Evidence-based science communication in the COVID-19 era

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Evidence-based science communication in the COVID-19 era

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Editorial: Evidence-based science communication in the COVID-19 era

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Editorial on the Research Topic
Evidence-based science communication in the COVID-19 era

When Jensen and Gerber (2020) introduced *Evidence-Based Science Communication* (EBSC) in January 2020, no one could have anticipated how a global pandemic would change the world only a few weeks after its publication. The public health crisis that unfurled in spring and summer 2020 generated an unprecedented level of uncertainty about the public communication of science and its influence on regulatory decisions to deal with the pandemic. This was the backdrop for the decision by Frontiers to follow up on the original EBSC article with an entire Research Topic to discuss the implications of the concept for the pandemic and beyond. In total, we were grateful that we could accept and publish 10 manuscripts and 2 additional data reports by 56 authors in total.

All contributions were based on the EBSC premise that it is pivotal to understand and apply effective and inclusive means of science communication for modern society to deal with pressing societal challenges, such as the global public health emergency created by COVID-19. The question at stake was literally how human lives could be saved by acknowledging decades of social and behavioral science research that have provided us with a breadth of relevant evidence, alongside decades of lessons learned from experiments in practice.

Throughout the pandemic, governmental authorities worldwide struggled with public skepticism against mitigation measures such as mask-wearing, curfews, and, later, vaccinations — all of which could only be as effective as people's willingness to comply with the recommendations or regulations. The work published by Jensen et al. addressed exactly this key challenge. Their representative survey of the German population provides a thorough empirical analysis of predictors and outcomes associated with people's conspiracy beliefs about COVID-19 vaccinations and their attitudes toward mitigation measures, respectively. In coherence with the best available evidence on conspiracy mindedness, the study revealed correlations with trust in scientific and governmental information sources, respondents' self-assessment of being informed about science, and general conspiracy mindedness.

To analyse public health efforts in countering dis- and misinformation about COVID-19, Madvig et al. examined messages posted on the Danish Health Authority's Facebook page during the early months of the pandemic. The case study reveals an "invisible majority" quietly engaging with information on the page, while at the same time, communication staff at the Danish Health Authority dealt with the complaints and frustration of a clear minority, culminating in outright trolling once vaccinations came onto the agenda. Perhaps, the authors conclude, this form of debate with a minority is the price to pay for informing the majority via social media.

In this context of dealing with misinformation, the pandemic also emphasized how important it is to engage a wide variety of stakeholders. Judd and McKinnon concluded from their comprehensive literature review that, despite social inequalities manifesting also within the structures of science communication at large, there is very limited available evidence to guide our decisions as to which diverse, marginalized, and/or excluded groups to engage and the most effective ways of doing this. Despite increased research efforts recently being directed to issues of equity, diversity, and inclusion in science communication, the authors do not consider this attention to be "equitably distributed across historically under-served and minoritised audiences," which is why it did not sufficiently catalyze the systemic change "required to create inclusive science communication theory and practice."

One of the approaches to make public health communication more effective and inclusive is the use of visualizations for health literacy, which is why Jarreau et al. created a series of illustrated (sequential art) courses, so-called "flashcards," to conduct a survey experiment. They showed the illustrations to 1,775 health app users and tried to analyse potential effects on the participants' attitudes and intentions toward COVID-19. The study showed that viewing the flashcards was associated with improved self-efficacy and changes in the participants' behavioral intentions toward prevention.

Such visualizations of complex scientific processes and data in particular have been used particularly often in documentary films and cinema more generally. Yet what do we really know about how audiences respond to such visualizations? An essay by Jensen et al., published as part of this Research Topic, synthesized relevant research literature, highlighting key findings, research gaps, and directions for future investigation. The authors identified recurring methodological limitations in the existing body of evidence, thus confirming the research–practice divide as described in the EBSC model. Specifically, this article highlights the disconnect between film producers' focus on audiences and the under-developed research literature on audience responses. Nonetheless, the essay describes several broadly relevant findings relating to intelligibility, film content, and immersion.

The pandemic also reminded us how most science communication efforts lack methodologically robust ways of assessing effectiveness and impact in practice. By analyzing various evaluation reports and conducting a survey, Ziegler et al. provided further proof for this lack of evidence. Practitioners, however,

should also not be expected to become scholars of evaluation, the authors argue, which is why new forms of collaboration are needed. They recommend determining at which point external experts should be involved in evaluation and where to draw the line between evaluation and research.

Not only as part of impact evaluation but also far beyond, online surveys are now among the most commonly used methods in science communication research, particularly because they seem so easy and cheap to deploy. However, the temptation comes with a long list of pitfalls and limitations that many researchers do not seem to be sufficiently aware of, as Kennedy et al. suggest. They explain key principles of survey design and provide a best-practice guide on how to ensure data quality even when deploying surveys under time pressure in a public health crisis such as COVID-19. In one such survey during the pandemic, Gibson et al. showed that the sampled U.S. citizens' intent to act more environmentally consciously was correlated with their social media use and certain demographic characteristics.

A rare glimpse behind the scenes of social research was provided by the coordinators of eight science communication projects funded as part of the same EU programme ("Science with and for Society," SwafS). Roche et al. not only summarized their insights about changes in science–society relations during the pandemic but also shared how the global health crisis forced all eight projects to adapt their approaches, also discussing the subsequent implications for science communication policy and research funding.

The most recent contribution to our Research Topic by Marín-González et al. suggests that the pandemic has not changed researchers' views on interacting with the news media directly (in this case, academics and medical professionals from southern Europe involved in COVID-19 research themselves).

While the coronavirus reminded societies worldwide drastically of the importance of science communication in general, most contributions to this Research Topic have also emphasized the need for a quality assurance discourse and much more effective transfer mechanisms between scholarship and practice. The journey toward a more evidence-based science communication has clearly only just begun.

Author contributions

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Evaluation of Science Communication: Current Practices, Challenges, and Future Implications

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Scientifically substantiated evaluations are pivotal to ensuring the effectiveness and improvement of the growing number of science communication projects. Yet current evaluation practices are still lacking in various respects. Based on a systematic review of evaluation reports, an online survey of, as well as discussion rounds with science communication practitioners in the German-speaking countries, we discuss three main challenges of science communication evaluation: (1) There is a conflation of impact goals and measurable project objectives as well as a lack of precise definitions of objectives and target groups, which complicates the assessment of the projects' success. (2) Although many evaluations highlight the impact-oriented interest of those responsible, the methods chosen rarely allow scientifically valid evaluations of effects. The lack of comparative reference points and the partially unsuitable use of self-report measures are key issues in this regard. (3) The fact that few evaluation processes are made transparent and that formative evaluation designs are a rarity indicates a tendency to understand evaluations as the final 'success story' of a project rather than a learning process. This stands in the way of a constructive discussion of the actual impact of science communication. Our exploratory insights contribute to an understanding of the weaknesses of science communication evaluation and needs in the field. They also provide impulses for future improvements in the field for the stakeholders in practice, research, funding, and science management.

Keywords: science communication, public communication of science and technology, evaluation, impact, impact of science communication, evaluation of science communication

INTRODUCTION

For those dedicated to science communication, 2020 will probably be remembered as the year their fields took on new significance in the public eye. Science communication has already changed profoundly in recent years and has become increasingly institutionalized and diversified: New types of actors like the Science Media Centre (2012) have entered the field, and the networks for exchange in the science communication community are growing (e.g., European Citizen Science Association, 2021; European Science Engagement Association, n.d.). Apart from that, the variety of science communication activities and channels increases as new online communication services emerge and offer novel ways for interaction with audiences (Schäfer, 2017, p. 52). This trend can also be observed in Germany, where more and more science communicators

experiment, for example, with Twitch (Winkels, 2020) or Augmented Reality (Weißschädel, 2020). At the same time, a rising number of academic and political institutions formulate position papers on science communication (Ziegler and Fischer, 2020), and future directions of the field are intensively debated (Bundesverband Hochschulkommunikation, 2020).

