. http://research.unsw.edu.au/artu/



The academy and beyond

A quick glance back…

In our original report, we identified three key areas of change – these are featured in the blue boxes below. Each of these is accompanied by a bulleted breakdown of the shifts we anticipated would occur as that change unfolded.

Taken from ***Research futures 2019***

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 increases to show a return on investment, 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 do so 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.

Now, three years into the 10-year window and with COVID-19 impacting every element of our lives, how are those predictions standing up?

We have used a traffic light system to give an indication: red for no progress, amber for some progress, and green for a reasonable amount of progress.

Read the original **"The academy and beyond"** essay in *Research futures*
www.elsevier.com/research-intelligence/resource-library/research-futures

Key findings

- Every aspect of university life has been affected by the pandemic, from teaching and research to funding.
- University incomes have been hit by a loss of international student fees, and refunds and that may well continue, 33 percent of researchers think there will be less students over the next 2-5 years.
- The pandemic has led to a surge of interest in EdTech and speeded up adoption of online learning for students and teachers.
- Tech companies are increasingly prominent in education and have powered the switch to online learning and online conferences.
- Hybrid models of online and in-person teaching are expected to continue after the pandemic with the majority (56 percent) believing that most of their teaching will be online.
- This is in spite of only 29% agreeing the shift online positively impacts teachers and 21% agreeing it positively impacts students.
- The pandemic has heightened awareness of the need for data skills. Life-long learning is becoming a priority and a potential new income source for institutes.

The pandemic has hit most sectors hard. Many have suffered financially, some logistically, while others, such as the healthcare sector, have seen employees tested emotionally and physically. One of the worst hit areas has been education, with schools and universities closed for lengthy periods in all parts of the world. According to a UNESCO assessment of the impact of the pandemic on education, more than 1.6 billion students in over 190 countries were not in school, college or university at the worst point in the pandemic in 2020. In March 2021, half of the global student population, numbering more than 800 million students, was still facing full or partial closures. [1]

In the case of universities, the impact of COVID-19 has proved sweeping and seismic. A survey by the International Association of Universities (IAU) of 424 universities and higher education institutes around the world found that almost 80 percent of respondents believe that COVID-19 has had an impact on the enrolment numbers for the 2020-2021 academic year, with 46 percent expecting both local and international student numbers to be affected. [2]

The impacts are expected to be lasting. Our latest survey shows that researchers expect falling student enrolments to persist 2 to 5 years beyond the pandemic. Just 17 percent of respondents think that that the longer-term impact of COVID-19 will see more students going to university, compared with 33 percent who believe it will lead to fewer students going to university.

COVID-19 impact on university student numbers

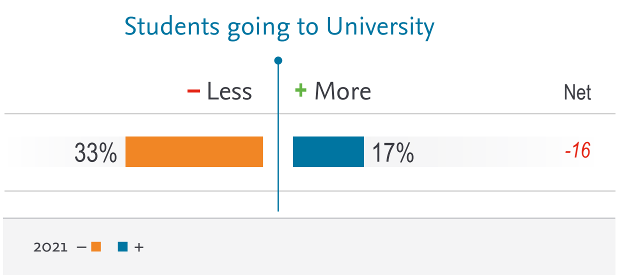


***Figure 57**: Question: "Do you think the longer term impact of COVID-19 will lead to … scale was 'Fewer', 'no change', 'Less'…students going to university" Source: Researcher survey 2021. Base=1,141.*

As the University of Michigan's Professor Jason Owen-Smith remarks in a pandemic thought piece, for the first time in contemporary history, universities in the USA encountered a challenge that stresses "all aspects of the university mission and budget model at the same time." [3] He says that while many universities were in "challenging straits" prior to COVID-19, the pandemic has for many "illuminated and exacerbated" those effects. [3]

At the same time, universities faced cuts to external funding, including government, philanthropic and corporate sources, as well as institutional income streams such as tuition fees. The resulting impact is likely to be uneven across different national research ecosystems. As one report on the pandemic suggested: "Just as a severe economic shock can lead to a 'scarring' of the economy, damage to the research system in the short-term also risks a permanent loss of capacity." [4]

For some countries, this will likely have a negative economic effect, as evidence indicates that "tertiary education systems [research and teaching] can boost the future productive potential, and competitiveness, of the economy, as well as lowering unemployment." [4]

The fact that it's not just one hurdle that universities face, but many – and simultaneously – is a point that has been raised by a number of industry watchers. They pointed to the negative impact of social distancing on research, learning and networking, and the strain that the transition to digital placed on lecturers, libraries and existing infrastructure.

They also highlighted the repurposing of research labs, teams and even grants for COVID-19-related activities, and the disproportionate impact of the pandemic on particular researcher groups. We explore many of these aspects in our essay **"How researchers work – change ahead"**.

"The university increased my workload and it shut down my research."

Mathematics, USA, aged 65+

A deeper look at the impacts

A look at enrolment numbers indicates the impact of the pandemic has been broad, but uneven. An overview by National Student Clearinghouse Research Center of US enrolment data for Fall 2021 shows that undergraduate numbers have been hit harder than graduate numbers. Undergraduate numbers were 9.2 percent lower than in 2019 and 3.1 percent lower than 2020. Graduate enrolments were less affected, 0.4 percent lower in 2021 compared to 2020. [5] Similarly, there have been declines in the UK where total university applications for the new academic year (starting September 2022) declined 0.9% to 610,720 [6]

As we explored in our original *Research futures* report and more recently in our *University leaders: opportunities and challenges* study, [7] change has been on the cards for universities for many years now; the pandemic has simply forced it upon them at a rate that few could ever have anticipated. So, what is shifting and how are researchers and institutions responding?

What does the pandemic mean for key income streams?

The pandemic has dealt a blow to economies globally with wide-ranging implications for investment in research and development (R&D) and higher education. In many countries, it is likely that governments will reduce, or redirect, their funding for institutions. Although some nations have factored cash injections for colleges and universities into their COVID-19 relief plans, critics claim the sums are not high enough. For example, the USA's pandemic rescue package, which was signed into law in March 2021, included an extra US$40 billion for the sector – institutions had been lobbying for US$120 billion. [8] At the same time, funding from some philanthropic and industry sources was impacted by the pandemic. We examine these financial shifts in greater detail in our essay **Funding the future"**.

The degree to which universities rely on these key funding sources varies according to their structure, location, status and type. Some are also able to access alternative income streams they turn to; for example, for universities with an associated medical school, income flows from elective surgeries. Many also benefit from gifts and legacies. In the USA, endowments can play a key role and in the fiscal year 2021 (up to June 2021) many endowments performed well, particularly for the wealthiest colleges, driven by a rebound in the stock markets. [9] Moreover, in recent years, tuition fees from both domestic and international students have become a vital strand of the university funding story. As we note in our 2020 Elsevier report, *University leaders: opportunities and challenges*, the rise in their importance corresponds directly with a reduction in government and philanthropic investment. [7] Some believe the pandemic exposed this shift as a frailty of the existing funding system. [4]

Student Enrolments

As we mentioned earlier in this essay, when it comes to income from domestic tuition fees, institutions in some countries have reported a fall in student enrolments. For example, in Japan, applications to 107 private universities were 12 percent lower than the norm in 2021, while 1,300 higher education students dropped out of Japanese institutions between April-Dec 2020, citing loneliness, a lack of campus life and financial difficulties. [10] An Australian study suggests that prospective female students were disproportionately affected by the pandemic, with 7 percent fewer women enrolling in university and vocational courses than in previous years; for men, that figure is 2 percent. [11] If this proves to be the case globally, it's a worrying result, given that female researchers were among the groups whose work was most impacted by the pandemic (see **"How researchers work: change ahead"**).

It is worth noting, however, that the growing popularity of some subjects may have skewed the figures. For example, the pandemic prompted a 30 percent rise in applications for nursing degrees. [12] The final intake for nursing and midwifery in programs in England in 2021-2022 was 30,185, a 1.5 percent increase from the 29,740 students accepted in 2020 and a sizeable increase on the 23,630 accepted in 2019. [13]

Similarly, the US has seen a rise of 2.6 percent in the number of medical students in 2021-2022, with a total of 23,711 students accepted, the largest number ever accepted. Applications to medical school for the year also increased by a record high of 17.8 percent for the year, driven by large increases in the number of applicants from under-represented minorities, according to the Association of American Medical Colleges. [14]

These numbers reflect a growing demand for healthcare workers. In the US, a combination of longer life expectancy and an increase in the number of patients with chronic conditions, as well as aging baby boomers, is set to see demand for healthcare workers increase markedly over the next decade. We discuss these drivers in the chapter 'The Future "Total Health" Clinician' in our *Clinician of the Future* report.[15] According to figures from the US Bureau of Labor Statistics, total employment in healthcare and social assistance is set to grow by 16 percent from 2020 to 2030. Healthcare support is expected to be the fastest growing group at 23 percent, or an additional 1.6 million jobs, with nursing occupations the fastest growing occupation, with nurse practitioners set to increase by 52 percent, nursing instructors by 22 percent, and registered nurses by 9 percent. The number of physicians is expected to grow by 5 percent, while the number of surgeons will fall by 3 percent.[14]

However, while demand for healthcare workers is set to grow in the USA, their income is not. A combination of low pay and high stress is leading to high percentages of expected resignations, which may fuel further demand. In a survey of 46,000 doctors in the USA, average pay increased by 3.8 percent from 2020 to 2021, much lower than the 12-month inflation rate of 6.2 percent. Not surprisingly, 73 percent reported feeling overworked and 50 percent said their workload during the pandemic has made them consider either changing career or retiring. [16] Moreover, 74 percent of clinicians believe there will be a shortage of nurses and 68 percent agreed there will be a shortage of doctors in the next decade. [15]

As well as these changes to healthcare student admissions, the effects of the pandemic can also be seen in international student numbers, which have shown a marked decrease in many parts of the world. New Zealand's international student numbers were expected to more than halve for the academic year 2021-2022. [17] That prediction proved accurate, with just under 9,000 full-fee-paying students enrolled in the country's universities as of December 2021, half the number at the start of the pandemic. [18] In the UK, UCAS data shows a drop of 56 percent in accepted applications from students from EU countries compared to 2020, while accepted applications from non-EU students rose by 9 percent. It is likely that the decrease in the number of EU students is due to the impact of Brexit. The loss of EU student fees in British universities is expected to amount to £62.5 million per year. [19] Among non-EU students, the number of students from China increased to 9,740 in 2021, up from 8,570 in 2020, and students from India increased to 3,200 in 2021 compared to 2,680 in 2020. [20] The rise in the number of Chinese students may be due, in part, to some of the factors we explore in our **"Funding the future"** essay: with tensions between China and Australia and the USA escalating, some believe Chinese students will turn to British, European and Asian universities instead.

