Independent SAGE as an example of science-public dialogue

Trish Greenhalgh[1], Anthony Costello[2], Sheena Cruickshank[3], Stephen Griffin[4], Aris Katzourakis[5], Lennard Lee[6], Martin McKee[7], Susan Michie[8], Christina Pagel[9], Stephen Reicher[10], Alice Roberts[11], Duncan Robertson[12,13], Helen Salisbury[1], Kit Yates[14]

On behalf of the membership of Independent SAGE

1. Nuffield Department of Primary Care Health Sciences, University of Oxford, Oxford, UK
2. Institute for Global Health, University College London, UK
3. Lydia Becker Institute of Immunology and Inflammation, University of Manchester, Manchester, UK
4. Leeds Institute of Medical Research, School of Medicine, University of Leeds, Leeds, UK
5. Department of Biology, University of Oxford, Oxford, UK
6. Centre for Immuno-oncology, University of Oxford, UK
7. London School of Hygiene and Tropical Medicine, London, UK
8. Centre for Behaviour Change, University College London, UK
9. Clinical Operational Research Unit, University College London, UK
10. School of Psychology and Neuroscience, University of St Andrews, UK
11. School of Biosciences, University of Birmingham
12. Management Science and Operations Group, Loughborough Business School, Loughborough University, Loughborough, UK
13. St Catherine's College, University of Oxford, Oxford, UK
14. Department of Mathematical Sciences, University of Bath, UK

Abstract

The WHO declared COVID-19 to be a Public Health Emergency of International Concern (PHEIC) on 30 January 2020 and a pandemic on 11 March 2020. In early 2020, a group of volunteer UK scientists came together to provide the public with up-to-date and transparent scientific information. The group formed the Independent Scientific Advisory Group for Emergencies and provided live weekly briefings to the public via YouTube. In this Perspective, we describe how and why the group came together and the challenges it faced. We reflect on four years of scientific information broadcasting and suggest some guiding principles for scientist-public dialogue during public health emergencies which may be broadly transferable to future settings, namely: providing clarity and transparency; engaging with the science-policy interface; practicing interdisciplinarity; addressing inequity; dialoguing and partnering with the public; supporting advocacy groups; diversifying communication channels and modalities; adopting regular and organized internal communications; resourcing and supporting the group communications; and actively combating misinformation and disinformation. We reflect on what we might do differently next time and suggest research aimed at building the evidence base for optimizing informal scientific advisory groups in crisis situations.

Introduction

In early 2020, as the COVID-19 pandemic took hold in the UK, an interdisciplinary group of scientists came together to engage with the public both directly (using social media[1]) and indirectly (through the mainstream media). They called themselves 'Independent SAGE' (not to be confused with SAGE, the UK Government's Scientific Advisory Group for Emergencies). The Twitter (now X) feeds of these scientists quickly became points of reference for both lay people and scientists who sought to understand the layers of complexity intersecting the fields of virology, epidemiology, public health, psychology, communications, statistical modelling, and immunology, and examine how this complex science was being used to inform governmental policies and guidelines. As the haunting images from across the world revealed the extent of the danger that pandemics pose in a globalized world, the task for the Independent SAGE public communication efforts was clear: we sought to provide clarity and transparency in a fast-unfolding situation of unprecedented magnitude in the modern era. From the get-go, it became evident that the appetite for direct, timely, open and honest communication during public health crises was huge.

Why did the group form? What did Independent SAGE do? And now that the acute phase of the COVID-19 pandemic has come to an end, what lessons were learned from the Independent SAGE group that might help the world face the next global public health emergency? We discuss our experience on Independent SAGE in three sections covering the group's inception, its development as an example of science-public dialogue, and how it came to a natural close. We consider how the learning from Independent SAGE might serve as guiding principles for other, similar, groups in future emergencies. We also reflect on the limitations of our approach and what we might we do differently next time. Finally, we identify some evidence gaps which could be filled by future research on science communication.

Context and origins

By late January 2020, the severity and scale of the novel coronavirus outbreak in China was clear. In the high-stakes, low-certainty context of a fast-unfolding global public health crisis,[2] policymakers worldwide had the unenviable task of weighing competing options with stark life-and-death implications—and deciding how and how quickly to act as more evidence emerged.[3] In those early weeks, openness around UK policy decisions was scarce.[4] There was much debate (some of it acrimonious) about how the UK government should respond. Should borders close? Should mass testing be introduced, and if so, how? Should masks be worn—and if so, by whom and in what circumstances? If the health service became overwhelmed, who should be prioritized for treatment?

In the UK, the maxim "scientists advise; ministers decide"[5] was much repeated but obscured two problems. First, the attempt to draw a firm distinction between science and policy ignores that the implementation of research findings is itself a scientific issue, whether it be discussed through the lens of implementation science,[6] the social science of research utilization by policymakers,[7,8] or as policy choices in the context of political economy.[9] Second, it begs the question of *what* (and *whose*) science was being used to advise.

Government policy drew most directly on input from SAGE, the official UK Government Scientific Advisory Group for Emergencies. The membership of SAGE, along with sub-groups on modeling, behavioral science and emerging respiratory viruses, was decided by the government's Chief Scientific Advisor, working alongside the Chief Medical Officer.

Membership and deliberations of SAGE and its sub-groups were initially not public, until the UK government began to disclose—from May 2020— their membership, minutes and reports.[4,10] This change in approach followed a series of "secrecy rows" over the public disclosure of financial and other interests held by members of SAGE. Until then, no-one outside government and SAGE itself had any direct knowledge of either who offered advice to Government (and, consequently, which areas of science were under-represented or excluded from the advisory process) or of what that advice involved (and, hence, whether the government really was "following the science", as was being claimed[11]). Onlookers simply could not tell if lessons from previous UK pandemics and pandemic exercises,[12 13,14] or from the experience of other countries,[15] had been learnt, remembered, or actioned.

We acknowledge that, as a reviewer of an earlier draft of this paper pointed out, "It has to be noted that SAGE sits as a subgroup of COBRA [Cabinet Office Briefing Rooms], a Cabinet Office committee for national emergencies which sits in the National Security Secretariat, and as such a level of confidentiality is expected." Such constraints notwithstanding, the prevailing lack of information about the scientific basis of Government COVID decision-making in early 2020, and a perceived lack of candour over uncertainty,[16] was troubling to those outside the corridors of power. Transparency is a critical antecedent of trust,[17] and trust (in both scientists and Government) is a powerful determinant of adherence to public health measures.[18] While overall public trust in the government in the early months of 2020 was high, it was lower in more highly-educated people and fell significantly over the next few months.[19-22] At the same time, there was a surfeit of scientific information circulating on social media, much of it in the form of scientific pre-prints and hastily-prepared peer-reviewed articles of varying quality.[23] It became clear that something more was needed to help the public understand and navigate the scientific evidence relevant to policy responses to the pandemic.

In April 2020, Pulitzer-nominated journalist Carole Cadwalladr had the idea of convening an independent group of scientists to assess the UK's pandemic approach, and to conduct a public discussion on options for moving out of lockdown. Cadwalladr had recently founded 'The Citizens', a not-for-profit journalism organization focused on democracy, data rights, and addressing disinformation. Cadwalladr invited Sir David King (UK Government Chief Scientific Adviser, 2000-2007) to chair the group and asked Professor Anthony Costello (ex-WHO, global public health expert) to suggest other potential members.