With this push for more science communication, demands for a thorough exploration of what it actually achieves, who it reaches, and what impact it has are also becoming louder. These questions have been of concern for experts of varying disciplines, such as risk communication (e.g., Breakwell, 2000), environmental communication (e.g., Kahan, 2014), or health communication (e.g., van der Sanden and Meijman, 2008). But as more resources are invested in science communication projects, some worry that this might lead to an increase in communication efforts without sufficient attention to their effects or motives (Marcinkowski and Kohring, 2014, p. 5 ff.; Weingart and Joubert, 2019). Especially now, the relevance of science reaching the public is even more apparent with many political measures to fight the coronavirus pandemic being informed by science. This calls for a critical examination of how projects need to be designed to fulfill their intended impact. An essential tool in this effort is meaningful evaluation. By that, we mean an evaluation practice that is based on a clear set of realistic and relevant goals, that puts an emphasis on a stringent and scientifically sound use of methods, that is transparent about the evaluation process and its limitations, and that reflects its results in order to formulate helpful recommendations for future action.

It is, however, no news that evaluation in science communication does not meet this standard: Many evaluations lack methodological rigor (Jensen, 2014), are based exclusively on descriptive data (Weitkamp, 2015, p. 2), are unable to offer a long-term perspective (King et al., 2015, p. 2), and their traditional methods are often not suited for interactive settings (Grand and Sardo, 2017, p. 5). Science communicators are facing many challenges during evaluation and, also, when trying to improve their work on the basis of evaluation and scientific evidence (Jensen and Gerber, 2020).

At the *Impact Unit*, a project by the German national organization for science communication—Wissenschaft im Dialog—and funded by the German Federal Ministry of Education and Research, we have taken on the task to support evaluation practice in German science communication[1] by offering tools, creating opportunities for exchange, and addressing open questions at the interface between research and practice. For this, we rely on analyses that offer insight into science communication and its evaluation with an emphasis on the practitioners' perspectives. In this article, we want to share our observations, especially the challenges we have identified in the current evaluation practice, and reflect on the changes necessary to set adequate evaluation standards. These reflections are based

on analyses and exchanges with various stakeholders, especially the following:

- An online survey with 109 German science communicators (Impact Unit, 2019)[2], focusing on the goals of science communication, their evaluation experiences and routines, their perceptions of the quality of evaluation, and the needs they identify for better evaluation.
- A systematic review of 55 evaluation reports (Ziegler and Hedder, 2020) of German-speaking science communication projects, focusing on the projects' goals, objectives, and target groups, as well as motives and methods for evaluation.
- Several informal discussion rounds on challenges and needs (2019–2020), with stakeholders from science communication research, funding, and practice in Germany. These included practitioners with varying experiences in evaluation.

This article's claims underlie several constraints. Our analyses are mostly focused on the German case, relying on small sample sizes or only on publicly available sources (such as evaluation reports). Nevertheless, we have observed three challenges that come up consistently throughout all our analyses and exchanges. Based on our extensive reflection, we believe these to be central when working toward a better evaluation practice for impactful science communication. In the following, we outline these challenges, before discussing the roles of researchers, practitioners, and other relevant stakeholders within the academic system in overcoming them.

STRATEGIC APPROACH TO PROJECT DESIGN

Clear expectations of what a project is supposed to accomplish and why, are necessary criteria for a strategic project design and an informative evaluation of its effectiveness (Spicer, 2017, p. 21 f.). Strategic communication differentiates between goals, meaning general guidelines or end results, and objectives, which are the concrete communication outcomes desired (Hon, 1998, p. 105) that contribute to reaching the goals (Hallahan, 2015, p. 247). For science communication to be strategic, this implies "choosing one's goal for communication, determining interim communication objectives […], and then selecting tactics that have a realistic chance of meeting those objectives" (Besley et al., 2018, p. 709). But there are doubts whether science communication projects appropriately do so. Scholars question if the choice of activities and tactics is in line with the project initiators' communication objectives (Stilgoe et al., 2014, p. 6), while others see a disconnect between objectives and evaluated outcomes (Phillips et al., 2018). Looking at the German case, we see similar issues reflected in the way objectives and target groups are defined.

For one, the phrasing of objectives lacks precision: There might be the formulation of a wish to raise awareness of an issue, without defining what it means 'to be aware.' Other projects

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[1]The initiative's focus lies mainly on science communication as institutional communication of scientific organizations and research institutes, targeting publics outside of academia directly, therefore excluding science journalism. This is a pragmatic choice and does not deny the multifaceted nature of science communication taking place in different societal settings.

[2]The details of the survey, including data collection instruments and ethical procedures, are available in the public report (Impact Unit, 2019). The dataset is available on Zenodo: https://doi.org/10.5281/zenodo.4608091.

might strive to 'encourage' people to think about scientific topics or to gain 'more' visitors, without giving reference points. This cautious phrasing lowers the bar to meet expectations but complicates the judgment of the success of a project or an activity's potential. Furthermore, broadly formulated objectives put the focus on detecting any effect instead of the size of specific effects (Ziegler and Hedder, 2020, p. 19 f.).

This room for interpretation might reflect a wish to maintain flexibility when it comes to managing expectations or even an uncertainty about where to actually set the bar, especially when exploring new formats or experimenting. According to our community survey, 73% of the participants stated that their projects are born mostly out of curiosity about a new activity and new ideas rather than chosen based on their fit to achieve predefined objectives (n = 94; Impact Unit, 2019, p. 19).

Part of the problem seems to be the process of breaking down goals into concrete objectives. Our review of evaluation reports shows that the practitioners are experienced in explaining their long-term missions (Ziegler and Hedder, 2020, p. 16 ff.) and positioning their projects within the big picture. Discussions with the practitioners left the impression that difficulties occur when they need to pick apart the mission and identify those puzzle pieces which are measurable within a time-limited activity—an issue that has also been brought up by Weitkamp (2015) and King et al. (2015).

But this is not the only obstacle: Once objectives have been derived from goals, suitable tactics and activities need to be found *and* tailored to a specific target group. However, in our review of evaluations, target groups are mostly described in broad terms by referring to basic sociodemographic characteristics, prominently age and gender. More concrete descriptions of the desired audience are rare. Even when more specific demographics are defined, using terms like 'main target group' opens a backdoor to include others (Ziegler and Hedder, 2020, p. 19). Examples of this are the frequently mentioned target groups 'school children' or 'the general public.' Members of both groups are defined by a small set of indicators they have in common—being young and in school or being part of the public. However, this misses a chance of appropriately addressing the multiple subgroups they contain. As Schäfer and Metag point out, another look at the differences within, especially regarding science attitudes, can be informative for planning communication activities (Schäfer and Metag, 2021, p. 300) and, consequently, their evaluation. This does not mean that comprehensive target groups cannot be of interest, but it is advisable that their diversity is considered.

We believe it is important that practitioners recognize the value of a strategic mindset when planning their activities. Objectives should not serve as low hurdles that can be easily overcome but as motivation and orientation for what is important within the project. Similarly, target groups can help navigate the wide choice of communication activities when their special preferences and peculiarities are considered. With this in mind, defining goals, objectives, and target groups can offer the opportunity for reflection on a project and how it can be meaningfully evaluated.

CHOICE OF METHODS AND STUDY DESIGN

Many characteristics of the evaluations in our review, like their summative evaluation designs, posed research questions, and chosen data sources, indicate that the examination of effects is a key motivator (Ziegler and Hedder, 2020). Whenever effects are in the focus of an evaluation and elaborated designs are necessary, a lack of precision of objectives and target groups can complicate the choice of study design and methods. Accordingly, the methodological flaws mentioned by Jensen (2014) also apply in our context: To gather insights into effects, reference points for comparison are essential. After all, no change, for better or for worse, can be determined with only one data point. A credible procedure to provide such comparisons would be repeated measures as in pre- and post-designs but also the use of control groups during evaluation. Looking at current evaluation practices, such comparisons are rare. Both the community survey and the evaluation report review show that control groups are seldom used in science communication evaluations. Pre- and post-designs come up more regularly-in roughly a third of the cases (Impact Unit, 2019, p. 22; Ziegler and Hedder, 2020, p. 24). Consequently, for the remaining evaluations interested in effects, these can only be judged based on insufficient data as they rely on self-report, meaning survey participants' memory and ability to reflect and compare their feelings, judgments, and thoughts. This is exacerbated when third parties like teachers are asked to judge the effects of an activity on the target group (e.g., school students). Overvaluing these sources that can only offer indirect information increases the risk of redesigning formats while missing the real target groups' interests (Jensen, 2014, p. 2).