In the European Union, concerns over possible falling international student numbers have been widespread. German universities have seen a decline in international first-year students and are concerned about retaining those already attending their universities. The number of international students attending higher education institutions in 2020-2021 grew by 2 percent but the number of first-time international students fell by 20 percent compared to the previous year.[21] For Professor Joybrato Mukherjee, President of the German Academic Exchange Service (DAAD), this is not only problematic for the universities, it could also damage the economy: "International students are ideal candidates when it comes to attracting skilled workers to German research and industry – especially in view of a post-pandemic upturn."C [20]

In other parts of the EU, however, the picture was more positive. In a survey carried out in June-July 2021 by the European Association for International Education (EIAE) of more than 330 higher education institutes in the European Higher Education Area, over half of respondents (55 percent) reported a higher number of applications compared to 2020, while 13 percent reported a drop. For enrolments, the picture was similar, with 53 percent reporting higher expected international student enrolments for the September 2021 intake compared to a year earlier, and just 14 percent expecting lower numbers than they had seen in 2020. [22]

In the USA, international student numbers fell in the academic year 2020-2021. According to the US State Department-sponsored 2021 *Open Doors Report on International Educational Exchange*, the total number of international students enrolled for the year was 914,000. Of these, 35 percent were from China and 18 percent from India, the two most significant countries of origin. The total number of international student enrolments was 15 percent less than in the 2019-2020 academic year, with decreases seen in the numbers enrolled from China (down 15 percent), India (down 13 percent) and South Korea (down 21 percent). [23] Among graduate students the fall was even greater, with 66,000 enrolling in 2020-2021, down from 120,000 a year earlier, a decrease of 45 percent. [24]

In July 2021, the US Department of Education and the State Department issued a joint statement with a renewed commitment to international education. There are signs that international student numbers are starting to recover. In May and June 2021, the US issued 117,000 student visas, not far short of the 126,000 issued in the same months in 2019. Included in the figure are 57,000 visas for China, a larger number than the 55,000 issued in 2019. [25]

In Australia, analysis suggests that if one in five international students fail to re-enroll, it will not only plunge "half of all Australian universities into financial turmoil or budget deficit," there will also be repercussions for jobs, local industry, research and Australia's reputation as a destination for quality higher education. [26] The country closed its doors for much of the pandemic and was slow to formulate plans to allow international students to return. Overall, the country's attractiveness to international students has suffered as a result of long border closures. International enrolments fell by 120,000 this in 2021, and universities saw a drop of 6 percent in their incomes in 2020. However, enrolments by Chinese students in the country's leading research institutions rose 6 percent in 2021 compared to July 2020. [27]

Falls in university incomes

For some universities, the fall in income coincides with rising expenditure on public health measures, such as testing and new cleaning protocols, and urgent investments to support online instruction. [28] In tandem with a drop in enrolments, students who were unable to attend on-site studies sought discounts or refunds to make up for the lack of in-person teaching and access to campuses and facilities. At least three major universities in Australia offered discounts of up to 20 percent to international students. [29] In South Korea, 40 percent of universities, comprising 30 public and 50 private institutions, agreed to a partial refund of fees for all students whose courses were disrupted by the pandemic. [30] Universities in Thailand offered students a 50 percent reduction in fees, with 60 percent of the cost subsidized by the government. In Malaysia, students were offered cost reductions of between 10 to 35 percent of their tuition fees. [31]

In the USA, a number of elite institutions, including Princeton University and American University, offered substantial and "unprecedented" discounts for their fully online tuition experience. [32] As of September 2021, at least 70 universities in the USA were being sued by students for refunds in class-action lawsuits. As well as reimbursement for fees and expenses already paid, many of the cases claim that online teaching does not bring the same benefits as in-person classes. [33]

Most of the researchers in our survey agree that online teaching does not benefit students, as we discuss later in this essay.

In some countries, governments helped universities pacify and retain frustrated students. In the UK, the government pledged to freeze English tuition fees for 2022-23[34] ; however, that may prove a double-edged sword for universities, as they won't have the option to claw back missing income by increasing student charges. In the Netherlands, most undergraduate students received a 50 percent discount on their university fees to compensate for disruptions to their studies in the academic year 2021-2022. In England, following student rent strikes and protests, the government awarded universities a total of £70m to support students struggling financially and/or emotionally; although both students and universities wanted more. [35] In addition, UK institutions were warned against increasing the number of "unconditional offers" they made to prospective students. [36] Yet, as participants in our University leaders report noted, when tuition fees remain static, increasing student numbers is often the only option to increase revenue. [7]

Counting the cost: closures, redundancies, but also cause for optimism

According to Owen-Smith, the result of rising costs and declining revenue is that "the 'university finance balloon' is coming to lack the elasticity it needs to avoid destructive competition and its consequences." [3]
For the heads of universities, these are worrying times. As we noted in our Elsevier report *University leaders: opportunities and challenges*, prior to the pandemic, funding was already an issue and some institutions were unsure how to respond to challenges from government and wider society, or how to navigate the increasingly hypercompetitive environment in which they found themselves operating. [7] During the height of COVID-19, the International Association of University Presidents (IAUP) and Santander Universidades surveyed nearly 800 university presidents and vice presidents from 90 countries. They found that 73 percent expected revenue to decline in 2020-21, with 43 percent predicting the drop would be moderate to significant.

More than half anticipated a fall in university-industry collaboration (55 per cent). [37] Just 37 percent considered that their institution was prepared for a pandemic like COVID-19; as a result, they faced a host of unexpected challenges.

In many countries the consequences of those challenges are already visible. In the USA, universities took strategic, but hard decisions. For example, Indiana University of Pennsylvania chose to focus on just five core academic areas and to lay off up to 20 percent of the workforce, including 15 percent of the university's tenured faculty, while Concordia University Chicago College intended to cut around 7 percent of its workforce and close 15 academic programs. [38] Some institutions were forced to take even more drastic steps.

Becker College in Massachusetts is part of a growing list of small, private, liberal arts colleges that decided to close "after failing to find a viable path through the pandemic's financial pressure cooker." [39] Others simply delayed the start of new terms or semesters in the hope that things would improve. [40]

Estimates suggest that a total of 650,000 jobs were lost in the USA's higher education sector in 2020. This 13 percent drop was the steepest since records began in the 1950s. [41] It seems that researchers from black, Asian, and minority ethnic (BAME) backgrounds were more severely affected by staff cuts, with women of color being disproportionately impacted. [4] This prompted calls for "the recognition of diversity in academia, and for national governments to support the sector in addressing structural inequality." [4]

Other institutions avoided redundancies by implementing hiring and recruitment freezes or salary cuts, suspending payments into pension schemes, or leveraging their government's furlough schemes. [33] In Australia, the University of Adelaide is considering cutting 130 jobs or more due to the loss of income from international students. [42]

But there are also glimmers of light amid the gloom. The scale of the pandemic's impact on a university is generally linked to its type, location and status. In the case of two USA universities – Ohio State and Syracuse – it's also linked to their aspirations, with both pursuing ambitious tenure-track faculty hiring plans for the coming two years. [43] Moreover, Moody's, the credit rating service, predicts a return to stability for the American higher education sector in 2022. It forecasts a 4 to 6 percent rise in revenues as students return to campuses, and associated revenue streams are restored. Similarly, Fitch Ratings forecasts a neutral outlook for the sector as recovery is boosted by small increases in enrolment numbers, state budget proposals, return of associated revenue streams, endowment returns and federal stimulus. Risks include low international student enrolment numbers and local COVID-19 outbreaks. [44]

In Australia, contrary to earlier predictions, some top-ranked universities achieved operating surpluses in 2020; however, that did not stop them pushing ahead with planned redundancies. [45] In a package of measures announced by the Dutch government in February 2021, the contracts of 20,000 junior researchers who had not been able to complete their work due to lab closures and lack of fieldwork were extended.[46] In the UK, government analysis suggests the sector generally "responded well" to the pandemic and the overall financial position is "sound", although the report acknowledged that the situation is very uncertain.[47]

Impact on Study Destinations

The pandemic and its restrictions on mobility appear to have impacted preferences for study destinations for international students. While the USA has long been the favorite destination for international students, in a survey of 3,650 students in 55 countries conducted by IDP Connect in August-September 2021, 39 percent of students ranked Canada as their first choice for overseas studies for post-secondary education, followed by the USA and UK (17 percent each) and Australia (16 percent). Practical considerations seem to be paramount among these prospective international students, with 72 percent of those who picked Canada as their top choice citing that being able to work part-time while studying was a priority, followed by affordable fees (66 percent), and the cost of living (64 percent). [49]

Health considerations also play a part in the attractiveness of institutions. When it comes to vaccine requirements, a QS.com study showed that 59 percent of prospective international students think vaccines should be mandatory for students before travelling to the country of their institution. The same study showed that 53 percent believe that vaccine passports should also be required. [48]

International students appear to be eager to travel and return to on-campus learning, with 81 percent in the same study saying they were focusing on on-campus study options and just 10 percent saying they would study an online-only program while staying in their own country. [49]

Canada has increased its international undergraduate fees in response to the surge in interest, with fees for 2021-2022 academic year up by 4.9 percent, compared to a rise of 1.7 percent for local students. [50]

Chinese students' study plans appear to have been more impacted by the pandemic than students from the EU, North America and India, but they have remained committed to studying abroad: according to a study published in Sprinter, only 4 percent intend to give up their overseas study plans. [51]

In a survey of almost 8,000 Chinese students enrolled in overseas courses but who were forced to return to or stay in China because of the pandemic, 92 percent plan to return to their destination countries to continue their overseas studies. Most Chinese students have found overseas study to be a positive experience and more than 70 percent would recommend it to their friends. [52]

As we explore in our essay "**How researchers work: the change ahead"**, a growing preference for Canada is also reflected among researchers in our most recent survey, with double the number of researchers in 2021 (12 percent) 2021 saying they would choose Canada compared to 2020 (6 percent).