By May 2020, the inaugural group of UK scientists had been convened. They were drawn from a purposefully wide range of disciplines including public health, epidemiology, mathematics, immunology, virology, evolutionary biology, clinical medicine, primary healthcare, behavioral and social sciences, and public engagement with science. An expert in race equality was also invited into the group. The group chose the title 'Independent SAGE', to communicate its aim to serve as an advisory group, but also to signify autonomy from the government and other potential sources of political interference.

From its inception, Independent SAGE considered that as much evidence as possible should be publicly accessible and communicated clearly, allowing this to be examined collectively to inform public debate. But more than this, there was an urgent need to address critical questions about public health measures *with* the public. This meant establishing a two-way dialogue, answering questions, respecting public doubts, and acknowledging uncertainties. This was an evidence-based approach in itself, given that health interventions are known to be more effective when there is mutual [19] and cooperation between scientists and the public.[24]

The science-policy ecosystem in UK

Official SAGE and Independent SAGE were by no means the only actors in what might be called the 'science-policy ecosystem' in the early phase of the pandemic. Other official actors included other government advisory groups (e.g. Joint Committee on Vaccines and Immunisation, JCVI), Public Health England (which had a public facing dashboard and gave regular briefings) and the Office of National Statistics (ONS, which ran a regular infection survey and produced weekly statistics on COVID cases). Other unofficial actors inlcuded various fact-checking services (e.g. Full Fact), public-facing platforms set up by scientists to broadcast their own emerging research findings (e.g. the large REACT-1 study of changing COVID prevalence across UK), and those established by research bodies (e.g. UK Research and Innovation's 'coronavirus explained' website) and academic societies (e.g. the Royal Society's Data Evaluation and Learning for Viral Epidemics [DELVE] and Rapid Assistance in Modelling the Pandemic [RAMP] initiatives, which also involved interdisciplinary groups of scientists who sought to produce data-driven advice and recommendations outside the official government space), initiatives led by mainstream media (e.g. the popular BBC radio programme on statistics, *More or Less*, which pivoted to explaining and fact-checking COVID-19 statistics during the pandemic), and the independent Science Media Centre, which showcased key research findings and collated expert commentaries on them in a public-facing website. Some individual scientists established citizen science initiatives which recruited large numbers of lay people (e.g. Professor Tim Spector repurposed the 'Zoe app' and recruited over 4 million people in UK to record their symptoms [or lack of them] and test results, and also used the app for communicating advice and information).

In this complex ecosystem, the unique aspects of Independent SAGE were threefold. First, our live interactions with the public were frequent (weekly), intensive (90 minutes), driven by topics and issues proposed by the public, and systematically recorded and archived. Second, and mainly as a result of this frequent and intense interaction with the public, we developed a particular focus on inequalities and vulnerable groups, including the socio-economically disadvantaged, minority ethnic groups and the clinically extremely vulnerable. Third, as explained further below, we linked in a responsive and emergent way with unions, advocates and campaign groups to support them in pursuing their goals.

The Independent SAGE approach

The first official meeting of Independent SAGE was held on 4th May 2020, as a two-hour broadcast live-streamed on Twitter and YouTube, where the scientists discussed the UK response to date and options for the future.[25] Key themes were learning from abroad, contact tracing, addressing the pandemic's unequal impact, and (re)building resilience in the health system. It drew an audience of several thousand. After the meeting, the members produced a report of broad public health and policy recommendations. This initial meeting showed that there was high demand for public-facing, interdisciplinary science and the group held several live briefings over the following weeks on specific topics (e.g. education,[26] contact tracing[27]) where people were invited to ask questions directly to the group.

When (from 23 June 2020) the UK government ended its daily public briefings, Independent SAGE committed to a weekly one-hour briefing live-streamed every Friday lunchtime, which soon evolved into a structured format:

- The numbers: a presentation of the latest data and trends in the UK and globally.

- Topic of the week: a specialist segment presenting a new Independent SAGE report or covering a theme in detail, featuring expert guests.
- Live questions from the audience, submitted by a very broad range of people including members of the public with either a personal issue (e.g. concerns about vaccines and infertility) or a responsibility for others (e.g. a teacher seeking to make a classroom safe), press (both local and national), trade unions (e.g. for health and care workers) and journalists, politicians and policymakers from UK and abroad.

As the group became established, the aim of Independent SAGE became clearer: to scrutinize and communicate the best available scientific evidence, to listen to the experiences, concerns and perspectives of diverse members of the public and to put these together in ways that would support those faced with difficult decisions. Many questions raised issues that we were not sufficiently expert to tackle (e.g. how best to control indoor air quality; support for mental health of young people), so we used those as prompts to seek additional expert guest speakers on the briefings. These individuals were selected on the basis of their scientific reputation and publications and their willingness to enter into direct dialogue with the public.

Some members were involved in both Independent SAGE and official SAGE, and gave the same advice in each setting. The main difference lay in whether and how they engaged with the public in these respective roles.

From mid-2020 to late 2023, briefings by Independent SAGE were broadcast live on YouTube and Twitter. The Citizens developed and supported the Independent SAGE website (www.independentsage.org) and Twitter account (@independentsage), facilitated the weekly briefings, and fielded questions from the public and media enquiries. An example of the weekly briefing is described in Box 1.

BOX 1 HERE

Independent SAGE also produced numerous written outputs, shared on their website. These included downloadable reports and policy recommendations, short statements on emerging topics, fact sheets, visualizations (e.g. accessible graphs and diagrams) and a collection of short-format 'myth-busting' videos. Its members frequently contributed to broadcast and printed national and international media, as well as engaging on social media.

Independent SAGE came to be seen by many as an accessible and timely source of evidence-based advice and information, both inside the UK and internationally.[28] Its reports were cited and members quoted across the full range of both broadsheet and tabloid press, as well as in the UK Parliament and legislatures of the devolved nations (Scotland, Wales and Northern Ireland).

Impact of Independent SAGE

We were not resourced to measure the impact of our activities, and indeed because we were operating in a complex and fast-changing open system, this would have been difficult. In terms of metrics, we produced around 150 weekly live briefings (all of which are recorded and archived on YouTube), over 50 in-depth scientific reports, 16 mythbuster videos and made over 500 appearances on live television and radio. At the height of the pandemic, for example, well over

100,000 people watched our live-streamed briefing every week (e.g. over 200,000 views for the 30 December 2020 briefing).[29,30] Independent SAGE's feed on Twitter/X attracted over 170,000 followers. Informal feedback from the lay public indicated strong support for our interactive sessions where they could put questions directly to us in real time. The weekly 'numbers' slot, in which experts presented figures graphically, explained their significance and discussed the associated uncertainties, was extremely popular. Sub-groups of the population greatly valued our work on particular issues (e.g. those planning or going through a pregnancy appreciated nuanced discussions on the risks and benefits of COVID vaccines in pregnancy).

In addition, our collaborative activities with advocacy groups and unions generated a number of tangible outputs. For example, collaboration with health and safety specialists and trades unions drove two initiatives aimed at emphasising, illustrating and signposting the need for infection-resilient environments in allowing safe return to schools, universities, and workplaces. The "scores on the doors" plan saw the design of clear signage to indicate the air quality within indoor spaces as well as their appropriate safe use. Later, the "COVID pledge" (a manifesto for safe workplaces) expanded on infection resilient environments by involving multiple charities, trades unions, and other stakeholders in the commitment to ensure all members of the public would have the best possible access to healthy indoor environments.[31] This initiative also contributed to the Scottish Government's policy on clean indoor air.