Since we did not witness the decision-making processes during these evaluations, we were not able to reconstruct the choices that were made. However, looking back on discussion rounds with practitioners, we felt that short-term planning seems to be a central factor. Choosing the right methods, defining suitable data sources, scheduling repeated measures, and preparing instruments require early evaluation planning. In reality, it is often too late for many of these decisions once practitioners (can) start planning evaluations. In such cases, they might inevitably turn to what is well-known, seemingly cost-efficient, and presumably easy to conduct. Limited knowledge about possible methods and data sources might result in evaluations being planned around what data one knows how to collect, instead of what information is of actual interest.

We are aware that measuring effects is ambitious. If it cannot be done properly, practitioners are better off focusing on examinations of descriptive findings that enable an informed reflection. However, methodological rigor is indispensable, no matter the interest of the evaluation. To make sure that appropriate conclusions are drawn, evaluations need to be systematically planned, starting with clear questions that lead to the data of interest, to the most valid data sources and, finally, to the best-fitting methods and time frames for data collection. Practitioners not only need time and resources to

undergo this process but also the relevant information to base their decisions on.

UNDERSTANDING OF EVALUATION

According to our survey, 36% of the science communicators in Germany agree that projects are evaluated often if not always ($n = 96$; Impact Unit, 2019, p. 21). Unfortunately, this does not mean that these evaluations are open to everyone to learn from. Our own search for accessible best practices in the German-speaking community demonstrated how difficult it is to find benchmarks in comparable contexts. Our examination of the first 50 findings of each of the 68 keyword combinations we searched for (Ziegler and Hedder, 2020, p. 36 ff) yielded a relatively small number of 55 science communication evaluation reports. This is not surprising though: As the community survey shows, evaluations are mostly used in order to reflect upon a project within the team (79%), improve future projects (64%), and their findings are commonly passed on to supervisors and/or funders (65%). Sharing findings for research purposes is not as established (18%; $n = 72$; Impact Unit, 2019, p. 26). Also, the examples we found online were mostly reports of summative evaluations. Formative evaluations that would allow a deeper understanding of how a project is developed, reflected, and improved are scarce.

These observations may be related to a persistent framing of evaluations as 'telling success stories.' Following this logic, the evaluation process is not as valuable for outsiders as its results. A further reason for not making evaluations accessible is that it might invite criticism. Therefore, failed attempts or mediocre results, which could still stimulate learning, are not disclosed. In our discussion rounds, the practitioners expressed a worry about their work being assessed negatively by others, especially when evaluations are closely linked to the justification of budgets or funding.

In contrast to this, a constructive approach to evaluation needs to be based on curiosity about a project's potential and openness to learning from failures. Certainly, wanting to shift the idea of evaluation in a more productive direction where honest reflections and transparency are encouraged is not a controversial standpoint (e.g., Jensen and Gerber, 2020). Practitioners, researchers, and institutional stakeholders would agree that issues like time and resources pose a greater challenge than motivation. Difficulties arise when it comes to determining the practical implications and assigning roles and responsibilities within the science communication community in this process.

IMPLICATIONS FOR FUTURE PRACTICE

It has become clear that evaluations in science communication are still lacking in central aspects. In order to make evaluation a deliberately planned learning process that builds on existing knowledge, delivers insights into the impact of science communication, and thereby allows evidence-based decisions concerning its development and funding, profound changes need to be made. This will only be possible through the contributions of all the stakeholders in the field.

Practitioners can contribute decisively by strategically planning activities and allocating resources within projects. Their work needs to be based on a regular critical reflection and a motivation to apply the latest knowledge in the field. But practitioners should not be expected to do the same work as researchers; therefore, meaningful cooperation between research and practice is key. Even if practitioners are equipped with the right information and tools, social scientists' expertise will remain relevant to measuring impact and developing strategies for effective science communication. The contribution of scientists researching science communication includes not only enabling access to scientific results but also communicating findings that are especially relevant to practice. Moreover, the stakeholders at the management level of scientific organizations and research institutes, as well as the funders of and the policymakers for science communication, need to be clear about their science communication goals so that the practitioners are able to derive their project objectives accordingly. By providing the wider context, they become part of the conversation about appropriate goals of science communication.

Further training for practitioners plays an important role in improving evaluations. Consequently, there should be opportunities and support for learning within organizations and funding schemes, for example, in the form of training programs on evaluation and strategic project planning. Learning opportunities are also central to addressing methodological shortcomings in evaluation practice. Experts from social sciences and evaluation research can be of help by making instruments, measures, and scales more readily available. This allows practitioners to use scientifically sound examples as orientation, instead of designing their own instruments from scratch. Of course, this will not solve the need for guidelines and quality standards in evaluation, including minimum requirements concerning methodological rigor for a wide spectrum of methods and study designs. This task requires scientific expertise and, ideally, an international exchange but cannot succeed without funders and executives as a driving force to accept and implement these standards.

However, it is undeniable that elaborate evaluation designs cannot be conducted 'on the side.' Even though evaluation practice should embrace quality standards, it will not replace academic impact research. There needs to be a discussion of what can be expected from meaningful evaluations conducted by practitioners, at which point external experts or researchers are appointed, and where we draw the line between evaluation and research. Finally, we encourage the stakeholders from the management level, the funders, and the policymakers to demand meaningful and reasonable evaluation planning early on but also to provide sufficient resources for it. For practitioners to evaluate honestly and with enthusiasm, these stakeholders must show interest in a project's learning opportunities, not only in its final results.

Even though resolving these issues will take time, we are convinced that our field will benefit from a better understanding of how specific activities of science communication work, when to use them, and where to invest resources to actually make a difference.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found at: https://zenodo.org/record/4608091#.YGLT7mhCRhA.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

RZ conceived the concept for this perspective. IH contributed to the final conceptualization and wrote the first draft of the manuscript. LF, IH, and RZ revised the manuscript and contributed to the critical editing and finalizing of the manuscript. All authors approve the submitted version.

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What Drives Belief in Vaccination Conspiracy Theories in Germany?

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In the midst of a pandemic, the efficacy of official measures to mitigate the COVID-19 crisis largely depends on public attitudes towards them, where conspiracy beliefs represent potential threats to the efficacy of measures such as vaccination. Here, we present predictors and outcomes associated with a COVID-19 vaccination conspiracy belief. In a representative survey of Germany, sociodemographic predictors of this belief were found to include age, federal state, migration background and school leaving qualification. The study revealed correlations with trust in scientific and governmental information sources, respondents' self-assessment of being informed about science, general conspiracy mindedness, the frequency of using Twitter and messaging apps, as well as willingness to voluntarily take the COVID-19 vaccine. Our results cohere with and build on the general literature on conspiracy mindedness and related factors. The findings provide an evidence base for more effective health and crisis communication in Germany and beyond.

Keywords: COVID-19, vaccination, conspiracy theories, health communcation, crisis communication

INTRODUCTION

Public attitudes towards science are a matter of life and death in the midst of a public health crisis. Conspiracy thinking, anti-vaccine movements and distrust of expert institutions threaten to prolong the devastating impact of the COVID-19 pandemic by limiting uptake of life-saving vaccines. Here, we investigate a particular vaccine-linked conspiracy belief, namely that "*The coronavirus (COVID-19) is part of a global effort to enforce mandatory vaccination*", to gain more insight about subsets of the population in Germany that tend to express agreement with it. Following previous literature (e.g., Franks et al., 2013), we understand conspiracy theories as attempts to explain seemingly random events through the work of malicious agents that operate behind the scenes. According to these beliefs, nothing happens by accident; nothing is as it seems; and everything is connected (Burkun, 2013, p. 3–4).