The shift to remote teaching and learning

As we noted in our original *Research futures* report, EdTech, or education technology, has had a transformative effect on learning. The term "encompasses everything from the simple use of computers to teach math 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".[53] Since the pandemic, which resulted in the closure of many campuses and limited student capacity on others, EdTech has come to symbolize the rapid shift to remote and online learning.

According to the International Association of Universities (IAU) survey, two-thirds of HEIs reported that distance teaching and learning had replaced classroom teaching. The biggest challenges to the switch were access to technical infrastructure and appropriate pedagogies for distance learning. [2]
In response to the pandemic, 60 percent of HEIs have adopted either virtual mobility or collaborative online learning to enable teaching to continue in the absence of face to face classes. [50]

The switch to online learning and the increased use of technology in classrooms is one of the drivers of the **"Tech Titans"** scenario in our original report. In this scenario, we envisaged EdTech changing the way that education is delivered, by improving online and distance learning. The pandemic has accelerated this change faster than we could have anticipated in 2019.

Our scenario also envisaged closer corporate involvement in education. This has also been happening at speed, propelled by the pandemic. Google Classroom, for example, a free service teachers can use to set and receive assignments and communicate with students, achieved stellar growth during the early months of the pandemic. Active user rates doubled to more than 100 million in the month from early March to early April 2020. [54] In the same month, the company received a request from the Italian ministry of education asking for its assistance to move the country's entire school system online. In the following weeks, similar requests to enable online learning followed from more countries around the world, including China and the UK. A broader program, now called Google Workspace for Education Fundamentals, offers free higher level and professional programs such as drive, docs, sheets and slides. Its users grew to 120 million in April 2020, up from 90 million a year earlier.

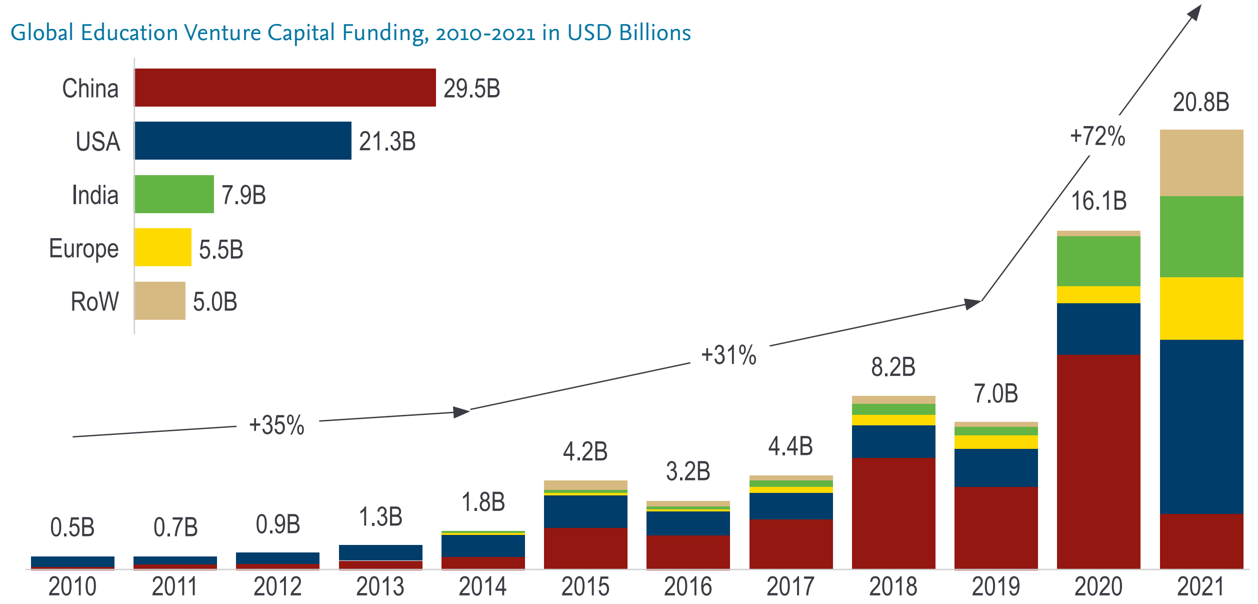
Similarly, a package of free programs from Microsoft, Microsoft Teams, saw its active users rise from 44 million in March 2020 to 75 million a month later. [55] It gained popularity during the pandemic for its videoconferencing abilities, but as the world is now transitioning to "durable, hybrid models of work and learning", it is now increasingly focused on enabling collaboration. [56]

Products such as Google Expeditions use virtual reality (VR) and augmented reality (AR) to provide enhanced learning experiences, such as virtual trips to explore volcanoes or the ocean floor, or to museums or historical sites. As well as taking students on virtual field trips, AR can enhance students' visual learning by allowing them to see images of the human body or dinosaurs in 3D.

However, it has certainly not been smooth sailing for all countries or institutions. In Pakistan, some instructors lacked the tools to teach online, while many students couldn't access reliable Internet at home. This forced Pakistan's Higher Education Commission to intervene, standardizing online teaching and urging telecommunication companies to offer students cheaper mobile-broadband packages. [60]

EdTech Venture Funding

$20.8B of EdTech Venture Funding for 2021, 3x pre-pandemic levels.
Massive US and EU surge covering an $8B China EdTech VC collapse.



Source: HolonIQ, 3 January 2022. All numbers rounded and may not sum exactly due to rounding. All years calculated at historic FX.

***Figure 58**: Source: HolonIQ. https://www.holoniq.com/notes/global-edtech-venture-capital-report-full-year-2021*

Overall, investment in EdTech surged during the pandemic. Venture capital funding for EdTech in 2019 was US$7 billion, and more than doubled to US$16.[1] billion in 2020. More than half of this investment was in China. In 2021, investment surged to more than US$20 billion, three times the pre-pandemic level. However, China's investment growth dropped in 2021, whilst the USA showed strong growth. [57]

Some institutions and students have welcomed this move to digital teaching. For example, in the UK, a survey of more than 27,000 students found that almost 70 percent were positive about their online learning experiences during COVID-19, praising the interactivity and flexibility that allowed them to catch up on classes and re-watch sessions. [58] A similarly-sized German survey established that 75 percent of students were satisfied with their digital learning. [59]

Globally, however, students have also reported issues around unsuitable technical equipment or study environments, concentration and isolation, as well as difficulties in meeting course requirements. Enterprising institutions have found ways to solve this last problem by leveraging the pandemic; for example, at one college in the USA, nursing students unable to gain their usual 60 hours of clinical experience were allowed to swap them for time spent supporting COVID-19 testing sites. [61]

Meanwhile, a US survey in late 2020 of more than 1,000 college students found that over half (55 percent) believe that the quality of education has dropped since it moved online. Despite this, 76 percent would prefer classes to remain either wholly or partially online in 2021-22. [62]

For some institutions, there have been challenges around establishing an effective digital infrastructure, while there were reports of lecturers struggling to cope with the increased workload involved in moving lessons online. It has generally been the younger researchers, who often have heavier teaching loads than their senior counterparts and young families, who have been hardest hit by the shift, as well as researchers from more economically-challenged backgrounds, who sometimes lacked the necessary equipment, network connections or home office space. [4]

With campuses cautiously or partially reopening, many institutions offered a hybrid model of teaching, [63] a situation that more than 70 percent of the university leaders who responded to the IAUP/ Santander Universidades survey expect to continue, as our research survey also shows. In South Korea, Seoul National University announced the resumption of in-person classes, while other universities in the country including Yonsei University, Korea University and Sungkyunkwan University are choosing a hybrid model. [64]

It seems then that, having surmounted many of the obstacles involved in the shift to digital teaching, there appears to be widespread support for it continuing – at least in some form.

"More remote learning and communication, more technology in the classroom: working models, simulators, experiments, etc., based in silico."

Biological Sciences, Portugal, aged 65+

Switch to online teaching – impacts for teachers and students

In our survey in 2021, less than one-third of researchers (29 percent) see the shift to online teaching as a positive development for teachers. One of the benefits cited is that online teaching saves faculty travel time and allows them to reach a larger number of students, regardless of where they live. Of the 46 percent who disagree that online teaching is positive, researchers state that online teaching is not as effective, and also requires extensive preparation, which means less time for lab activities and fieldwork.