Winding down

Independent SAGE was assembled in response to the acute phase of the COVID-19 pandemic. Nobody at the time knew how long it would be needed for. As the pandemic developed, Independent SAGE expanded, with additional experts joining from disciplines including virology, immunology, primary health care and social sciences.

Membership of Independent SAGE was entirely voluntary and unpaid, undertaken in addition to each member's day job. At the height of the early pandemic, preparation for the weekly briefing could involve several days' work, especially for a member presenting "the numbers" or the special topic. Members balanced this in different ways, sometimes by aligning their Independent SAGE work with their remunerated day job, and sometimes by carving out time outside office hours. To some extent, the global camaraderie of scientists responding to the pandemic energized us. Over time, however, some members stepped down, almost always because they were unable to commit further to the time required. Inevitably, in a situation characterized by considerable uncertainty with decisions that require complex trade-offs, there were some disagreements among members. These could almost always be reduced (though not always fully resolved) by discussion, though on one occasion an unresolved disagreement precipitated a member's decision to leave the group.

After more than three years of weekly briefings, and as COVID-19 transitioned from an acute to a long-term public health challenge, the sense of crisis became less acute. In addition, many members had a backlog of other commitments that had been put on hold. Whilst the group has not formally disbanded, the live weekly briefings moved to every two weeks in spring 2023 and ended in December 2023. The group established a Substack channel ('Independent SAGE Continues'); they are still in close contact with one another through social media channels and occasional online or in-person meetings.

Ten learning points from Independent SAGE's development

As a voluntary unofficial group working in their 'spare time', Independent SAGE had a collegiate culture and little internal hierarchy, although chairs were assigned to oversee preparatory meetings and host the live sessions. Whilst this ethos of informal, non-bureaucratic scientific dialogue remained as the group grew and matured over time, a number of learning points emerged across scientific, ethical, practical and operational domains. We offer these learning points (which broadly reflect academic literature on science-public and science-policy dialogue[1,18,32,33]) as potential guiding principles. We hypothesize that they are likely to be applicable, to some extent and with modification, to public health emergencies more generally. Importantly, however, the points below should not be seen as a universal formula or blueprint. Independent SAGE emerged in a particular country at a particular time in response to a unique set of circumstances and events. Other emergencies, in other settings, will have their own priorities and constraints.

Clarity and transparency

Good science communication in a pandemic involves conveying complex concepts (e.g. the nature of viruses and their evolution, data on cases and transmission) to a lay audience. This task is complicated when false or contradictory evidence is freely circulating, often without being contextualised. Clear and concise messages, supported by visual representations of data, are key. Public trust [18,32] in science and science-based policy is diminished by secrecy, whereas it increases when both facts and uncertainties are openly shared with the public.[34-38]

It is also important to convey the estimated level of uncertainty around a scientific question or issue (a task on which much has been written[34,35,38]) and, where appropriate, to change position in the light of new evidence rather than sticking to one that was reached before key evidence was available. For example, we were initially cautious about the early proposals for repeated mass testing using lateral flow tests, given that the available documentation on what was termed a "Moonshot" project was strong on ambition but deficient in detail. As improved tests became available, we revisited the evidence base and after reviewing data on test performance and experience in other countries, came to a more positive conclusion.

Independent SAGE was also transparent about its collective values: it advocated for evidence-based policy that protected lives, reduced pressure on health services and took into account social influences on and consequences of health decisions. Members were asked to declare any conflicts of interest and agree to follow a code of conduct when they joined.

Engaging with the science-policy interface

The maxim "*scientists advise, ministers decide*" overlooks how, in reality, policymaking (and especially *crisis* policymaking) requires a dialogue between scientists and policymakers.[2,39] Scientists must not only convey research findings, but also explain why they matter, what is at stake, how a situation is likely to unfold with, or without, implementing a particular policy and how to implement scientific insights in ways that will be effective in achieving the desired ends. Policymakers must make clear to scientists that, in addition to academic concerns, policymakers must take account of expectations, practical constraints, timescales and cost implications for key decisions, thus producing a two-way dialogue on the realities of implementing the best scientific practices.[4,39]

David Easton — an early advocate of systems theory in political sciences—defined policymaking as "*the authoritative allocation of values for the whole of society*".[40] Under that premise, scientific 'facts' can be value-laden in the sense that they can be mobilized rhetorically to support or advise against particular policies.[7] Independent SAGE sought to present scientific data not in a value-free bubble but as inextricably tied to the values which informed particular policy options. Sometimes

this meant challenging the government on policies which we did not consider evidence-based and/or risked causing harm, such as when lifting all restrictions in the name of "freedom" placed vulnerable groups at risk.

Interdisciplinarity

In a fast-unfolding public health crisis, scientists and other scholars from a range of backgrounds and disciplines need to work together and understand each other. For example, questions about potential individual- and population-level impacts of the virus touched on genetics, medicine, immunology, virology, evolutionary biology, ecology, behavioral sciences, mathematical modelling, public health, actuarial sciences, and sociology. New research findings from genetics, immunology or other fundamental science might suggest that a change in individual behavior is needed, requiring input from the behavioral and social sciences (e.g., strategies for building trust in science[41] or addressing the reasons for vaccine hesitancy[42]).

Independent SAGE members covered a deliberately wide range of expertise and, because of interdisciplinary insights, its outputs were more than the sum of its parts. Interdisciplinarity played out partly through allocation of topics and tasks (certain people were clearly expert on particular subjects and methods, for example mathematical modeling) and also through group dialogue (as we discussed a multifaceted topic it sometimes became clear that an additional disciplinary lens was needed, for example the psychology of how people interpret models). An example of interdisciplinary output is our early report on test/trace/isolate, which drew on our collective expertise in public health, virology, addressing inequalities, behavioural science, communication and health policy.[43]

As the group worked together, each member developed a clearer understanding of how their own scientific contribution complemented that of other members, allowing us to draw flexibly on each other's expertise and form small ad hoc working groups for particular reports and presentations. If a particular discipline was needed for a topic but not present within the group, we invited an external expert.

A question raised by a reviewer of an earlier draft of this paper was how Independent SAGE dealt with the issue of 'bias' (on the implicit assumption that experts in a field can develop a kind of tunnel vision based on their own narrow topic interest). Whilst we do not claim to have been bias-free, one important buttress against our respective individual biases was ongoing interdisciplinary dialogue in which we each had to justify our position to others who may not have shared it (or even fully understood it). These interdisciplinary challenges were further enhanced by regular live interaction with a broad range of lay people.