Vaccinations have always been accompanied by conspiracy theories and general public skepticism. Since the middle of the 19th century, fierce debates about vaccines have been held within Germany, including publication of a large number of anti-vaccination books and papers (Meyer and Reiter, 2004). Within this literature could be found the claim that vaccination was part a Jewish conspiracy to damage the German population. Mandatory smallpox vaccinations for children were first introduced in Germany in 1874 with the "Reichsimpfgesetz" (Vaccination Act). In response to this, journals such as "Der Impfgegner" (the vaccination objector) were created by skeptics to advance their opposition. Scepticism and critical attitudes towards vaccinations have occurred in the German population since then, influencing vaccine acceptance up to the present day.

With the first cases being reported in Wuhan (China) in December 2019 (WHO, 2020), the novel SARS-Cov-2 virus quickly spread around the world with the first official case inside Germany being confirmed on January 27th 2020. Following the national pandemic plan, advised by the Robert Koch Institute (RKI), on March 13th the country entered the *protection stage*, closing schools and borders. A first loosening of restrictions occurred in mid-April 2020. Despite a relatively calm summer, the number of cases increased from the end of August, followed by a second national partial lockdown starting on November 2nd, 2020. By the end of November, Germany reached the total number of one million reported infections. In spite of a hard lockdown imposed on December 15th, infection numbers were persistently high and only began declining from mid-January 2021.

Since March 2020, vaccination has been lauded as the key to exiting the pandemic. While in April 2020 79% of the Germany population was willing to get vaccinated, this dropped to 62% as of January 2021 (COSMO - COVID-19 Snapshot Monitory, 2021). In general, many factors influence the willingness to get vaccinated, for example, fear of unforeseen side effects (Neumann-Böhme and Sabat, 2021), past immunisation experiences, expert advice and perceived efficacy (Deshpande et al., 2021).

Widening our perspective beyond the COVID-19 pandemic, conspiracy theories tend to appear during social crises to cope with collective uncertainty and fear (van Prooijen and Douglas, 2017; Larson, 2020). Conspiracy theory emergence can be seen as an attempt to make complex and threatening situations more understandable and predictable (Franks et al., 2013). It is in keeping with this general pattern that Freeman et al. (2020) identified an increased emergence of conspiracy theories in the United Kingdom during the COVID-19 pandemic. Schließer and colleagues (2020) report similar tendencies for Germany. However, they highlight that a high conspiracy mentality has long been evident in Germany, which is now becoming more overt, e.g., through the *Querdenker* protest movement that unites a multitude of sociodemographic groups with a high conspiracy mentality.

Studies have shown that the belief in vaccination conspiracies has real-life consequences for health-related behaviours. Jolley and Douglas (2014) found a significant negative relationship between anti-vaccination conspiracy beliefs and intentions to have a fictitious child vaccinated in a United Kingdom-based study. They further describe the mediating role of the perceived danger of vaccines, feelings of powerlessness, and mistrust in authorities. In the COVID-19 context in the United Kingdom and Turkey, Salali and Uysal (2020) found that believing in a natural (wildlife) origin of the coronavirus significantly increased odds of COVID-19 vaccine acceptance compared to believing in an artificial origin (e.g,. originated in a laboratory). Additionally, susceptibility to misinformation was associated with a significant decrease in the likelihood to get vaccinated and recommending the vaccination to vulnerable friends and family in the United States, the United Kingdom and Mexico (Roozenbeek et al., 2020).

It is likely that the relationship between belief in vaccination conspiracy theories and vaccination intentions is tied to a general psychological tendency to believe in conspiracies, as has been shown by Lewandowsky et al. (2013). Their model, based on US data, revealed that the endorsement of 'classic' conspiracy beliefs (e.g,. about the Moon Landing) is also associated with negative attitudes toward vaccines. Furthermore, all investigated conspiracy theories had similar predictors. They found a negative correlation with political trust, political knowledge, and education, as well as a positive correlation with authoritarianism. Conspiracy beliefs, as well as a conspiracy mentality, negatively predicted participants' intentions to be vaccinated against COVID-19 in a French sample (Bertin et al., 2020). This is consistent with earlier studies which have found an interconnectedness of different conspiracy beliefs, pointing to the existence of a general "Conspiracy mentality" (Moscovici, 1987; Bruder et al., 2013).

Although negative correlations between the belief in (vaccination) conspiracies and vaccination intentions have been repeatedly established (Lewandowsky et al., 2013; Jolley and Douglas, 2014; Bertin et al., 2020; Roozenbeek et al., 2020; Salali and Uysal, 2020), the effect size remains modest, ranging between $r^2 = 0.05$ (Bertin et al., 2020) and $r^2 = 0.27$ (Lewandowsky et al., 2013). Much of the variance still needs to be explained and to the authors' knowledge, the topic has not been investigated within Germany before. Filling this gap in times in which a long documented high conspiracy mentality in Germany (cp. Schließer et al., 2020) is discussed in public more openly (e.g,. through the *Querdenker* movement) seems to present a unique opportunity. What could also foster conspiracy mentalities in the current pandemic is the organization of vaccinations in Germany. Initially, these were organized centrally in vaccination centers (which are still in operation) before general practitioners were also allowed to vaccinate. This could be particularly relevant as GPs in Germany have been shown to have had a central role in vaccination in terms of trust (Rehmet et al., 2002).

This study thus aims to reveal the specific dimensions of the vaccine-related conspiracy belief and its links to other beliefs and socio-demographic characteristics. It is important to assess if the same correlations hold in the German context, as well as the current, dynamic and ever-evolving COVID-19 vaccination debate. Specifically, we aim to answer the following questions:

1. What are the predictors of belief in the mandatory vaccination conspiracy?
2. How heavily correlated is belief in the mandatory vaccination conspiracy with others and with general conspiracy-mindedness?
3. How heavily correlated is the belief in the mandatory vaccination conspiracy with vaccination intentions?

METHODS

Sampling and Data Management

In this study, we examined relevant items from a nationally representative survey which was conducted from October 30, 2020 to December 14, 2020 in Germany as part of the *Viral Communication* project (viralcomm.info).

Participants were recruited by sending postcard invitations to a random selection of 30.000 households, using the German postal service's (Deutsche Post) address database. Addresses were stratified by population across federal states in Germany (Destatis, 2020). Following data collection, survey data was cleansed by applying a range of inclusion criteria. Valid cases needed to include non-missing responses for *age group*, *sex*, *nationality group* (German/other), *migration background*, *federal state*, *highest school leaving qualification*, and *highest professional qualification*. These criteria were strictly required as weighting was applied next, using the latest available German census (Zensus 2011, 2011). This meant that these key sociodemographic questions were asked exactly as they were in the census, and that the sample was then weighted based on the corresponding sociodemographic distributions from the latest German census so as to represent the German population as accurately as possible. All questions used for weighting had therefore been exactly aligned with their census counterparts in the survey design stage. The weighted dataset allows for inferences beyond the sample.

In total, 1,480 survey entries were registered. 547 participants were excluded for not fitting the inclusion criteria, and 208 participants did not answer the vaccination conspiracy item. The final sample had $N = 725$ participants ($n_{woman} = 421$, $M_{age} = 48.9$, $SD = 18.8$).

Survey Design

For each of the survey items described below, participants were given a "Not applicable/No Opinion" response option.

COVID-19 Conspiracy Beliefs and Conspiracy Mentality

Different COVID-19 conspiracy beliefs were assessed using a standard 7-point Likert-type scale, ranging from "Strongly Disagree" to "Strongly Agree", with "Neutral" as the midpoint (used throughout the survey). Respondents were asked to indicate their level of agreement with certain statements, including the vaccination conspiracy belief in the center of our analysis, namely "*The coronavirus (COVID-19) is part of a global effort to enforce mandatory vaccination*". Other conspiracy beliefs tested for correlation with the primary item above are "*The coronavirus (COVID-19) was bioengineered in a military lab*", "*The new 5G network is making us more susceptible to the virus*", "*The coronavirus (COVID-19) is a hoax*", and "*The Coronavirus (COVID-19) originated in a Chinese lab*".