"Students are disengaged online… teaching becomes less rewarding for both students and teachers"

Physics, Australia, aged 36-45

Percentage who agree the shift to online learning has a positive impact on teachers

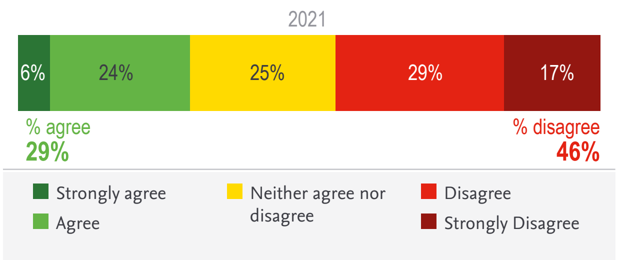


Figure 59: *Question: "To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: 'The shift of teaching to online positively impacts teachers." Source: Researcher survey 2021. Base= All researchers (n=1,173) Chart excludes don't knows*

Looking ahead to a post-pandemic world, the majority of researchers in our 2021 survey believe that most of their teaching will be online after COVID-19 - 56 percent. Though this is still the majority view it is less than the 64 percent the prior year. The drop is likely due to issues already discussed in this section becoming more apparent to some teachers as they gained more experience of online teaching. (See figure 32 in the essay **"How researchers work: change ahead"**, as well as the accompanying full research analyses accompanying this report for more detail).

When we look at the results by specialty, researchers in Engineering are most likely (40 percent) to agree that the move to online learning benefits teachers, followed by Medicine & Allied Health (37 percent) and Life Sciences (34 percent). Those working in Physics & Astronomy (17 percent) and Materials Science (18 percent) are least likely to see benefits for teachers in the move to online teaching.

Percentage who agree the shift to online learning has a positive impact on teachers

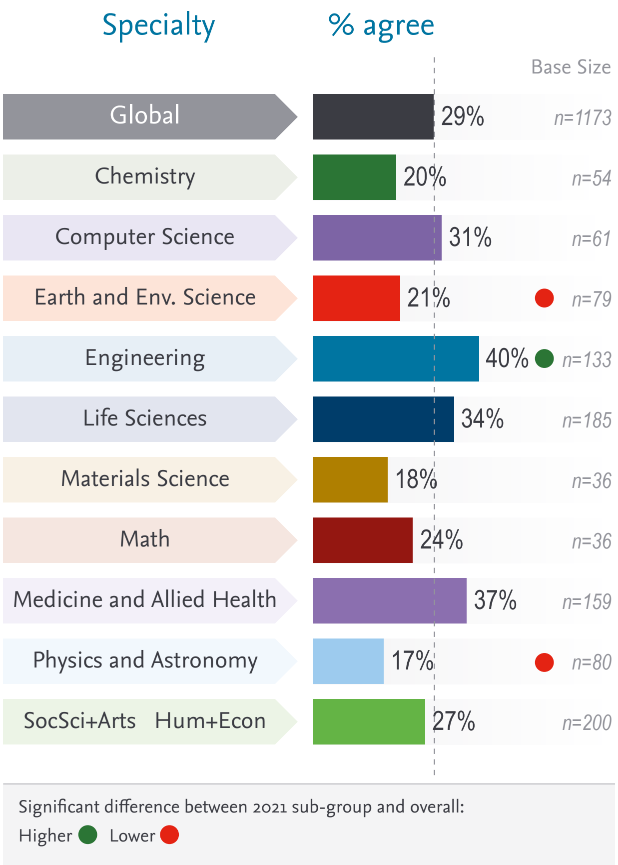


***Figure 60**: Question: "The shift to online positively impacts teachers." - % agree. Source: Researcher survey 2021. Base 1173.*

On a regional level, researchers in Latin America are most likely to say that online teaching benefits teachers, with 45 percent agreeing. Western Europe and Eastern Europe are most likely to disagree, with just 19 percent in both regions agreeing, followed by North America, where 20 percent agree.

Heads of Department are the most positive of all roles about the benefits to teachers of online learning, with 39 percent agreeing that the shift to online benefits teachers. Researchers (30 percent) and Senior Researchers (27 percent) are less likely to agree than Heads of Department. Women are less enthusiastic than men about the benefits to teachers of online learning, with 23 percent agreeing compared to 31 percent of men. Researchers aged 56 and over are slightly less inclined to agree that online teaching benefits teachers, with 27 percent agreeing compared to 31 percent in the 36 to 55 age bracket, and 29 percent of those aged under 36.

Percentage who agree the shift to online learning has a positive impact on teachers

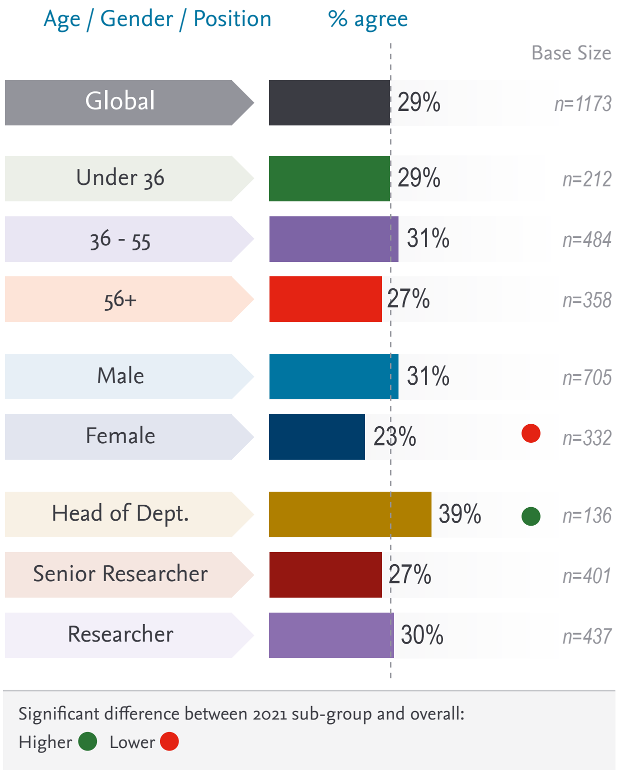


***Figure 61**: Question: "The shift to online positively impacts teachers." - % agree. Source: Researcher survey 2021. Base 1173*

When it comes to considering the impact on students, researchers see even fewer benefits from online teaching. More than half (53 percent) disagree that the switch to online teaching is a positive one for students.

Percentage who agree the shift to online learning has a positive impact on students

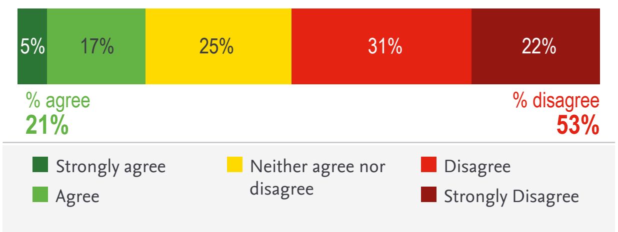


***Figure 62**: Question: "To better understand your attitudes towards research and scholarly publishing, please indicate how much you agree or disagree with the following statement: 'The shift to online positively impacts students'". Source: Researcher survey 2021. Base: All researchers (n=1173)*

For those that disagree that online learning has a positive impact they consider online teaching impersonal and believe it forces students to be disconnected from their teachers. Further, there is less of the informal chatting and casual discussions that are often crucial to effective learning and understanding.

"Online-only education cannot provide a similar level of student engagement, community building and interpersonal communication--all critical for successful learning outcomes"

Biochemistry, USA, aged 56-65

Of the 21 percent who believe that online teaching benefits students, flexibility of time and a wider variety of learning tools are cited as some of the benefits, as well as a better work-life balance.

"Online teaching gives students the flexibility of engagement hours and also put multiple sources of information at their disposal.... content delivery more engaging for the students."

Environmental, India, aged 36-45

When we asked different specialties for their views, those in Engineering were most likely to agree that the shift to online learning benefits students (31 percent) perhaps because that is also the specialty that sees the most benefits for teachers. For students of Math, Physics & Astronomy, and Earth & Environmental Sciences, few researchers saw benefits for students in a switch to online learning, with just 8, 9 and 10 percent, respectively, agreeing.

Percentage who agree the shift to online learning has a positive impact on students

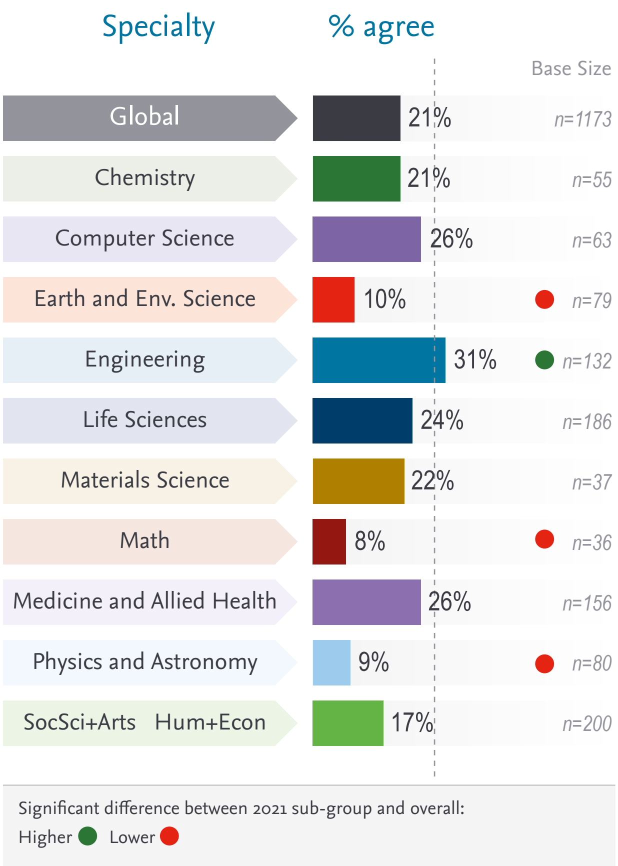


***Figure 63**: Question: "The shift to online positively impacts students." - % agree. Source: Researcher survey 2021. Base 1173.*

When considered by region, APAC is most positive about the benefits online learning can bring for students (29 percent). This contrasts with Eastern Europe and the Middle East, where just 7 percent and 12 percent, respectively, see benefits for students, as well as North America (13 percent) and Western Europe (17 percent). We also examined results by level of seniority but identified no significant differences.