Addressing inequality

The COVID-19 pandemic exacerbated existing inequalities throughout society.[44,45] It disproportionately affected various marginalized and vulnerable groups including those in deprived areas, black and minority ethnic communities, those with learning difficulties, and clinically vulnerable people. Similarly, the COVID response affected these groups in different ways, and policymakers' failure to acknowledge this and mitigate against it (say by providing learning resources to all children during school closures) only exacerbated those inequalities. From the earliest days of the pandemic, Independent SAGE were concerned that its impact would be disproportionate on more vulnerable groups. We explicitly and proactively advocated for the cause of many such groups and featured their voices and experiences in many of the live sessions. One of our first ever reports was on the disproportionate number of Black and minority ethnic deaths from COVID-19 in early 2020.[46]

More generally, we repeatedly raised the pervasive issue of inequalities both in written academic reports[47,48] and in dedicated live sessions featuring expert guest speakers including one on links between socio-economic deprivation and COVID-19 with Professor Michael Marmot and Debbie Abrahams MP,[49] and another on inequalities with Professors Clare Bambra and Arpana Verma.[50] We wrote many articles for the lay press on the importance of welfare support (such as sick pay). We raised concerns both in our independent reports[51] and in academic journals about vaccine inequity.[52,53] We covered the pandemic's impact on children and young people and called for more action—including vaccination and attention to indoor air quality—to protect them.[54,55]

Interaction and dialogue with the public

Independent SAGE's commitment to respecting and involving the public contrasted with a government response which (some argue) saw the public as a problem.[56] Treating the communication of the different aspects of the scientific discourse as a genuine dialogue helped ensure that multiple voices were heard (see principle 4). This commitment to an open dialogue with the public reflects what has been termed 'mode two science'—occurring, at least in part, outside the walls of the university.[33] This involves reflection on the role and ethical significance of science in society and celebrating the 'agora' (public space) where democratic discussion between scientists and the public occurs.[33,39] Some of these dialogues were brief and focused on information-giving, such as answering questions posed by the public our weekly briefings (e.g. "should I have the Astra Zeneca vaccine I've been offered or shop around for a different one?"), though not infrequently these questions promoted us to produce resources such as factsheets (e.g. on vaccination in young people), animations (e.g. on indoor air quality) or brief videos (e.g. our 'mythbusters' series). Other dialogues (see next point) consisted of ongoing and collaborative interactions with groups or organisations.

Supporting advocacy and interest groups

'The public' and other bodies include well-informed and committed groups with particular expertise and/or interests on a variety of issues. Parents, for example, want schools to be safe. Trade unions seek to secure safe working conditions for their members. Members of Parliament have a duty to raise questions on behalf of their constituents. Clinically vulnerable people and their loved ones know that safe public spaces can be a matter of life or death. Long COVID sufferers understand how important research into the condition is. We found that early and respectful dialogue with such groups could hone the key questions that needed answering and create effective channels for disseminating key findings. Conversely, advocacy and pressure groups found that engaging with a group of respected scientists like Independent SAGE increased their visibility and credibility. We worked with numerous groups, including

- various Long COVID patient support groups;
- Clinically Vulnerable Families,[57] a network to support immunosuppressed, frail, or those with multiple health conditions that may impair immunity, and who became Core Participants in the UK COVID-19 Inquiry;
- COVID-19 Bereaved Families for Justice, a UK pressure group fighting to ensure that the mistakes of the COVID-19 pandemic are never repeated;
- various trades unions (e.g. Unite, the leading workers' union in UK and the Scottish Trade Union Congress) and worker support groups (e.g. Hazards, Doctors in Unite) to develop the COVID Pledge described above.[31]

In some of these collaborations, the mode of interaction might legitimately be described as co-production of outputs *with* advocacy and interest groups rather than production of resources *for* those groups.

Multiple communication channels and modalities

Different sectors of the population get their information from a wide range of different sources and in different formats. Independent SAGE members, facilitated by The Citizens, proactively engaged with diverse knowledge outlets, including social media microblogging sites (Twitter/X, Mastodon, BlueSky, YouTube), longer blogs, public-facing academic platforms such as *The Conversation,*[58,59] bulletins, podcasts, and mainstream broadcast and print media (Figure 1). Alongside the weekly live briefings, social and traditional media, Independent SAGE members also produced (for example) scripted team presentations as YouTube videos and video clips, blogs, infographics and animations. Members also wrote accessible papers and books aimed at a broad scientific and practitioner audience. Examples are given in Table 1.

FIGURE 1 AND TABLE 1 HERE

Regular and organized internal communications

The scientists in the group did not have to publicly agree on every issue on every occasion, but they did spend time deliberating collectively on the significance of emerging data and learning from each other. For Independent SAGE, this 'backstage' activity typically occurred in pre-briefing meetings and discussions via videoconference. These informal meetings facilitated scrutinizing content, setting the tone for forthcoming public presentations, allocating tasks, sharing ideas for guest speakers, flagging and dealing with concerns, shaping the collective identity and affirming its shared values.

A good example of this was how we prepared for a special briefing one year on from UK's 'Freedom Day' (19th June 2021—the day the UK dropped most protective measures) by considering various angles to cover (impact on incidence of COVID-19; impact on clinically vulnerable people; sickness absence among healthcare staff; pressure on services; risk of emergence of new variants) and the disciplinary expertise needed to address them (modelling, statistics, clinical medicine, public health, evolutionary virology). Our 'backstage' meetings also provided shared learning and support for members who experienced abuse on social - or indeed traditional – media, or via email. This experience was far more common for the women (particularly the women of color) in the group, and those promoting the scientific evidence on issues that became politicized, such as facemasks and vaccines. The rich internal communications helped members become more rounded commentators, able to field questions beyond their immediate expertise, for example, by acknowledging the importance of the topic and providing a steer as to what kind of expert would be needed to answer the question in more detail.

Resourcing and supporting the group communications

Even when scientists give their time for free, financial and human support is needed to run a website, stage live digital briefings, process questions and comments from the public, and make reports and publications accessible. 'Amateur' media clips such as short Tik-Tok videos have some advantages by being able to be made quickly, cheaply and may humanize the scientists. However, there is also a place for professional-quality multimedia presentations that can be showcased to policy audiences and widely shared across multiple platforms. Technical support for making such presentations can be costly, but if the scientists have national reach, crowdfunding is a possible source of support. Independent SAGE used two crowdfunder exercises to raise relatively modest sums (£15,000 to £20,000 each time) to continue supporting briefings and communication activity in 2022 and 2023.

In each case, the crowdfunders were closed after a few days due to the rapid and generous responses. Fundraising efforts should be clear, transparent and focused as people need to know what will be done with any donations. These approaches can also enable the public and scientists to feel joint ownership of the collective endeavor.

Combating misinformation and disinformation

Pandemics provide fertile soil for misinformation (unintentionally misleading information) and disinformation (deliberate falsehoods),[60,61] which potentially subvert the choices made by individuals or by society collectively. Behavioral and social scientists on Independent SAGE provided evidence-based strategies for responding to false and misleading information.[62] These included providing consistent and accurate messages, being honest if in doubt, communicating uncertainty, producing diagrams and infographics, and tailoring messages to different social and cultural groups. One specific initiative we undertook was preparing 16 'mythbuster' videos on topics (such as the benefit-harm balance of vaccines) that were characterized by mis/disinformation (see Table 1).

Critical reflections on the Independent SAGE approach

The model of communication used by Independent SAGE had many strengths and (we believe) provided an important contribution to the science-policy ecosystem at a critical time. But it was not perfect, and in retrospect there are things we would have done differently. We consider some of these below.

The name 'Independent SAGE' was chosen somewhat hastily and without full consideration of the consequences. In its favour, the name conveyed both authority (it was a 'scientific advisory group') and independence [of the UK Government], thus distinguishing it from official SAGE. But the name led to confusion among the lay public (some people assumed we *were* part of the official advisory process, and others believed we had set ourselves up in opposition to SAGE) and caused some offence in official circles (because the name was too close to that of official SAGE). The confusion was perhaps exacerbated by the fact that three members of Independent SAGE also sat on a sub-group of official SAGE and in many cases both groups were putting out similar or identical advice and Independent SAGE outputs often drew on SAGE reports. In retrospect, a less loaded name would, we believe, have been better.