Based on the Conspiracy Mentality Questionnaire (CMQ) by Bruder and colleagues (2013), a four-item scale was developed to assess general conspiracy mindedness. The questions were adapted to the specific context of the COVID-19 pandemic, including items such as "*The Coronavirus (COVID-19) situation has provided an excuse for government agencies to closely monitor all citizens*" and "*Many important decisions about the Coronavirus (COVID-19) situation are made without the public ever being informed*". Respondents were able to rate all items on the aforementioned agreement scale. A conspiracy mindedness score was calculated for each participant by taking the average of all answered conspiracy items listed above.

Vaccination Intentions

A 5-point Likert-type scale ranging from "Definitely not" to "Definitely", with "Maybe" as the midpoint, was used to assess participants' willingness to voluntarily vaccinate against COVID-19, using the following question: "*Would you take the following measures on a voluntary basis?*"

Trust in Political and Scientific Actors

To measure trust in key institutional sources of information on the pandemic (i.e., RKI, WHO, respective state government, German Public Health Ministry, German health minister Jens Spahn, German virologist Christian Drosten and Angela Merkel), respondents were asked to rate their level of trust on a 5-point Likert-type scale ranging from 'Completely distrust' to 'Completely trust', with 'Neutral' as the midpoint.

Accessing Information on Social Media

For measuring the frequency at which people access information about the COVID-19 situation on different social media and messaging platforms, respondents were first asked which platforms they used, followed by a 7-point Likert-type scale (ranging from 'Never' to 'Always', with 'Sometimes' as the midpoint) for each selected platform. The platforms included were Facebook, YouTube, Twitter, Instagram, and the messaging services WhatsApp, Threema or Telegram.

Data Analysis

To ascertain predictors of belief in the vaccination conspiracy, correlation analyses and independence tests were performed with socio-demographic variables, trust in different COVID-19 information sources, and political orientation as independent variables. Due to the ordinal nature of the dependent variable, Kendall's Tau was used to identify non-parametric correlations with other ordinal or interval variables. Kruskall-Wallis and corresponding post-hoc tests with Bonferroni correction were used for nominal independent variables. Compound variables for attitudes towards science, trust in scientific actors and conspiracy-mindedness were computed by taking the average of the relevant (and responded-to) items. Throughout this paper, statistically significant results are reported at $\alpha < 0.05$.

RESULTS

75% of people in Germany, 95% CI (0.724, 0.784), disagreed with the statement that "the coronavirus is part of a global effort to enforce mandatory vaccination", with the response option *Strongly Disagree* representing the median as well as the mode at 52%, 95% CI (0.482, 0.552). Yet, there was a notable 15% minority of people, 95% CI (0.127, 0.178), who at least somewhat agreed with this statement. The sub-proportions of people who agreed with the conspiracy belief were 6% for "somewhat agree", 95% CI (0.046, 0.080), 7% for "agree", 95% CI (0.053, 0.089), and 2% for "strongly agree", 95% CI (0.009, 0.027).

Sociodemographic Predictors

There were significant differences in levels of agreement with this statement on the basis of geographical location by federal state

within Germany, H (15) = 130.826, $p < 0.001$, $\eta^2 = 0.17$. Overall, geographical location within Germany explained 16.6% of variance in level of agreement with this vaccine conspiracy belief. The following effects were particularly high: Berlin (mean rank = 199.81) scored consistently low compared to Schleswig-Holstein (mean rank = 430.33), $Z = -4.329$, $p = 0.002$, $r = 0.57$, and Brandenburg (mean rank = 448.07), $Z = -4.460$, $p = 0.001$, $r = 0.60$. Similarly, Rheinland-Pfalz (mean rank = 206.43) scored considerably lower than Schleswig-Holstein, $Z = -4.278$, $p = 0.002$, $r = 0.53$, and Brandenburg, $Z = 4.410$, $p = 0.001$, $r = 0.56$.

Although there was no noteworthy correlation with age, $r_\tau = -0.07$, $p = 0.002$, between different age groups, there were statistically significant differences, $H (7) = 20.098$, $p = 0.005$, $\eta^2 = 0.02$. However, age groups as a whole explained just 2.0% of variance in agreement with the vaccine conspiracy belief. The only at least moderate significant pairwise comparison between age groups responsible for the significant Kruskal-Wallis H test was the difference between people aged 80 + and 30–39 year-olds, $Z = 4.235$, $p = 0.001$, $r = 0.33$. Specifically, 30% of people in Germany between 30 and 39 years of age, 95% CI (0.210, 0.386), agreed to some degree that the coronavirus is a global effort to enforce mandatory vaccination, while only 8% within the 80 + category, 95% CI (0.005, 0.158), agreed with this statement.

There was a statistically significant effect on the basis of school leaving qualification, $H (4) = 64.685$, $p < 0.001$, $\eta^2 = 0.09$, which explained 8.6% of variance in vaccine conspiracy belief agreement overall. However, the only moderate effect size identified based on school leaving qualification was between people with an Abitur, the highest secondary degree in Germany (mean rank = 258.30), and people with a Volksschule-diploma, a lower-level secondary degree (mean rank = 418.32), $Z = 7.841$, $p = 0.002$, $r = 0.36$, explaining 13% of the variance.

Gender did not play a major role in belief in this conspiracy as only 3% of the variance is attributable to this variable, $U = 52,180.50$, $p < 0.001$, $r = 0.17$, $\eta^2 = 0.03$. German residents with a migration background, on the other hand, were more likely to believe in the vaccine conspiracy than people without a migration background, $U = 25,326.50$, $p < .001$, $r = .30$, $\eta^2 = .09$, accounting for 9% of the variance. Specifically, we found 43% of people with a migration background, 95% CI (0.349, 0.506), agreed to some extent with the vaccine conspiracy statement, whereas just 9% of people without a migration background, 95% CI (0.064, 0.108), agreed.

There was only a negligible correlation with political orientation, $r_\tau = 0.11$, $p < 0.001$, with only 1.2% of the variance explained. However, a Kruskall-Wallis test revealed significant differences between different self-affiliated political groupings, $H (6) = 39.547$, $p < 0.001$, $\eta^2 = 0.05$ (5.3% shared variance). The only group responsible for the significant result seems to have been the far-right group, $Mdn = 6$ (Agree): Especially compared to the far-left group, $Z = -4.261$, $p < 0.001$, $r = 0.73$ (53.4% shared variance), but also compared to second-farthest right group, $Z = -3.246$, $p = 0.025$, $r = 0.56$ (31% shared variance), people who categorized themselves as far-right scored substantially higher. Differences on the basis of highest

professional qualification were only marginal, accounting for just 4% shared variance, $H (5) = 32.506$, $p < 0.001$, $\eta^2 = 0.04$.

Attitudinal and Behavioral Predictors

To a moderate degree, attitudes toward science were negatively correlated with the belief in the vaccine conspiracy, $r_\tau = -0.32$, $p < 0.001$: People with more positive attitudes toward science were less likely to agree with the conspiracy statement (10.2% of variance explained). Also, trust in key scientific and official information sources was negatively correlated with this conspiracy belief. This applies to the German Public Health Ministry, $r_\tau = -0.34$, $p < 0.001$ (12.6% shared variance), pandemic-relevant research organizations such as the Robert Koch Institute, $r_\tau = -0.33$, $p < 0.001$ (10.9% of variance explained), prominent researchers such as virologist Christian Drosten, $r_\tau = -0.30$, $p < 0.001$ (9% of variance explained), as well as the WHO, $r_\tau = -0.30$, $p < 0.001$ (9% shared variance). Trust in scientific institutions (compound variable including trust in Christian Drosten, the WHO, and the Robert Koch Institute) was moderately correlated with attitudes toward science, $r_\tau = 0.36$, $p < 0.001$ (13% of variance accounted for).

An additional interesting finding was that people who felt less informed about science were more likely to agree with the vaccination conspiracy, $r_\tau = -0.32$, $p < 0.001$, explaining 10.2% of variance.