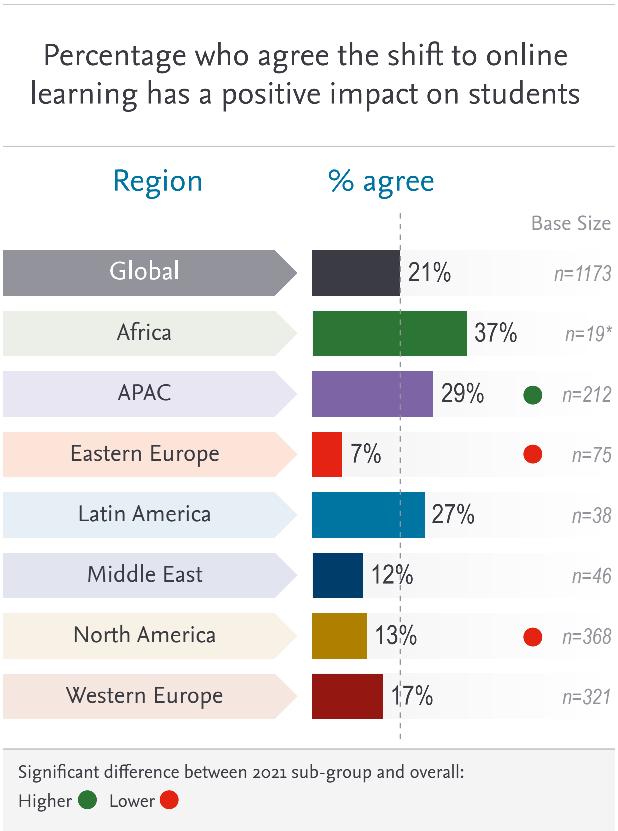


Figure 64:*Question: "The shift to online positively impacts students." - % agree. Source: Researcher survey 2021. Base 1173.*

How researchers expect teaching and learning to evolve

The majority of both students and teachers who responded to a large-scale German survey would like to see a combination of analog and digital teaching in the future, with only 20 percent of university professors seeking a return to pure face-to-face events, and only 2 percent in favor of a purely online model. [59] In Australia, several universities are planning to replace many long-form face-to-face lectures with shorter sessions and much more video content [65] while a group of European universities has urged the EU to help them develop programs that blend on-campus and virtual learning. [66] In the US, Sanjay Sarma, vice-president for open learning at the Massachusetts Institute of Technology, notes that many universities have learned that "Zoom university isn't proper online learning." He hopes to see a "two-way learning" model emerge, in which instructors distribute video lectures early, so that in-person time can focus on interacting with students. [71]

However, if a Japanese survey is anything to go by, while progress in moving lectures online has been strong, the digitalization of other university operational activities has been less successful. Up to 40 percent of administrative tasks, including applications for research funds, are still processed on paper. [67] In fact, according to Harvard Business Review, higher education has significantly lagged behind other industries in moving to a more digitally-driven, less people-intensive model, which suggests that the opportunity for technology-driven benefits is strong, but the risks of consequent disruption to systems and workforce are also significant. [68]

In our original *Research futures* report, we explored how technological developments such as virtual reality (VR) and augmented reality (AR) have proved a positive addition to traditional training methods, particularly in the health and medical fields. With the rise of remote learning, there are opportunities for the use of VR and AR to expand (see our essay **"Technology: revolution or evolution"**), although there currently seems to be little evidence of universities making greater use of these channels, possibly due to the necessary focus on establishing network connections (OR? digital infrastructures?) and ensuring lessons are delivered effectively.. It is likely we will see the use of VR and AR grow as online and blended learning becomes more commonplace.

As we explore in our report *University leaders*, we can also expect to see the use of artificial intelligence rise, not only to support teaching but collaboration, administration and more. [7]

Respondents to the survey we conducted for our latest *Research futures* survey believe that the new remote habits and tools now in place are likely to stay, with remote learning becoming normalized – although not all welcome this change.

> *"There will be ever-more adoption of remote learning and simulations to replace hands-on experience: not a trend to embrace."*

Earth and planetary science, Australia, aged 65 years+

In line with the predictions of the industry experts we interviewed for our original *Research future* report in 2019, they expect this to result in students behaving more like customers, demanding better value and tailored approaches based on the skills they want to acquire.

> *"Students will demand a 'personalized service' by a team of academics based on their individual interests. Not a 'single structured path' for large cohorts to reach the same location, but a 'map' showing areas to suit individuals."*

Social Sciences, Belgium, aged 46-55

Not only will students be more engaged in shaping their curriculum, they will also benefit from a greater focus on development of their personal skills, including a sense of responsibility for ethical considerations.

> *"Students are changing as well in their thinking, engagement, vision, ethics, rationality, needs and challenges."*

Agriculture, Morocco, aged 46-55

And with the increasing shift to digital learning and resources,, reliance on traditional tools, such as textbooks, is expected to wane.

Just as collaboration, specialization and larger teams are likely to play a greater role in research (see the essay **"How researchers work: change ahead"**), some of our respondents anticipate that students will become more specialized and work within multidisciplinary teams.

> *"More students [are] doing part of a very large project rather than a project they can call their own."*

Immunology and Microbiology, US, aged 56-65

But at least some of our respondents expect the fundamentals to remain unchanged; for example, the dynamics that drive PhDs…

> *"…research-based graduate students take part in an apprentice model working with more experienced scientists. Changing that would likely reduce the quality of STEM PhD training."*

Biochemistry, Genetics, and Molecular Biology, US, aged 26-35

…and the traditional relationship between educator and student.

> *"The fundamental triumvirate of the learner, the teacher, and the knowledge to be learned cannot change."*

Immunology and Microbiology, US, aged 46-55

Changing skills: training the workforce of the future

Pandemic-related redundancies and an uncertain job market are not only driving people to enrol for MOOCs – their reach is far broader. In the case of universities, they are reigniting the discussion around whether students should be graduating with the thirst for discovery that has led to many great advances, or the kind of practical skills that will help them find work.

In some countries, such as China, there are concerns about the fact that graduate numbers are exceeding the volume of jobs requiring a degree or post-graduate education.[69] Increasingly, many of these graduates face unemployment or the prospect of taking on blue-collar jobs that require no degree.

In China, a record 9.09 million graduates were expected to join the jobs market in 2021. According to the National Bureau of Statistics of China, in July 2021 the unemployment rate for 16-24-year olds was 16.2 percent. While the jobless rate typically increases in June and July each year as new graduates enter the market, the youth unemployment rate was more than three times the overall jobless rate, which was 5.1 percent in the same month. [70] Competition for jobs was also projected to increase in 2021 as 31 percent of students studying overseas were expected to return to China, an increase of 6 percent on the numbers returning a year earlier. [71] As we discuss in our **"Funding the future"** essay, the slowing birth rate in home will impact graduate numbers in the future, but in the meantime a slowing economy may further reduce opportunities for graduate employment.

One of the drivers in the "**Tech Titans"** scenario in our original report predicted that exploratory or blue-sky research would increasingly take a backseat to industry-funded research that focuses on commercial targets. This is a particular concern as researchers grapple with funding worries, as we explore in our **"Funding the future"** essay. Some believe this could lead to a cull in blue-sky thinking and research, and an increased focus on education and science with real world applications, a topic we discuss further in the essay **"Pathways to open science"**.

Although researchers are divided on the topic (see figure 17), applied research has the potential to provide universities with the revenues they so sorely need.[28] Concerns about such developments may be well-founded: there are signs that universities and funding agencies will be encouraged to focus on practical projects for a post-pandemic world; for instance, the UK government is setting up a research sustainability task force that will assess university research projects with an eye for planning for the country's long-term future. [71]

Universities are listening and many are attempting to respond. For example, in the UK, seven vice-chancellors have sent an open letter to the government, asking, among other things, for funding to provide short-term qualifications that will improve unemployed graduates' job prospects. [35]

"Universities are publicly funded - we should ensure what we are doing meets the public good and can be translated within a short to medium term."

Arts and Humanities, Australia, aged 56-65

This comes at a time when a report by the OECD, (the international Organization for Economic Co-operation and Development), states that: "Countries need to continue to support a breadth of research, whilst implementing measures to ensure that a new generation of researchers with inter- and trans-disciplinary skills is encouraged." [72] Others are urging funders to avoiding limiting their focus to applied research, and develop a "holistic strategy that acknowledges the role of blue-sky research projects and trains a new generation of researchers in understanding and driving societal impact." [4]

"Blue-sky research is vitally important in order to make the big discoveries. Focusing on immediate real-world benefit leads to incremental results."