The slogan 'following the science' was also somewhat ambiguous. The definite article ('the') implied that there was one (value-free) science that just needed to be identified and summarised, whereas the reality was of multiple scientific and science-related questions which were often value-laden and could be framed in various ways, multiple streams of potentially relevant evidence on which there was little or no consensus among experts, and multiple implications of that body of evidence for different policy decisions. On reflection, a less definitive strapline such as 'examining the science' might have been better.

We did not sufficiently clarify how wide our remit was in terms of topics. The clinical, epidemiological, virological, immunological, behavioural science and public health aspects of COVID-19 were clearly in scope for Independent SAGE, but there was ambiguity (for example) about how far we should engage with the impact of the pandemic on the economy, the ethics of crisis policymaking or the influence of political affiliation on policy decisions. As the pandemic played out, we made various decisions on how to cover these issues, and invited various experts onto the weekly briefings to be interviewed by us. But, notwithstanding the need to adjust our aims in response to a changing situation, it might have been better to have set clearer boundaries

on our remit early in the pandemic, or at least been clearer when remits changed or broadened over time.

Whilst we addressed misinformation and disinformation about COVID-19, we were perhaps, insufficiently proactive in responding to misleading information and deliberate untruths about Independent SAGE and its members. A leading UK medical journal depicted us as "rebel scientists", implying (incorrectly) that our views were radical and heterodox.[63] Some people incorrectly depicted us as politically motivated and wedded to particular extreme policies (such as pursuing an uncompromising 'zero COVID' agenda which included closing all schools, extending lockdown and imposing universal masking). In fact, our position on all these topics was far more nuanced. For example, we argued that targeted quarantine, test-and-trace, masking and attention to air quality might be adopted judiciously help *avoid* school closures or prolonged lockdowns. But we could have done more to make that nuanced position clearer and actively address the malicious caricatures propagated by some of our critics.

A final limitation of our work at Independent SAGE is that, as noted above, we did not formally set out to measure the impact of our work, and this goal was probably not realistic given our prevailing circumstances (e.g. having demanding full-time jobs) and resources (we were reliant on crowdsourcing). In the future, we believe it would be worthwhile to anticipate the need for independent research on the role of informal actors in the science-policy ecosystem. Because of the nature of this ecosystem (multiple actors emerging, responding and influencing one another), deterministic study designs seeking to measure the impact of actor X on outcome Y are unlikely to be helpful. But it should be possible to develop system-oriented mixed-method designs that can begin to tease out the strengths, contribution and synergies (as well as the limitations and caveats) of different kinds of actor, official and unofficial, in this complex ecosystem.

Conclusions

Global public health crises provide unique conditions for innovation in how scientific findings are debated and explained to a lay audience, and among experts across disciplines. The COVID-19 pandemic has changed the way scientists and policymakers work together to produce evidence-based decisions in crisis situations, and it provides the impetus for developing innovative models for visualizing and explaining emerging scientific findings to the public in real time. This is essential because the often-complex science has far-reaching implications for individual lives and freedoms, and individuals wish to exercise agency in moments of crisis.

We believe that the informal approach taken by Independent SAGE, applied adaptively to different contexts and situations, has much to offer in public health crises as part of a wider knowledge ecosystem of scientific and policy actors. Such informal models are designed to progress the science-policy-public dialogue in ways that complement (and, where appropriate, challenge) official structures and positions. In some ways, for example, official SAGE existed to provide formal advice which informed policy whereas Independent SAGE existed to provide informal advice which could include *challenging* policy.

While honesty and transparency are important rules of thumb, questions such as "what level of secrecy should official scientific advisory bodies follow during fast-unfolding pandemics?", "how much scientific and policy uncertainty should be shared with the public?" or "from whom, if anyone, should governments seek advice in addition to their official advisors?" cannot be

answered definitively or for all time. But we believe that in any particular unfolding crisis, such questions should be kept alive through vigorous public debate to which scientists can and should contribute.

In situations where the stakes are high, the facts uncertain, the values in dispute, but decisions are nevertheless urgent, it is more important than ever that scientists engage directly and democratically with the public. Their role must surely be to present the state of knowledge, ignorance and uncertainty on issues of the day, to support, inform and engage with the public, link with a wide range of advocacy and campaign groups and—where necessary—speak truth to power.