The correlation between the frequency in accessing a social media or messaging platform and the agreement with the vaccine conspiracy varied greatly by platform. The frequency of using Twitter was strongly correlated with vaccine conspiracy agreement, $r_\tau = 0.57$, $p < 0.001$, with 32.3% of variance explained. However, when comparing the correlation between people with and without migrant backgrounds, there were only significant findings for the group with migrant backgrounds, $r_\tau = 0.56$, $p < 0.001$, compared to $r_\tau = 0.32$, $p = 0.122$. Usage of messaging apps such as WhatsApp, Telegram or Threema was only moderately correlated with vaccine conspiracy belief, $r_\tau = 0.32$, $p < 0.001$. Using Facebook, $r_\tau = -0.05$, $p = 0.44$, and YouTube, $r_\tau = 0.03$, $p = 0.66$, were not correlated with this conspiracy belief. Instagram usage was only weakly correlated with the conspiracy belief, $r_\tau = 0.19$, $p = 0.028$.

Belief in the conspiracy idea that the coronavirus is a global effort to enforce mandatory vaccination correlated strongly with general conspiracy-mindedness, $r_\tau = 0.50$, $p < 0.001$. While this was to be expected, only 25% of variance was explained.

Additional correlations with belief in other conspiracy beliefs further support the interconnectedness of various conspiracy beliefs: A strong correlation with 30.5% shared variance was established with belief in the conspiracy that "the coronavirus is a hoax", $r_\tau = 0.55$, $p < 0.001$, that "the coronavirus was bioengineered in a military lab", $r_\tau = 0.47$, $p < 0.001$ (21.9% shared variance), that "the new 5G network is making us more susceptible to the virus", $r_\tau = 0.47$, $p < 0.001$ (22.5% shared variance), and that "the coronavirus originated in a Chinese lab", $r_\tau = 0.32$, $p < 0.001$ (10.4% shared variance). Further, the notably strong correlation with belief that "the coronavirus is a hoax" significantly differed from the moderate correlations with the

other conspiracy beliefs: $z = 2.106$, $p = 0.035$, $z = 1.972$, $p = 0.049$, and $z = 5.062$, $p < 0.001$, respectively.

Behavioral Effects

We found a negative correlation between agreement with the vaccine conspiracy and willingness to take a voluntary COVID-19 vaccination, $r_\tau = -0.29$, $p < 0.001$. The less people in Germany believed the vaccination conspiracy, the more likely they were to express willingness to take the novel coronavirus vaccine. However, the effect size here was moderate, with 8.4% of variance shared.

DISCUSSION

This study has analyzed survey results on a vaccination-related conspiracy belief, its predictors and links to willingness to get vaccinated. This article's jumping off point is that in Germany a notable 15% minority of people at least somewhat agreed with this statement "the coronavirus is part of a global effort to enforce mandatory vaccination."

People from the German capital of Berlin were less likely to agree with the vaccination conspiracy than people from another part of Germany (i.e., the state of Brandenburg). Demographic variables do not seem to explain these differences since Berlin has a younger and more migrant population than Brandenburg, where both factors tend to enhance agreement with the vaccination conspiracy (Statistik Berlin Brandenburg, 2019). These state differences may instead be related to political party affiliation patterns (e.g., right-wing oriented parties have a larger following in Brandenburg than in Berlin), given that people identifying as far-right politically tended to support the vaccination conspiracy belief. Additionally, measures in the more densely populated city-state Berlin are more visible and partly stricter than the ones in Brandenburg, e.g., already in October 2020 Berlin introduced a mask requirement in some squares and busy streets while in Brandenburg this was only introduced in the capital Potsdam. Thus, preliminarily, more or less strict policies could be a factor in regional differences. Of course, other factors related to state differences such as local press need to be taken into account - a potential focus of future studies.

Political orientation on a conventional left-right spectrum only negligibly correlated with the vaccine-related conspiracy belief. These findings are consistent with results from Sutton and Douglas (2020) suggesting that conspiracy beliefs are associated with ideological polarization rather than liberalism or conservatism. Other studies have highlighted the relevance of factors such as lack of recognition, political deprivation, a negative assessment of the economic situation and right-wing extremism (Schließler et al., 2020). However, a larger proportion of variance can be explained by the level of secondary education attained. Overall, age only has a minor influence, with 30–39 year-olds particularly "susceptible" to such beliefs. This age-specific finding may raise concerns given research showing that people aged 20–49 were responsible for 65% of SARS-CoV-2 infections in the US (Monod et al., 2021).

Existential motives for believing in a conspiracy belief, such as feeling safe and in control of one's environment, tend to be important in the context of a new vaccine (Douglas et al., 2017). People who feel a lack of instrumental control may seek this feeling of "safety" by rejecting official narratives and believing in a specific conspiracy (Goertzel, 1994). This may help explain why marginalized groups often subscribe to conspiracies at the highest frequency. In our research, 43% of people with a migration background agreed to some extent with the vaccine conspiracy statement, whereas just 9% of people without a migration background did the same. The difference between people with a migrant background and those without one could also be explained by exposure to misinformation: Although there was a general correlation between Twitter usage and vaccination conspiracy belief, it was only statistically significant for people with a migrant background. Future studies could more deeply investigate information behavior and the sources accessed among both groups as potential causes for this effect.

Trust in all types of information sources (i.e., governmental, scientific, and international) was a consistent factor related to belief in the vaccine conspiracy - less trust in various institutional information sources meant a higher tendency to believe in the conspiracy. This coheres with literature on the relation between conspiracy belief and distrust in governments (Sutton and Douglas, 2020) as well as specific institutions and professions (Freeman et al., 2020). The direction of causality, however, remains unclear. That is, we don't know from this study whether belief in conspiracies are responsible for distrust, whether there is an inverse effect, or whether they are mutually reinforcing.

This study found, in line with previous research, a high correlation between belief in the vaccination conspiracy and general conspiracy-mindedness, as well as moderate to strong correlations with other specific conspiracy beliefs. These findings support the established principle of interconnectedness of conspiracy beliefs (Goldberg and Richey, 2020; Uscinski et al., 2020), albeit with substantial unexplained variance.

Conspiracy beliefs tend to conform to characteristics of conspiracy mentality (hence the strong correlation to specific conspiracy beliefs), in which nothing is as it seems, everything is connected and a network of actors with evil intentions are driving events (Burkun, 2013). Moscovici (1987) points out that it is typically a "minority" that is held responsible for great upsets and social crises. In the case of the current pandemic, the strong correlation between vaccine conspiracy belief and agreement that "the coronavirus is a hoax" as well as an opposing belief that it "originated in a Chinese lab" implies conspiracy narratives which squarely fit the historical mold: The coronavirus pandemic would be used to enforce vaccination as part of a carefully orchestrated hoax or China's bad intentions. Yet, there are also variations that need to be accounted for by how they connect with local belief systems and existing relationships between groups. For example, belief in the conspiracy idea that "the coronavirus originated in a Chinese lab" (34% agreement) was relatively high in Germany, while belief that 'the coronavirus is a hoax' (3% agreement) was not.

We demonstrate that the belief in a vaccination conspiracy can affect people's health behaviors during the COVID-19 pandemic. This is in line with previous research reporting a negative

relationship between the belief in (vaccination) conspiracies and vaccination intentions in the United States, United Kingdom, France, Mexico, and Turkey (Bertin et al., 2020; Lewandowsky et al., 2013; Jolley and Douglas, 2014; Roozenbeek et al., 2020; Salali and Uysal, 2020). Hence, targeting vaccine conspiracy beliefs should also be an important factor in the efforts to increase vaccination intentions within Germany for the benefit of public health.

Nonetheless, we are not able to explain the causal direction of effects in this study, meaning that either the belief in the vaccination conspiracy could reduce vaccination intentions, or that low vaccination intentions might increase belief in the vaccination conspiracy belief. Therefore, an important next step for future studies would be to explore people's vaccination intentions in more detail (e.g., *via* follow-up interviews) to more closely follow the argumentation behind the intentions/hesitations to get vaccinated, and find out whether conspiracy thinking is used to justify the decision being made. Longitudinal research, which is also planned for the project underpinning this article, will also help to tease apart correlation and causation on this topic.