Physics, UK, aged 36-45

Online teaching via MOOCs

In our original *Research Futures* report, we explored the rise – and subsequent dip – in the popularity of MOOCs, or massive open online courses. Although MOOCs saw phenomenal growth after their star really started to ascend in 2012, more recently the global user base had declined. However, that has been gradually changing. Over the past couple of years, they have been "morphing from a B2C [business to consumer] higher education replacement to B2B [business to business] partner and builder of digital ecosystems," according to marketing intelligence company HolonIQ. By 2019, they offered more than 30,000 courses and 50 degrees and were partners with 1,000+ universities. [73]

With the advent of Covid-19, however, and the first pandemic lockdowns, registrations for MOOCs soared. The top three MOOC providers (Coursera, edX, and FutureLearn) registered as many new users in April 2020 as they did throughout the whole of 2019. Coursera alone received 35 million enrollments between the middle of March and the end of July. [74] The majority of their new students were based in the USA, India, Mexico, China and Brazil. [75]

"Massive open online courses (MOOCs) will become more widely used in teaching together with other on-line tools."

Physics, Russia, aged 46-55

Interestingly, the type of subjects that students select has shifted. According to one online course aggregation service, the most popular topics before the pandemic included computer science, programming and business. Since the onset of COVID-19, however, personal development, art & design and business take the top three slots. [83] The rise in enrolments is likely to have been driven by employees on furlough with time on their hands, along with people looking to update knowledge and skills amid labor market insecurity and rising unemployment. [84]

The MOOC Hype Cycle

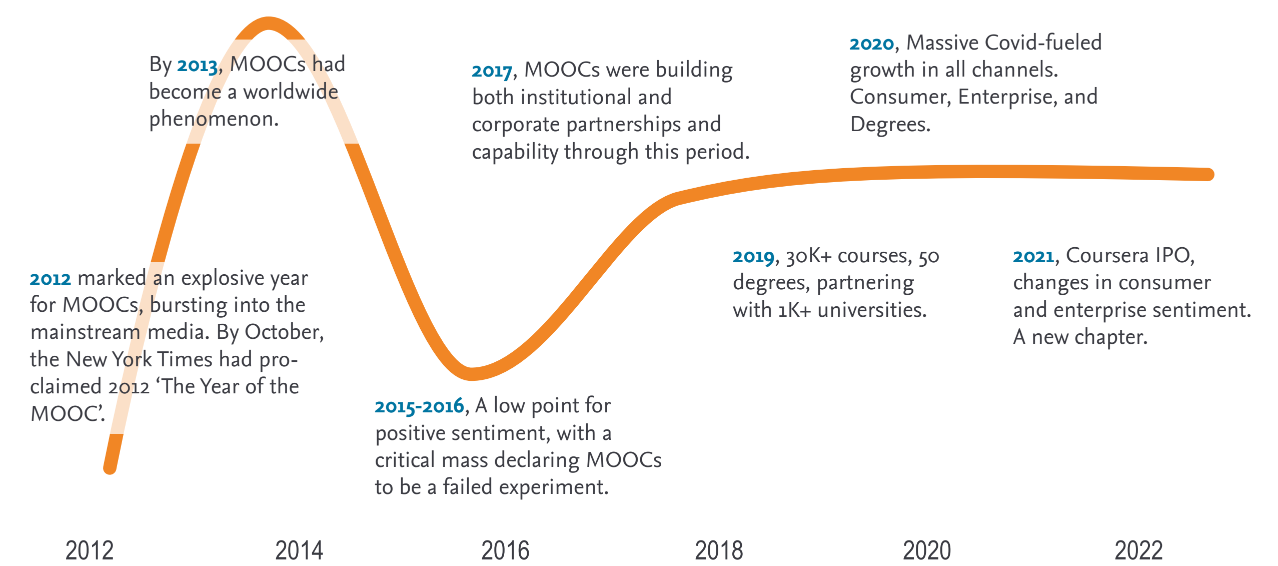
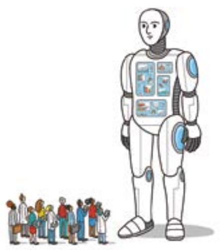


***Figure 65**: The evolution of MOOCs – a 10-year view. Source: "MOOCs. Then. Now. Next."* [69]

Data Skills

For many, the COVID-19 crisis has also highlighted the rising importance of data and data-related skills – a topic we discuss in many of the essays in this report. With countries such as the UK heading towards a digital skills “shortage disaster”, [76] universities are under pressure to ensure their courses are training the data stewards, software engineers and data analysts of the future. This includes ensuring their own institutions have the data skills they need. For example, in January 2020, the leaders of eight university networks from multiple nations signed the Sorbonne declaration on research data rights, committing to: “Encouraging our universities in setting up training and skills development programs that create an environment to promote open research data management” [88] Universities are also taking action on an individual basis, funding data steward roles and data champions, although some critics claim that current initiatives are too “ad hoc and short-term.” [88]



Scenario match

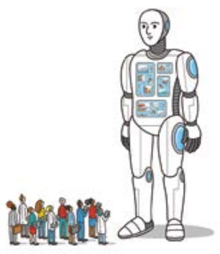
In the scenario **Tech titans** in our original *Research futures* report, we suggested that EdTech would change the way that education is delivered, with improved quality of online courses and high adoption of distance and flexible learning

For many, spending more time at home during the pandemic encouraged uptake of online courses. In 2021, excluding China, MOOC courses have been used by 220 million learners accessing 19,400 courses offered by 950 universities. These figures have grown exponentially since the launch of MOOC in 2012, when 300,000 learners could choose from three courses. In 2020, 60 million new learners signed up for at least one course, although this figure fell to 40 million in 2021. [77]

Just as with MOOCs, the pandemic may be driving a shift in the types of courses that students choose – as we’ve seen earlier in this essay, applications to nursing and medical courses have increased. In the technology area, data-related courses feature prominently among learners’ preferred courses.

Most of Coursera’s top 30 most popular technology courses in 2021 are data-related. These include an 11-month IBM Data Science Professional Certificate covering topics such as open source tools and libraries, data analysis and machine learning, and a similar IBM course for Data Analysis; a 60-hour machine learning course by Stanford University, a four-month course on deep learning, and a four month course on SQL Basics for Data Science Specialization run by the University of California, Davis. [78]

Over its 10-year history, more tech companies have been offering courses on the platform, including Google, Amazon, Facebook and Microsoft. On Coursera, they are now the leading providers: Microsoft now offers 668 courses on Coursera, Google offers 588, Google Cloud has 421, and IBM offers 314. [79]



Scenario match

In the scenario **Tech titans**, we predicted that industry would play a growing role in education.

Institutions are also being asked to provide “lifelong” or “renewable” learning opportunities. This involves opening up courses to students of every age and level of experience, and making them flexible enough to meet a wide range of needs. The pandemic has increased the urgency around providing these opportunities, with some calling them an “educational and economic necessity”. [80] A World Economic Forum report into the future of jobs has found that workers who remain in their roles will see 40 percent of the core skills required change in the next five years, and 50 percent of all employees will need reskilling. [81]

The report also highlighted:

- A four-fold increase in the number of individuals taking the initiative to seek online learning opportunities.
- A five-fold increase in employer provision of online learning opportunities to their workers.
- A nine-fold enrolment increase for learners accessing online learning through government programs.

Echoing the changing popularity of MOOC subjects we touched upon earlier: “Those in employment are placing larger emphasis on personal development courses, which have seen 88% growth among that population.” [81] The report found that those without work tend to be more interested in learning digital skills such as data analysis, computer science and information technology. [81]

While the need to upskill workers to help them adapt to new technologies and careers was already recognized, since the pandemic, this need to support lifelong learning has become a greater imperative, especially for disadvantaged groups. According to an OECD report released in mid-2021, between 18 and 25 percent of adult learning hours were estimated to have been lost during the 2020-2021 lockdowns. The report calls for governments to set aside some of the recovery resources to fund lifelong learning programs, as the crisis has accelerated the transformation of the global economy and the changing skills needed. “In the recovery efforts, skills will make the difference between staying ahead of the curve or falling behind in a world in constant flux. Countries need to invest part of the resources devoted to the recovery to lifelong learning programs, involving all key stakeholders and with a specific focus on vulnerable groups – including young people, women and workers whose jobs are most at risk of transformation.” [82]

Governments are signaling their support for lifelong learning through policy changes. In the UK, the government has pledged to provide all adults with a fully-funded level 3 course and a lifelong learning entitlement to four years of post-18 education. [83] The Health Foundation calculates that over the last decade, in real terms, further education funding has been cut by 11 percent between 2010-11 and 2020-2021. While the UK government has committed to launching a National Skills Fund to support lifelong learning the foundation says this would cover only about one-third of the cuts made.[84] In China, the country’s next five-year plan includes a commitment to: “Give full play to the advantages of online education, improve the lifelong learning system, and build a learning society.” [85]

“[I see] a more participative education focused on problem solving issues and capabilities.”

Electrical / Electronic Engineering, Brazil, aged 56-65

In an essay for Harvard Business Review, Sean Gallagher and Jason Palmer claim trends such as lifelong learning are contributing towards the “unbundling” of degrees into shorter-form, “more nimble, lower-priced, digital “credentialized packages” of learning and mastery valued by employers, which will be essential in a digital economy where continuous upskilling is needed to keep pace with technological advances and the shrinking shelf-life of skills.” [37] They believe it will be possible to stack these micro-credentials into a larger lifelong curriculum and move closer to “achieving the widely-embraced goal of greater education-workforce alignment”. [37] They anticipate that the necessary financial support for this transition will likely flow from start-up companies and private capital: US$4.5 billion was invested in global EdTech during the first half of 2020, a sum three times greater than the average six months of venture capital investment over the past decade. Much of this was focused on higher education and its intersection with the workforce. [37]

Much of what we’ve explored in this section chimes with the predictions in our original *Research futures* report. We anticipated that the coming decade would see academic institutions “adapt their infrastructures 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.” Of course, what couldn’t have been anticipated was just how quickly these changes would be rolled out, largely due to the seismic impact of the Covid-19 pandemic on all aspects of life, work and learning.