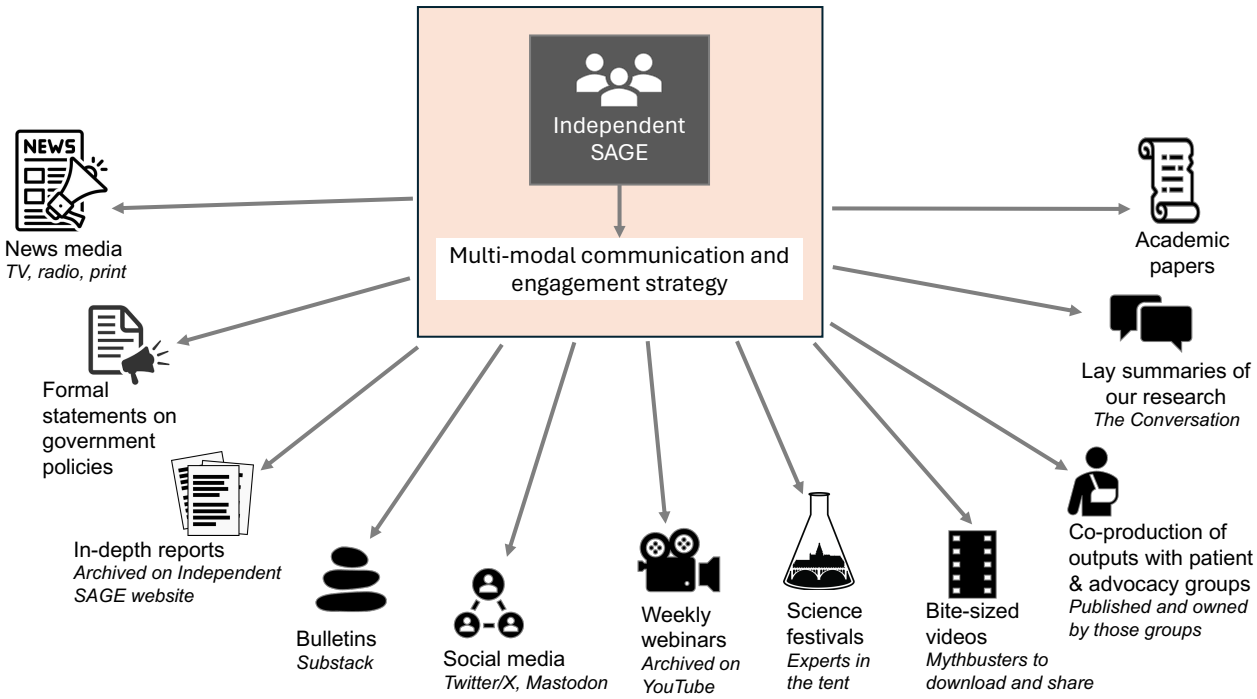

Figure 1: Independent SAGE's multi-modal communication and engagement strategy

TABLE 1: EXAMPLES OF DIFFERENT GENRES OF COMMUNCATION USED BY INDEPENDENT SAGE		
Genre	Format, intended audience and purpose	Example topics
In-depth reports	Rapid reviews (10-50 pages with references) on focused topics, aimed at policymakers and advocacy groups. Produced in house style with Independent SAGE logo and made open-access on our website (~50 reports produced to date)	Inequalities[49,50] Vaccines[51] Schools[26] Ventilation[64]
Formal statements	Short statements published on the Independent SAGE website on key government policy announcements.	Test and Trace 2020[65] Plans to end restrictions 2021[66]
Live public webinars	One-hour structured session with presenters joining by Zoom and public via YouTube, covering one or more defined topics and with 2-3 guest speakers. Included 15-20 minutes of live questions. Recorded and archived; free public access.	Vaccines, variants and immunity[67] (see Box 1) Schools[26]
Academic papers	Scholarly articles or letters published in open-access peer-reviewed journals, intended mainly for fellow academics (hundreds of articles, many as a direct development from our Independent SAGE public engagement and advocacy work)	Viral evolution[68] Mathematical modelling[69] Vaccine equity[52,54] A 7-point plan to suppress infections[70]
Lay summaries of academic papers (e.g. The Conversation)	800-word summaries of our reports and academic papers, pitched for a lay audience and published open-access; often syndicated more widely.	How long does immunity last?[71] Austerity and COVID-19[72] Airborne spread of SARS-CoV-2[58]
Social media	Active presence (@IndependentSAGE) on Twitter (now X), plus members have accounts on X, Mastodon, BlueSky, Threads and more. Included cartoon animations of key messages.	Postings about Independent SAGE activities and reports; dialogue with public and policymakers
Mythbuster videos	Video clips short enough to post on social media (2.5 minutes), addressing topics of confusion (often as a result of mis- or disinformation). Archived on Independent SAGE website.	"The models were always wrong"[73] "It's lockdown or nothing"[74] "Vaccines were rushed through"[75]
Mainstream mass media	Independent SAGE members made hundreds of TV and radio appearances including news channels, breakfast shows, documentaries, special reports and more.	Topics covered included modeling the growth of cases, predicting burden on health services, lockdown, masks, vaccines, new genetic variants, psychology of public behavior
Science festivals	Open-air science / camping event featuring 'celebrity' shows and public lectures held in marquees	Open public session on COVID-19 at BlueDot 2023[76]
Oral evidence to official committees	All-Party Parliamentary Group on Coronavirus	Evidence session: Easing of Restrictions (2022)[77]
Co-production of outputs with patient and advocacy groups	Independent SAGE members provided bespoke scientific support and advice to various groups and contributed to patient- and lay-led public debate (e.g. through podcasts) and bolstering the voices of vulnerable groups.	Podcast on impact of COVID-19 on cancer patients[78]
Substack 'Independent SAGE continues'	A series of blogs introduced in late 2023 to provide a continuing outlet for public-facing science after the end of the weekly live briefings. Aimed mainly at the lay audiences who followed these weekly briefings.	Withdrawal of AstraZeneca vaccine[79] COVID-19 situation report[80]

Box 1 – A worked example of a weekly briefing: 1 July 2022 (total viewership: 40,000)

The recording of this briefing is available on YouTube[67]

By 2022, the COVID-19 landscape had changed dramatically. Most countries had dropped measures such as mandatory masking and many people had received 1-2 vaccines to protect against severe infection. The virus had continued to mutate and 2022 saw the dominance of the Omicron variant of concern. Omicron subvariants had developed marked changes in the spike protein structure resulting in more immune evasion. Coupled with this, many people were many months, to sometimes over a year away from their primary set of vaccines, so waning immunity made them more susceptible to infections even without a more evasive viral variant compounding issues. Thus, despite the lower individual risk achieved by vaccines, the initial Omicron waves were immense, causing significant deaths, hospitalisations, and morbidity by sheer weight of numbers. Moreover, people with milder disease were left feeling fairly miserable and ill when they contracted COVID-19, but also confused as many felt they should be better protected due to their vaccines. There was growing uncertainty about why vaccines were necessary and why more boosters would or could be needed. Questions too were being asked by the scientific community as we learned more about what people's chequered history of infection and vaccination meant for ongoing immunity and future immunisations. Even as relatively wealthy countries such as the UK and USA were looking ahead to possible booster campaigns, many countries in the world had enjoyed only limited access to any vaccines, and whilst large pockets of susceptible individuals remained across the world, it was likely the virus would continue to mutate.

To tackle this thorny topic of vaccines, immunity and equity, our briefing on 1 July 2022 brought in three eminent speakers from the UK and USA. The briefing was led by Independent SAGE members Prof Sheena Cruickshank and Prof Danny Altmann (both experts in immunology). The session started by showing the latest data (Dr Duncan Robertson), which contextualized the session to follow. We explained that the BA-5 lineage was dominant in the UK and prevalence was high, with approximately 1 in 18 people infected. We also presented vaccine coverage data from the UK. Professor Rosemary Boyton discussed the latest research and thinking on immunity and duration of immunity following infection with different variants, and raised the issue that the Omicron variants were poor at durably boosting or inducing protective immunity compared to vaccines. Professor John Moore focused on USA's plans for a booster campaign with new bivalent vaccines which were in the process of being approved. This raised questions as to what the autumn campaign might be in the UK (which at time had not been announced). Finally, Professor Maria Botazzi discussed ways in which her research was working with countries to boost manufacturing capacity for vaccines as well as addressing costs for purchase, licensing and the need for bringing in communities to tackle vaccine hesitancy and decolonize vaccine development. Finally, public questions focused upon vaccines regarding what groups should have access to boosters, who was most susceptible to infection, and why different boosters were needed. Collectively, this session shows how we sought to bring cutting edge developments and research straight to the public in an accessible way.

ACKNOWLEDGEMENTS

We acknowledge support, collaboration and intellectual input from other current and previous members of Independent SAGE, and from numerous additional scientists and advocates who have acted as advisors, guest speakers and critical friends to Independent SAGE the past few years. Responsibility for what is written in this article, however, rests with the authors. We thank Carole Cadwalladr for her inspiration and energy in initiating Independent SAGE, and The Citizens for their unfailing support and guidance on how best to communicate complex science to (and with) diverse audiences. Finally, we thank patients and the public—both individuals and groups—for their crucial input to ongoing debates about science and how science should influence policy. We thank four anonymous reviewers for helpful suggestions to improve this paper. In particular, two reviewers suggested the science policy ecosystem and one proposed the additional actors we have listed in the paper.

COMPETING INTERESTS

All authors are members of Independent SAGE. TG is an unpaid advisor to the philanthropic group Balvi. MM is Past President of the British Medical Association and European Public Health Association, Research Director of the European Observatory on Health Systems and Policy, a partnership of governments, international agencies, and universities, and an advisor to the World Health Organisation Regional Director for Europe. SR is a member of the UK's Independent Scientific Pandemic Insights Group on Behaviours (SPI-B) and the Scottish Government Covid Advisory Group.

References

1. McKee, M.*, et al.* Open science communication: The first year of the UK's Independent Scientific Advisory Group for Emergencies. *Health Policy* **126**, 234-244 (2022).

2. Boin, A., Stern, E. & Sundelius, B. *The politics of crisis management: Public leadership under pressure*, (Cambridge University Press, Cambridge, 2016).

3. European Commission. *The precautionary principle: decision making under uncertainty*, (European Commission, Brussels, 2017. Accessed 7th December 2023 at https://ec.europa.eu/environment/integration/research/newsalert/pdf/precautionary_principle_decision_making_under_uncertainty_FB18_en.pdf).

4. Michie, S., Ball, P., Wilsdon, J. & West, R. Lessons from the UK's handling of Covid-19 for the future of scientific advice to government: a contribution to the UK Covid-19 Public Inquiry. *Contemporary Social Science* **17**, 418-433 (2022).