Our findings indicate potential value in focusing COVID-19 vaccine engagement on the sociodemographic groups most susceptible to vaccine conspiracy beliefs, specifically people in Schleswig-Holstein and Brandenburg, people between 30–39 years of age, people with a Volksschule degree, and those with a migration background. Additionally, policies and (science) communication on the governmental and institutional level should aim to establish and maintain long-term, mutually beneficial relationships of trust with diverse publics (see e.g., Borchelt and Nielsen, 2014) to potentially inhibit the intake of

misinformation leading to conspiracy beliefs and an adverse course of the pandemic.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://zenodo.org/record/4590017.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of the Sigmund Freud University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors contributed to the survey design. AP and LL set up the survey system. Data collection was conceptualized by EJ, BW, and MW and implemented by LL. AP performed the data management and statistical analyses. LH with input from BW and MW wrote up the introduction. AP and LH wrote up the methods. AP wrote up the results. EJ, AP, LH, BW, and MW wrote up the discussion and together with LL contributed with general editing. EJ did final editing.

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COVID ISSUE: Visual Narratives About COVID-19 Improve Message Accessibility, Self-Efficacy, and Health Precautions

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Visual narratives are promising tools for science and health communication, especially for broad audiences in times of public health crisis, such as during the COVID-19 pandemic. In this study, we used the Lifeology illustrated "flashcard" course platform to construct visual narratives about COVID-19, and then assessed their impact on behavioral intentions. We conducted a survey experiment among 1,775 health app users. Participants viewed illustrated (sequential art) courses about: 1) sleep, 2) what COVID-19 is and how to protect oneself, 3) mechanisms of how the virus works in the body and risk factors for severe disease. Each participant viewed one of these courses and then answered questions about their understanding of the course, how much they learned, and their perceptions and behavioral intentions toward COVID-19. Participants generally evaluated "flashcard" courses as easy to understand. Viewing a COVID-19 "flashcard" course was also associated with improved self-efficacy and behavioral intentions toward COVID-19 disease prevention as compared to viewing a "flashcard" course about sleep science. Our findings support the use of visual narratives to improve health literacy and provide individuals with the capacity to act on health information that they may know of but find difficult to process or apply to their daily lives.

Keywords: COVID-19, visual narratives, public engagement, visual communication, storytelling

INTRODUCTION

The COVID-19 (Coronavirus Disease 2019) pandemic is a serious global health threat. COVID-19 has spread quickly and unrelentingly since its emergence in Wuhan, China in December 2019. The pandemic has had devastating impacts on human lives, public health, and the global economy. But it has also unified the scientific community in a mission to educate and engage the public in solutions such as public health precautions, including social distancing, testing, masks, engagement in clinical trials for vaccine candidates, and vaccination with approved vaccines. Educational resources about COVID-19 have subsequently exploded. However, communication efforts have left out large segments of the population with low health literacy skills (Frieden, 2020).

Health information has historically been presented such that it is not accessible to most Americans ["Health Literacy" by CDC (2021)]. Nearly a third of Americans have low general health literacy (Paasche-Orlow et al., 2005). While in this study we focused on developing and

assessing health literate COVID-19 materials in a U.S. context, low health literacy and a lack of health literate materials are also problems globally. Nearly half of all Europeans have inadequate and problematic health literacy skills according to a WHO report (Kickbusch et al., 2013). Further, nine out of 10 adults in the U.S. struggle to understand and use personal and public health information that doesn't follow health literacy guidelines ["Health Literacy" by CDC (2021)]. Much of the information about COVID-19 has fallen into this trap and is not accurate, trustworthy, *and* understandable by most people (Caballero et al., 2020). Many experts have pointed out that health literacy has been underestimated as a public health problem during the COVID-19 pandemic (Abdel-Latif, 2020; Paakkari and Okan, 2020).

Health-related educational resources designed for broad audiences, especially for adults with low levels of formal education, adults with mental health issues or disabilities (Kamalakannan et al., 2021), non-English speakers, or children, should follow health literacy best practices (CDC, 2021). They should be accurate, accessible, and actionable (CDC, 2021). They should make effective use of plain language, narrative, and visuals or multimedia to improve accessibility. But COVID-19 educational resources incorporating all of these elements remain rare as of the writing of this manuscript. Caballero and colleagues (2020) found that only 39% of assessed COVID-19 consumer materials from the internet included visual images that would have helped readers understand the information. Most of the materials failed to use plain language. Other experts have pointed out similar problems, including infectious disease specialist Benjamin P. Linas, MD. In late March, Linas observed an "absence of COVID-19 health education materials that could speak across language, literacy levels, and cultural norms" (Bailey, 2020).

Broadly accessible resources increased in availability in the months following the outbreak of COVID-19 and stay-at-home orders in the U.S. People produced simple cartoon-like patient factsheets in multiple languages (Bailey, 2020), kids' visual storybooks, and other accessible resources[1]. Yet, these resources remained limited and urgently needed in more languages and on more topics, such as updated information on COVID-19, immune system responses, and vaccine candidates.

Early in the outbreak of COVID-19 in the U.S., we observed few educational materials or graphics that were accessible and actionable. We observed few resources that helped people understand how they should prepare, how and when they should self-isolate, what they could *expect* if they got sick, how their bodies would fight the virus, and who should seek emergency care and when. Such actionable information is critical given the devastating potential impact of COVID-19 for people with any risk factors, and every person's role in helping limit the spread of COVID-19.

Park and colleagues (2020) found that among more than 1,000 U.S. adults recruited to a survey via Amazon's Mechanical Turk, many people expressed uncertainty about length of quarantine and social distancing requirements. In another study from Germany, up to 52% of just over 1,000 participants reported difficulty accessing, understanding and applying information about how to recognize infection, when and how to find professional help upon infection, and risk factors of disease (Okan et al., 2020). Although these findings don't necessarily mean that there weren't educational materials available on these topics, materials on these topics may not have been accessible, easy to understand or health literate.

In addition, while stories of people's COVID-19 infection experiences did start to appear in the local news media once COVID-19 began to spread in their communities, we didn't see these stories within the educational resources of government and healthcare institutions. Most resources (especially visual ones) that we saw focused on the history and science of SARS-CoV-2 and the respiratory disease it causes, or abstract concepts such as "flatten the curve". Meanwhile, there were mixed messages about mask wearing, risk factors and airborne infection risks. There seemed to be a gap in visual and broadly accessible educational materials covering the COVID-19 experience and how people should navigate the disease from prevention to treatment.

More accessible COVID-19 educational resources on a variety of topics are critical for the one in five U.S. adults with low literacy skills[2] and the nearly one-third with low health literacy. But they are also important for people who may be experiencing isolation-exacerbated feelings of fear, stress, anxiety, and/or depression (Park et al., 2020). Stress and mental health issues can make it more difficult for people to process technical health-related information (CDC, 2021) and adhere to public health recommendations (Middleton et al., 2013; Beutel et al., 2018). Stress can lower health literacy or an individual's capacity to put recommended preventative health behaviors into action.

In this study, we started to evaluate the impact of educational resources designed to address the audience and COVID-19 education gaps highlighted above. To do this, we leveraged a new visual science communication format developed by the science-art platform Lifeology.io. In March 2020, Lifeology published two expert-created illustrated "flashcard" courses about COVID-19 that contained plain language visual narratives suitable for broad audiences and people with low health literacy. The courses featured visuals created by professional artists. They were available in 20 + languages and addressed the topic gaps we identified above. One course ("Prevention Primer") covered the basics of COVID-19 prevention and care, through the story of a family learning to navigate the pandemic. The other course ("Mechanism") was more technical and covered the mechanisms of COVID-19 inside the body, risk factors and medical considerations for at-risk individuals.

The goal of this study was to test the impact of these two different "flashcard" courses on people's self-reported self-

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[1]https://education.gsu.edu/research-outreach/alrc/adult-literacy-coronavirus-resource-links/

[2]https://www.oecd.org/skills/piaac/; https://nces.ed.gov/datapoints/2019179.asp

efficacy, perceived threat, and behavioral intentions toward COVID-19, based on the Extended Parallel Process Model (EPPM). Another goal was to evaluate the ability of these courses to improve health literacy by helping people understand and use information about COVID-19. We did this through self-reported data of people's experiences with and takeaways from the course content. We conducted an online survey experiment *via* Qualtrics. We were particularly interested to see any differences in impact between a course with more basic information about COVID-19, a course with more technical information about the mechanisms and risk factors of SARS-CoV-2 infection, and a control course about the general health benefits of sleep.