References

1 19 March 2021. One year into COVID-19 education disruption: Where do we stand? https://unesdoc.unesco.org/ark:/48223/pf0000380398

2 School and university closure numbers: Marinoni G. et al. May 2020. The impact of COVID-19 on higher education around the world. https://www.iau-aiu.net/IMG/pdf/iau_covid19_and_he_survey_report_final_may_2020.pdf

3 Owen-Smith, J. The U.S. Academic Research Enterprise (US-ARE): Possible Paths from the Pandemic. Springer Nature. 21 October 2020. https://doi.org/10.21987/9hpw-fw18https://doi.org/10.21987/9hpw-fw18

4 Fosci, M. et al. Emerging from uncertainty: International perspectives on the impact of COVID-19 on university research. Research Consulting prepared on behalf of Springer Nature. November 2020. https://resource-cms.springernature.com/springer-cms/rest/v1/content/18537754/data/v6

5 NSCRC: Full Report released January 13th 2022. https://nscresearchcenter.org/stay-informed/

6 UCAS accessed March 4th, 2022 https://www.ucas.com/data-and-analysis/undergraduate-statistics-and-reports/ucas-undergraduate-releases/ucas-undergraduate-applicant-releases-2022-cycle

7 University leaders: opportunities and challenges. Elsevier. September 2020. https://www.elsevier.com/connect/university-leaders-report

8 Murakami, K. $40 Billion for Colleges. Inside Higher Education. 8 March 2021. https://www.insidehighered.com/news/2021/03/08/senate-approves-40-billion-colleges

9 Whitford, E. Endowments Skyrocket for the Wealthiest Colleges. October1st 2021. https://www.insidehighered.com/news/2021/10/01/wealthy-colleges-see-double-digit-returns-fiscal-2021?utm_source=Inside+Higher+Ed&utm_campaign=53c66aa537-DNU_2021_COPY_03&utm_medium=email&utm_term=0_1fcbc04421-53c66aa537-236757174&mc_cid=53c66aa537&mc_eid=6f45fb27de

10 Kakuchi, S. Student dropout rate on the rise due to pandemic impact. University World News. 10 March 2021. https://www.universityworldnews.com/post.php?story=2021031006383627

11 Zhou, N. Female enrolment at Australian universities dropped by 86,000 in 2020 as 'pink recession' hit. The Guardian. 11 November 2020. https://www.theguardian.com/australia-news/2020/nov/12/female-enrolment-at-australian-universities-dropped-by-86000-in-2020-as-pink-recession-hit

12 Hall, R. Demand for UK nursing degrees rises by a third in pandemic. The Guardian. 18 February 2021. https://www.theguardian.com/society/2021/feb/18/demand-for-uk-nursing-degrees-rises-by-a-third-in-pandemic

13 Howarth G. Nursing Times. 9 December 2021. https://www.nursingtimes.net/news/education/final-ucas-data-for-2021-confirms-record-rise-in-student-nurses-in-england-09-12-2021/

14 Boyle P. AAMC.org. 8 December 2021. https://www.aamc.org/news-insights/medical-school-applicants-and-enrollments-hit-record-highs-underrepresented-minorities-lead-surge

15 Clinician of the Future: a 2022 report. March 15, 2022. https://www.elsevier.com/connect/clinician-of-the-future

16 Landl H. Fierce Healthcare. 16 December 2021. https://www.fiercehealthcare.com/practices/a-list-20-highest-paid-specialties-2021-as-average-pay-for-doctors-slumps-doximity

17 Menchin, J. 10,000 international students "best case" for NZ HE campuses this year. The Pie. 28 January 2021. https://thepienews.com/news/10000-intl-students-best-case-for-new-zealand-he-this-year/

18 Erudera College News. 27 October 2021 https://collegenews.org/new-zealand-to-welcome-1000-international-students-in-mid-2022/

19 ICEF Monitor. 3 March 2021. https://monitor.icef.com/2021/03/new-analysis-projects-brexits-impact-on-eu-enrolment-in-british-higher-education/

20 Stacey V. The Pie. 15 November 2021 https://thepienews.com/news/us-enrolment-drops-see-economy-12-1bn-worse-off/

21 Concern regarding international students. DAAD. 2 March 2021. https://www.daad.de/en/the-daad/communication-publications/press/press_releases/sorge-um-internationale-studierende/

22 19 July 2021. International admissions: encouraging signs for 2021–2022? https://www.eaie.org/blog/international-admissions-survey-2021-2022.html

23 Open Doors Data. Enrollment Trends. https://opendoorsdata.org/data/international-students/enrollment-trends/

24 OpenDoors. Institute of International Education. US. As at January 2022. https://www.iie.org/Research-and-Insights/Open-Doors

25 The Chronicle, 23 July 2021 https://store.chronicle.com/products/the-chronicle-of-higher-education-july-23-2021

26 Yezdani, O. Which universities are best placed financially to weather COVID? The Conversation. 3 February 2021. https://theconversation.com/which-universities-are-best-placed-financially-to-weather-covid-154079

27 Kelly C. 7 October 2021. The Guardian. https://www.theguardian.com/australia-news/2021/oct/07/international-students-fear-cost-of-return-to-australia-as-pilot-schemes-announced

28 Radecki, J. & Schonfeld, R. C. The Impacts of COVID-19 on the Research Enterprise: A Landscape Review. Ithaka S+R. 26 October 2020.

29 Zhou, N. Universities discount fees for international students stuck outside Australia. The Guardian. 1 February 2021. https://www.theguardian.com/australia-news/2021/feb/01/universities-discount-fees-for-international-students-stuck-outside-australia

30 6 August 2020. South Korean universities offer partial tuition fee refund https://www.studyinternational.com/news/south-korean-universities-tuition-fee-refunds/

31 Inside Higher Education. 20 August 2021. https://www.insidehighered.com/news/2021/08/20/discounts-thailand-and-malaysia-amid-pandemic

32 Gallagher, S. & Palmer, J. The Pandemic Pushed Universities Online. The Change Was Long Overdue. Harvard Business Review. 29 September 2020. https://hbr.org/2020/09/the-pandemic-pushed-universities-online-the-change-was-long-overdue

33 Cappellino A. 9 September 2021. Expertinstitute.com https://www.expertinstitute.com/resources/insights/universities-sued-for-covid-19-refunds-following-campus-closures/

34 Morgan, J. UK budget: Sunak pledges new visa route and freezes fee cap. Times Higher Education. 3 March 2021. https://www.timeshighereducation.com/news/uk-budget-sunak-pledges-new-visa-route-and-freezes-fee-cap

35 Weale, S. & Hall, R. English universities to get £50m for students in financial distress. The Guardian. 2 February 2021. https://www.theguardian.com/education/2021/feb/02/english-universities-to-get-50m-for-students-in-financial-distress

36 Newschain. News Break. Accessed on 31 March 2021. https://www.newsbreak.com/contents/2183719935890/universities-must-not-sacrifice-quality-for-inflated-intakes-regulator-warns

37 Bothwell, E. Global university leaders expecting further revenue declines. Times Higher Education. 11 November 2020. https://www.timeshighereducation.com/news/global-university-leaders-expecting-further-revenue-declines

38 Gardner, L. The Great Contraction: Cuts alone will not be enough to turn colleges' fortunes around. The Chronicle of Higher Education. 15 February 2021. https://www.chronicle.com/article/the-great-contraction

39 Whitford, E. Becker College Will Close. Inside Higher Education. 30 March 2021. https://www.insidehighered.com/news/2021/03/30/becker-college-latest-small-private-college-close-doors

40 Dickler, J. In a last-minute scramble, some colleges scrap plans to reopen for the spring semester. CNBC. 12 January 2021. https://www.cnbc.com/2021/01/12/as-covid-cases-rise-colleges-scrap-plans-to-reopen-for-the-spring.html

41 Bauman, D. A Brutal Tally: Higher Ed Lost 650,000 Jobs Last Year. The Chronicle of Higher Education. 5 February 2021. https://www.chronicle.com/article/a-brutal-tally-higher-ed-lost-650-000-jobs-last-year

42 ABC.net.au 9 July 2021. https://www.abc.net.au/news/2021-07-08/sa-adelaide-university-job-cuts/100279146

43 Flaherty, C. Hiring Booms. Inside Higher Ed. 24 March 2021. https://www.insidehighered.com/news/2021/03/24/defying-trends-ohio-state-and-syracuse-will-hire-many-new-tenure-track-faculty

44 Whitford E. Inside Higher Ed. 8 December 2021. https://www.insidehighered.com/quicktakes/2021/12/08/higher-ed-sector-outlook-neutral-2022

45 Zhou, N. Australian universities flag more budget cuts, job losses in the next year. The Guardian. 26 February 2021. https://www.theguardian.com/australia-news/2021/feb/26/australian-universities-flag-more-budget-cuts-job-losses-in-the-next-year

46 Erasmus magazine. 18 February 2021. Coronavirus compensation. https://www.erasmusmagazine.nl/en/2021/02/18/coronavirus-compensation-50-percent-tuition-fee-reduction-and-relief-for-junior-researchers/

47 Bolton, P. & Hubble, S. Coronavirus: Financial impact on higher education. House of Commons Library, UK Parliament. 15 January 2021. https://commonslibrary.parliament.uk/research-briefings/cbp-8954/

48 QS.com Studying Abroad again. 22 June 2021. https://www.qs.com/portfolio-items/studying-abroad-again-current-and-prospective-international-students/?utm_source=Website&utm_medium=Blog&utm_campaign=Vaccines

49 Stacey V. The Pie News. 21 September 2021. https://thepienews.com/news/canada-average-international-tuition-rises-4-9-in-202122/