5. Koch, N. & Durodié, B. Scientists advise, ministers decide? The role of scientific expertise in UK policymaking during the coronavirus pandemic. *Journal of Risk Research* **25**, 1213-1222 (2022).

6. Bauer, M.S., Damschroder, L., Hagedorn, H., Smith, J. & Kilbourne, A.M. An introduction to implementation science for the non-specialist. *BMC psychology* **3**, 1-12 (2015).

7. Weiss, C.H. The many meanings of research utilization. *Public administration review* **39**, 426-431 (1979).

8. Oliver, K. & Cairney, P. The dos and don'ts of influencing policy: a systematic review of advice to academics. *Palgrave Communications* **5**, 1-11 (2019).

9. Shiffman, J. & Smith, S. Generation of political priority for global health initiatives: a framework and case study of maternal mortality. *The lancet* **370**, 1370-1379 (2007).

10. Freedman, L. Scientific Advice at a Time of Emergency. SAGE and Covid‐19. *The Political Quarterly* **91**, 514-522 (2020).

11. Colman, E., Wanat, M., Goossens, H., Tonkin-Crine, S. & Anthierens, S. Following the science? Views from scientists on government advisory boards during the COVID-19 pandemic: a qualitative interview study in five European countries. *BMJ global health* **6**, e006928 (2021).

12. Goddard, N., Delpech, V., Watson, J., Regan, M. & Nicoll, A. Lessons learned from SARS: the experience of the Health Protection Agency, England. *Public health* **120**, 27-32 (2006).

13. Public Health England. *Report: Exercise Alice Middle East Respiratory Syndrome Cornoavirus (MERS-CoV)*, (gov.uk, London, 2016).

14. Hine, D. *Independent review into the response to the 2009 swine flu pandemic*, (UK Cabinet Office. Accessed 4th August 2024 at https://www.gov.uk/government/publications/independent-review-into-the-response-to-the-2009-swine-flu-pandemic, London, 2010).

15. Han, E.*, et al.* Lessons learnt from easing COVID-19 restrictions: an analysis of countries and regions in Asia Pacific and Europe. *The Lancet* **396**, 1525-1534 (2020).

16. Pearce, W. Trouble in the trough: how uncertainties were downplayed in the UK's science advice on Covid-19. *Humanities and Social Sciences Communications* **7**(2020).

17. Tyler, T.R. *Why people obey the law*, (Princeton university press, 2006).

18. Cairney, P. & Wellstead, A. COVID-19: effective policymaking depends on trust in experts, politicians, and the public. *Policy Design and Practice* **4**, 1-14 (2021).

19. Weinberg, J. Trust, governance, and the Covid‐19 pandemic: an explainer using longitudinal data from the United Kingdom. *The Political Quarterly* **93**, 316-325 (2022).

20. Fancourt, D., Steptoe, A. & Wright, L. The Cummings effect: politics, trust, and behaviours during the COVID-19 pandemic. *The lancet* **396**, 464-465 (2020).

21. Enria, L*., et al.* Trust and transparency in times of crisis: Results from an online survey during the first wave (April 2020) of the COVID-19 epidemic in the UK. *PloS one* **16**, e0239247 (2021).

22. Newton, K. Government communications, political trust and compliant social behaviour: The politics of Covid‐19 in Britain. *The Political Quarterly* **91**, 502-513 (2020).

23. Capodici, A., Salussolia, A., Sanmarchi, F., Gori, D. & Golinelli, D. Biased, wrong and counterfeited evidences published during the COVID-19 pandemic, a systematic review of retracted COVID-19 papers. *Quality & quantity* **57**, 4881-4913 (2023).

24. Scheinerman, N. & McCoy, M. What does it mean to engage the public in the response to covid-19? *bmj* **373**(2021).

25. Independent SAGE. *indie_SAGE 04.05.20 - first committee meeting*, (Independent SAGE Youtube archive. Accessed 6th February 2024 at https://www.youtube.com/watch?v=L7uBwyr0sdg, London, 2020).

26. Independent SAGE. *Independent SAGE 22nd May interim report on schools*, (Independent SAGE YouTube archive. Accessed 6th February 2024 at https://www.youtube.com/watch?v=32OFgfH17KU, London, 2020).

27. Independent SAGE. *Independent SAGE 09.06.20*, (Independent SAGE YouTube archive. Accessed 6th February 2024 at https://www.youtube.com/watch?v=g34W-j9h0nI, London, 2020).

28. Rajan, S*., et al.* In the wake of the pandemic: preparing for long COVID. (2021).

29. Independent SAGE. *Independent SAGE is calling for an immediate national lockdown*, (Independent SAGE Twitter feed, 30th December. Accessed 6th February 2024 at https://x.com/IndependentSage/status/1344222227961548800?s=20 London, 2020).

30. Independent SAGE. *Independent SAGE public briefing 30th December*, (Independent SAGE YouTube archive. Accessed 6th February 2024 at https://www.youtube.com/watch?v=-kIcCUY5vWc, London, 2020).

31. COVID Pledge. *The COVID-19 Safety Pledge*, (COVID Pledge. Accessed 20th May 2024 at https://covidpledge.uk, London, 2022).

32. Pielke, R.A. *The Honest Broker: Making Sense of Science in Policy and Politics*, (Cambridge University Press, Cambridge, 2007).

33. Nowotny, H., Scott, P.B. & Gibbons, M.T. *Re-thinking science: Knowledge and the public in an age of uncertainty*, (John Wiley & Sons, 2013).

34. Van Der Bles, A.M.*, et al.* Communicating uncertainty about facts, numbers and science. *Royal Society open science* **6**, 181870 (2019).

35. Fischhoff, B. & Davis, A.L. Communicating scientific uncertainty. *Proceedings of the National Academy of Sciences* **111**, 13664-13671 (2014).

36. Warren, G.W. & Lofstedt, R. Risk communication and COVID-19 in Europe: lessons for future public health crises. *Journal of Risk Research* **25**, 1161-1175 (2022).

37. Rajan, D*., et al.* Governance of the Covid-19 response: a call for more inclusive and transparent decision-making. *BMJ global health* **5**(2020).

38. Renn, O*., et al.* Making sense of science for policy under conditions of complexity and uncertainty. (2019).

39. Greenhalgh, T. & Engebretsen, E. The science-policy relationship in times of crisis: an urgent call for a pragmatist turn. *Social Science and Medicine* **306**, 115140 (2022).

40. Easton, D. *The Political System*, (Knopf, New York, 1953).

41. Rolin, K. Trust in science. in *The routledge handbook of trust and philosophy* 354-366 (Routledge New York, 2020).

42. Machingaidze, S. & Wiysonge, C.S. Understanding COVID-19 vaccine hesitancy. *Nature medicine* **27**, 1338-1339 (2021).

43. Independent SAGE. *A Blueprint to Achieve an Excellent Find, Test, Trace, Isolate and Support System. Report No. 19.*, (Independent SAGE. Accessed 4th August 2024 at https://www.independentsage.org/wp-content/uploads/2020/10/New-FTTIS-System-final-06.50.pdf, London, 2020).

44. Scambler, G. Covid-19 as a 'breaching experiment': Exposing the fractured society. *Health Sociology Review* **29**, 140-148 (2020).

45. Bambra, C., Lynch, J. & Smith, K.E. *The Unequal Pandemic: COVID-19 and Health Inequalities*, (Bristol University Press, Bristol, 2021).

46. Independent SAGE. *Disparities in the impact of COVID-19 in Black and Minority Ethnic populations: review of the evidence and recommendations for action (Report 6)*, (Independent SAGE. Accessed 20th May 2024 at https://www.independentsage.org/wp-content/uploads/2020/07/Independent-SAGE-BME-Report_02July_FINAL.pdf, London, 2020).

47. Douglas, M., Katikireddi, S.V., Taulbut, M., McKee, M. & McCartney, G. Mitigating the wider health effects of covid-19 pandemic response. *Bmj* **369**(2020).

48. Independent SAGE. *COVID-19 and Health Inequality (Report no. 21)*, (Independent SAGE. Accessed 18th May 2024 at https://www.independentsage.org/wp-content/uploads/2020/11/Inequalities-_i_SAGE_FINAL-draft_corrected.pdf, London, 2021).

49. Independent SAGE. *The COVID-19 crisis and inequalities. Independent SAGE weekly briefing 4th March 2022.* , (Independent SAGE Youtube archive. Accessed 24th May 2024 at https://www.independentsage.org/weekly-briefing-4th-march-2022/, London, 2022).

50. Independent SAGE. *COVID-19 and the implications for health inequalities. Independent SAGE weekly briefing. 9th December 2022*, (Independent SAGE youtube archive. Accesed 18th May 2024 at https://www.independentsage.org/weekly-briefing-9th-dec-2022/, London, 2022).

51. Independent SAGE. *How to Achieve Global Vaccine Rollout. Report no. 35.*, (Independent SAGE. Accessed 20th May 2024 at https://www.independentsage.org/how-to-achieve-global-vaccine-rollout/, London, 2021).

52. Burgess, R.A*., et al.* The COVID-19 vaccines rush: participatory community engagement matters more than ever. *Lancet* **397**, 8-10 (2021).

53. Haque, Z. Vaccine inequality may undermine the booster programme. Vol. 375 (British Medical Journal Publishing Group, 2021).

54. Gurdasani, D*., et al.* Vaccinating adolescents against SARS-CoV-2 in England: a risk–benefit analysis. *Journal of the Royal Society of Medicine* **114**, 513-524 (2021).

55. Gurdasani, D*., et al.* Mass infection is not an option: we must do more to protect our young. *The Lancet* **398**, 297-298 (2021).

56. Health and Social Care Committee and Science and Technology Committee. *Coronavirus: lessons learnt to date.*, (Gov.uk, London, 2022).

57. Clinically Vulnerable Families (website). (https://www.clinicallyvulnerable.org/).

58. Greenhalgh, T., Jimenez, J.-L., Millller, S. & Peng, Z. Here's where (and how) you are most likely to catch COVID – new study. *The Conversation* **January 11th**, Accessed 5th February 2024 at https://theconversation.com/heres-where-and-how-you-are-most-likely-to-catch-covid-new-study-174473 (2022).

59. Michie, S.*, et al.* New COVID variants have changed the game, and vaccines will not be enough. We need global 'maximum suppression'. *The Conversation* **5th April**, Accessed 5th february 2024 at https://theconversation.com/new-covid-variants-have-changed-the-game-and-vaccines-will-not-be-enough-we-need-global-maximum-suppression-157870 (2021).

60. Iyengar, S. & Massey, D.S. Scientific communication in a post-truth society. *Proceedings of the National Academy of Sciences* **116**, 7656-7661 (2019).

61. Lee, C., Yang, T., Inchoco, G.D., Jones, G.M. & Satyanarayan, A. Viral Visualizations: How Coronavirus Skeptics Use Orthodox Data Practices to Promote Unorthodox Science Online. *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 1-18 (2021).

62. Ecker, U.K.*, et al.* The psychological drivers of misinformation belief and its resistance to correction. *Nature Reviews Psychology* **1**, 13-29 (2022).

63. Clarke, L. Covid-19's rebel scientists: has iSAGE been a success? *bmj* **375**(2021).

64. Independent SAGE. *Signs and 'Scores on the Doors': Communicating about ventilation*, (Independent SAGE. Accessed 2oth May 2024 t https://www.independentsage.org/wp-content/uploads/2022/03/Independent-SAGE-SotD-March-2022-FINAL-3-1.pdf, London, 2022).

65. Independent SAGE. *Statement on the Management of NHS Test and trace*, (Independent SAGE. Accessed 20th May 2024 at https://www.independentsage.org/statement-on-the-management-of-nhs-test-and-trace/, London, 2020).

66. Independent SAGE. *Independent SAGE statement on the UK Government's roadmap for ending all restrictions*, (Independent SAGE. Accessed 20th May 2024 at https://www.independentsage.org/indie-sage-statement-on-the-uk-government-roadmap-for-ending-all-restrictions/, London, 2021).

67. Independent SAGE. *Vaccines, variants and immunity. Independent SAGE 1st July 2022.*, (Independent SAGE YouTube archive. Accessed 6th February 2024 at https://www.youtube.com/watch?v=a3ymXVpE8Lc, London, 2022).

68. Katzourakis, A. COVID-19: endemic doesn't mean harmless. *Nature* **601**, 485-485 (2022).

69. Pagel, C. & Yates, C. Role of mathematical modelling in future pandemic response policy. *bmj* **378**, e070615 (2022).

70. Independent SAGE. A seven point plan to suppress covid infections and reduce disruptions. *BMJ* **378**, o1793 (2022).

71. Cruickshank, S. COVID-19 immunity: How long does it last? *The Conversation* **11th January**, Accessed 20th May 2024 at https://theconversation.com/covid-2019-immunity-how-long-does-it-last-152849 (2021).

72. Williams, S.N. & McKee, M. How Austerity Made the UK More Vulnerable to COVID. *The Conversation* **July 27**, Accessed 20th May 2024 at https://theconversation.com/how-austerity-made-the-uk-more-vulnerable-to-covid-208240 (2023).

73. Yates, K. *"The models were always wrong" (Independent SAGE Mythbuster series no. 5)*, (Accessed 20th May 2024 at https://www.youtube.com/watch?v=QQkjMb0-d3g, YouTube, 2022).

74. Pagel, C. *"It's lockdown or nothing" (Independent SAGE Mythbuster Series no. 4)*, (Accessed 24th May 2024 at https://www.youtube.com/watch?v=02zgVKXptDI, YouTube, 2022).

75. Cruickshank, S. *"Vaccines were rushed through" (Independent SAGE Mythbuster Series 7)*, (Accessed 20th May 2024 at https://www.youtube.com/watch?v=yZl47u8psXw, YouTube, 2022).

76. BlueDot. *Independent SAGE at BlueDot*, (BlueDot. Accessed 20th May 2024 at https://discoverthebluedot.com/profile/indie-sage/, Jodrell Bank, 2023).

77. All-Party Parliamentary Group on Cornoavirus. *Evidence session: Easing of restrictions*, (APPG. Accessed 20th May 2024 at https://www.youtube.com/watch?v=bOWUW55wMPU, London, 2022).

78. English, C. *Ripples: The forgotten 500,000*, (Accessed 20th May 2024 at https://open.spotify.com/show/2c3b8fVp1JTWAGPbFniAiX, Spotify, 2022).

79. Pagel, C. The Astra Zeneca Vaccine Saved Millions of Lives Globally. *Substack* **8th May**, Accessed 20th May 2024 at https://christinapagel.substack.com/p/the-astra-zeneca-covid-vaccine-saved (2024).

80. Independent SAGE. COVID-19 situation report, May 2024. *Substack* **9th May**, Accessed 20th May 2024 at https://independentsage.substack.com/p/covid-situation-report-may-2029-2024 (2024).