50 IDP connect. 14 October 2021. International market trends. https://www.idp-connect.com/canada/articles/international-market-trends/students-from-more-than-50-countries-crown-canada-as-top-post-secondary

51 Yang Q. et al. 19 October 2021. Changes in International Student Mobility amid the COVID-19 Pandemic and Response in the China Context https://link.springer.com/article/10.1007/s40647-021-00333-7

52 ICEF Monitor. 21 July 2021. https://monitor.icef.com/2021/07/survey-explores-perspective-of-foreign-enrolled-students-in-china/

53 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/

54 De Vynck G & Bergen M. Bloombergquint.com 10 April 2020. https://www.bloombergquint.com/business/google-widens-lead-in-education-market-as-students-rush-online

55 Aternity.com 28 August 2020. https://www.aternity.com/news/microsoft-teams-revenue-and-usage-statistics-2020/

56 Microsoft.com 28 October 2020. https://www.microsoft.com/en-us/microsoft-365/blog/2020/10/28/microsoft-teams-reaches-115-million-dau-plus-a-new-daily-collaboration-minutes-metric-for-microsoft-365/

57 Gallup. 25 August 2020. https://news.gallup.com/poll/317852/parents-satisfaction-child-education-slips.aspx

58 Most students pleased with their digital learning – Survey. University World News. 10 March 2021. https://www.universityworldnews.com/post.php?story=20210310140820973

59 Hardly any lectures at universities failed. Forschung & Lehre. 18 March 2021. https://www.forschung-und-lehre.de/lehre/kaum-vorlesungen-an-unis-ausgefallen-3580/

60 Witze, A. Universities will never be the same after the coronavirus crisis. Nature. 1 June 2020. https://www.nature.com/articles/d41586-020-01518-y

61 Macalus, A. Kitsap needs more COVID-19 testing. Nursing students at Olympic College are joining the effort. Kitsap Sun. Accessed on 5 April 2021. https://eu.kitsapsun.com/story/news/2020/11/10/olympic-college-nursing-students-staff-new-covid-19-testing-site/6230467002/

62 Hiler, T., Fishman, R. & Nguyen, S. One Semester Later: How Prospective and Current College Students' Perspectives of Higher Ed Have Changed between August and December 2020. Third Way. 21 January 2021. https://www.thirdway.org/memo/one-semester-later-how-prospective-and-current-college-students-perspectives-of-higher-ed-have-changed-between-august-and-december-2020

63 Leadership Responses to COVID-19: A Global Survey of College and University Leadership (Executive Summary). International Association of University Presidents and Santander Universidades. November 2020. https://www.iaup.org/wp-content/uploads/2020/11/IAUP-Survey-2020-ExecutiveSummary.pdf

64 Korea Joong Ang Daily. 18 February 2022. https://koreajoongangdaily.joins.com/2021/06/07/national/socialAffairs/Seoul-National-University-SNU-Covid19/20210607173300283.html

65 Ross, J. & McKie, A. More universities planning to drop lectures after pandemic. Times Higher Education. 7 January 2021. https://www.timeshighereducation.com/news/more-universities-planning-drop-lectures-after-pandemic

66 Lem, P. University group seeks EU support for blended learning. Research Professional News. 13 July 2020. https://www.researchprofessionalnews.com/rr-news-europe-universities-2020-7-university-group-seeks-eu-support-for-blended-learning/

67 Survey by faculty and staff Digitization of university office work is halfway through the corona wreck. University Journal Online. 14 March 2021. https://univ-journal.jp/86290/

68 Gallagher, S. & Palmer, J. The Pandemic Pushed Universities Online. Harvard Business Review. 29 September 2020. https://hbr.org/2020/09/the-pandemic-pushed-universities-online-the-change-was-long-overdue

69 Wang, V. China's College Graduates Can't Find Jobs. The Solution: Grad School. The New York Times. 18 January 2021. https://www.nytimes.com/2021/01/18/business/china-graduate-school-white-collar.html

70 National Bureau of Statistics of China. 15 September 2021. http://www.stats.gov.cn/english/PressRelease/202109/t20210915_1822089.html

71 The Straits Times. 16 August 2021. https://www.straitstimes.com/asia/east-asia/chinas-youth-unemployment-spikes-as-students-graduate

72 Science, Technology and Innovation Outlook 2021: Times of Crisis and Opportunity, OECD Publishing. 2021. https://doi.org/10.1787/75f79015-en

73 MOOCs. Then. Now. Next. HolonIQ. 1 April 2021. https://www.holoniq.com/notes/moocs-then-now-next/

74 Shah, D. By the Numbers: MOOCs During the Pandemic. The Report by Class Central. 16 August 2020. https://www.classcentral.com/report/mooc-stats-pandemic/

75 Huge increase in MOOCs during pandemic. Delta: Journalistic platform TU Delft. 30 October 2020. https://www.delta.tudelft.nl/article/huge-increase-moocs-during-pandemic

76 Russon, M-A. & Hooker, L. UK 'heading towards digital skills shortage disaster'. BBC. 22 March 2021. https://www.bbc.com/news/business-56479304

77 Shah D. 14 December 2021. https://www.classcentral.com/report/moocs-stats-and-trends-2021/

78 Leighton M et al. Business Insider. 13 February 2021. https://www.businessinsider.com/guides/learning/coursera-most-popular-online-classes?international=true&r=US&IR=T

79 Classcentral.com https://www.classcentral.com/institutions

80 Le Cunff, A-L. The educational and economic necessity of lifelong learning. Ness Labs. Accessed on 7 April 2021. https://nesslabs.com/lifelong-learning

81 The Future of Jobs Report 2020. World Economic Forum. 20 October 2020. https://www.weforum.org/reports/the-future-of-jobs-report-2020/in-full

82 Skills outlook 2021: Learning for life. 15 June 2021. https://www.oecd.org/skills/oecd-skills-outlook-e11c1c2d-en.htm

83 Tam, J. Funding for adult learners will boost the UK's economic recovery. Universities UK. 30 September 2020. https://www.universitiesuk.ac.uk/blog/Pages/funding-adult-learners-boost-uk-economic-recovery.aspx

84 Lifelong learning and levelling up: building blocks for good health. 24 September 2021. https://www.health.org.uk/publications/long-reads/lifelong-learning-and-levelling-up-building-blocks-for-good-health

85 (Authorized to issue) Proposals of the Central Committee of the Communist Party of China on Formulating the Fourteenth Five-Year Plan for National Economic and Social Development and Long-Term Goals for 2035. Xinhua News Agency. 3 November 2020. http://www.xinhuanet.com/politics/zywj/2020-11/03/c_1126693293.htm

Methodology

This report builds upon the original *Research Futures* Study published in 2019. Since the original report we have completed two new surveys over two years which allowed us to examine how matters had shifted, if at all, in regard to the trends, drivers, attitudes and behaviours that we had identified as shaping the future.

A recap on the approach in the original study

The prior study that we completed in 2018 and published in 2019 comprised several phases The first phase was a review of the published literature. This was followed in the second phase by a series of interviews with 56 experts from around the world in spring 2018. Their backgrounds were varied and including funding agencies, researchers and leaders at academic institutions, librarians, futurists, publishers, established technology companies and start-ups. You can see the details of who was interviewed in our original report. 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 findings from interviews were used to inform the third quantitative phase of the study. The focus of the research instrument was to test the constructs and forces that would drive the future. 2,055 respondents from a range of disciplines and geographies took the survey.

Finally, the fourth phase comprised three one-day workshops held with internal and external experts. Attendees considered the results from the various phases to identify tensions in the system and consider different possible futures and indicate which they thought would occur. The result: three credible scenarios, each envisaging what the future might look like a decade on.

Methodology in the 2020 and 2021 studies

In 2020, we felt the time was appropriate to revisit our first report and consider how the themes and scenarios we identified were playing out, particularly in light of COVID-19. We decided to carry out studies in 2020 and 2021 among researchers around the world to ask them questions on a range of topics from collaboration to education and open science to public engagement, aligned to the areas we covered in the earlier study. While many of the questions asked were not the same, a number were, and for those questions we have compared the results to the prior study.

Who we surveyed in 2020 and 2021

Sample source: To ensure a robust view of the research community, we approached approximately 100,000 individuals for each wave of the research. 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 received 1,066 respondents from a range of disciplines and geographies in 2020 and 1,173 in 2021.

Survey tool: both surveys were conducted online and available in English only via the Confirmit platform. Each survey took approximately 20 minutes to complete (median average).

Fieldwork took place in the second half of 2020 (July 2020) and 2021 (July-August 2021).

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 data). Base sizes shown in the report are unweighted, unless otherwise stated.

Statistical testing: Maximum error margin for 1,173 responses in 2021 is ± 2.4 percent and for 1,066 responses in 2020 is ± 2.5 percent at 90 percent confidence levels. When comparing the main group and sub-groups, we used a Z-test of proportion to identify differences between the overall average and the sub-group (90 percent confidence levels).

Differences are indicated by an upward or downward triangle or a dot. A green triangle indicates the 2021 result is higher than the 2020 result while a red triangle indicates it is lower. A green dot indicates the sub-group result is higher than the overall result while a red dot indicates it is lower in the 2021 set of results.

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 end of each chapter. We have been as neutral and objective as possible to reflect a balance of opinion, for example, through ensuring questions are balanced and by revealing Elsevier as the sponsor of the survey at the end.

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Research Futures 2.0: A new look at the drivers and scenarios that will define the decade

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Mirit Eldor
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Liana Cafolla
Freelance journalist and editor
Adrian Mulligan
Linda Willems
Blue Lime Communications

Report Communications

David Tucker
Andrew Davies
Elsevier

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Report Design

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