This study also represents a collaborative effort to put evidence-based science communication into practice (Jensen and Gerber, 2020) and then to measure some outcomes of that practice. We (the authors of this study) are a team of science communication researchers, health writers, industry science communicators, artists and designers. Evidence in science and health communication research, including literature in the field of health literacy reviewed below, informed the creation of the COVID-19 "flashcard" courses evaluated herein. These courses were viewed by over 24,000 people in 3 months; one course was translated into 20 + languages by community volunteers who wanted to share the courses with audiences in their own languages/countries/ communities. While the courses were still highly relevant, we began collecting data via survey experiment to evaluate their impact on people's self-efficacy and behavioral intentions, plugging practice back into research.

LITERATURE REVIEW

COVID-19 Pandemic and Educational Interventions

The necessity of clear, actionable, and broadly accessible health education (CDC, 2021) has never been more apparent than during the COVID-19 pandemic. According to the World Health Organization (WHO), risk communication and community engagement "is integral to the success of responses to health emergencies" (WHO, 2020a). Risk communication and community engagement "helps prevent "infodemics"; (an excessive amount of information about a problem that makes it difficult to identify a solution), builds trust in the response, and increases the probability that health advice will be followed" (WHO, 2020b, p. 1). Effective communication around COVID-19 should translate scientific information to improve understanding, make it relatable, and deliver it in an accessible manner to diverse populations and communities.

WHO has also provided specific recommendations for communication materials intended for community engagement during the pandemic. They have recommended that countries translate materials into relevant languages, adapt them to appropriate literacy levels, and create shareable (online) visuals/multimedia pieces that present key information. They have encouraged the creation of materials that "explain the

disease etiology, symptoms, transmission, how to protect oneself, and what to do if someone gets sick" (WHO, 2020a). The United Nations and WHO even launched an unprecedented global call to creators[3] to help stop the spread of COVID-19 through artwork, encouraging creativity and "empathetic communication" to promote the adoption of public health precautions across age groups, affiliations, geographies, and languages.

But despite these recommendations, there has been a dearth of COVID-19 educational materials in the U.S. that make information accessible to most adults and that are inclusive of different people and cultures. This has been despite the disproportionate impact of COVID-19 and related serious illness among racial and ethnic minority groups who are more likely to experience low health literacy (Eichler et al., 2009), including Hispanic/Latino and Black/African American persons (CDC, 2020).

Health Literacy and Models of Health Behavior Change

Health literacy has been defined as "the degree to which individuals have the capacity to obtain, process, and understand the basic health information and services needed to make appropriate health decisions" (Wagner et al., 2009, p. 860; Institute of Medicine, 2004). Modern definitions also focus on the capacity to process and understand health information and use and apply it. Health literacy "entails people's knowledge, motivation and competencies to access, understand, appraise, and apply health information in order to make judgments and take decisions in everyday life concerning healthcare, disease prevention and health promotion to maintain or improve quality of life during the life course" (Sorensen et al., 2012). Low health literacy is associated with poorer health outcomes (Institute of Medicine, 2004). Health literacy can impact health-related knowledge, beliefs, motivations, self-efficacy, and ability to problem-solve with regard to self-care as well as using healthcare services (Paasche-Orlow and Wolf, 2007). Health-related knowledge, beliefs, motivations, and self-efficacy (and fear) are critical in determining health behaviors according to theories of health behavior action and change. These theories include the Health Belief Model and the Extended parallel process model (Jones et al., 2015; Sheeran et al., 2016).

Difficult-to-read health information and an overabundance of conflicting media health messages (as seen in the COVID-19 "infodemic") exacerbate health literacy issues. They also contribute to poor health outcomes (Paasche-Orlow and Wolf, 2007). However, educational materials that are accessible and promote experiential learning, i.e., learning through a transforming experience (Kolb, 1984), can improve health literacy (Day, 2009). Improving health literacy can, in turn, improve beliefs, attitudes, and motivations toward health

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[3]https://www.talenthouse.com/i/united-nations-global-call-out-to-creatives-help-stop-the-spread-of-covid-19. The call has been controversial among artists on account of asking for free labor in exchange for "exposure".

behaviors (Wagner et al., 2009). Educational materials that improve health literacy and address determinants of health behavior change are most likely to drive better health outcomes. Educational materials about COVID-19 should improve health literacy and help people turn their perceived threat from COVID-19 into action by helping them believe that they can act in ways that make a difference.

Educational materials that follow guidelines for improving health literacy are easier to read, digest, understand, and act upon. Health literacy guidelines focus on plain language, actionable information, resources that include visuals such as pictures and drawings, and an audience-centered approach that includes culturally appropriate messages (CDC, 2021). A growing body of research also focuses on the positive impact of visual narratives or storytelling, as seen in the body of research on Graphic Medicine. Storytelling and visual narratives with relatable human characters provide a fun and experiential way of learning that allows people to reflect on information and relate to it on a personal level (Day, 2009).

With this study, we sought to evaluate the impact of health literate visual narratives (Lifeology "flashcard" courses) on content experiences, attitudes and behavioral intentions toward COVID-19. Below, we review relevant literature on the potential impact of visuals and storytelling on health literacy and determinants of health behavior.

Research Question RQ1: To what extent do people report visual narratives (about COVID-19 or another health topic) as being easy to understand, informative and engaging?

Role of Visuals in Science and Health Education

People typically enjoy content that is visual or that includes illustrations and sequential art (e.g., comics) more than they do content that is not visual (Z. Dayan, 2018). In a recent study, medical and healthcare students indicated enjoying multimedia (a mix of images and text, and sometimes sound) as a practical learning tool (Vagg et al., 2020). Visuals can also aid learning among students with different learning styles and preferences (Aisami, 2015). Visuals can improve people's motivation to learn (Aisami, 2015), increase their engagement with message content (Lazard and Atkinson, 2015), and improve information processing and retention: "Words are abstract and rather difficult for the brain to retain, whereas visuals are concrete and, as such, more easily remembered" (Aisami, 2015, p. 542). Scientific concepts, like words, are also abstract. Visuals can make them more concrete and easier to grasp.

Visuals can also stimulate critical thinking. Visual representations draw more attention than text-only messages. Visuals facilitate information processing and enhance message elaboration (Cvijikj and Michahelles, 2013; Kim et al., 2015; Lazard and Atkinson, 2015). Townsend et al. (2008) found that text with color photographs increases understanding and learning of a food behavior checklist most when compared with text alone, text with line drawings, and text with grayscale photographs. This highlights the positive potential of colorful

artwork in improving people's engagement with science and health information.

People with limited literacy or language skills in particular "benefit from illustrations, not just words" (Osborne, 2012 p. 214). Visuals "can help people take in information faster and more accurately, and remember it better" (Osborne, 2012, p. 214), improving attention to, comprehension of, and recall of technical and health information (Houts, et al., 2006). People with low literacy skills are especially likely to benefit from visuals accompanying text (Houts et al., 2006).

Healthcare providers are encouraged to use visuals and multimedia resources when communicating with people with low health literacy (Hart et al., 2015) to improve patient knowledge (Nova et al., 2019). Empathetic and positively framed visuals and data visualizations in health education materials may help reduce anxiety (Demircelik et al., 2016) and minimize emotional stress associated with risk communication and getting negative prognostic information (Kim et al., 2020). Visuals may even improve behavioral intentions and behaviors, especially among low literacy audiences (Houts et al., 2006). These impacts are observed when viewers have a positive emotional response to visuals in health education materials (Delp and Jones, 1996).

Visual Storytelling for Science and Health Communication

There is a growing field of research around the use of narrative visual formats, sequential art, or visual storytelling for science and health communication. These formats combine the power of visuals with the power of storytelling (Green and Brock, 2002; Leung et al., 2014; Wang X. et al., 2019) to aid information processing and recall, enhance understanding, and increase engagement. For example, comics are a form of sequential art that combines visuals and plain language storytelling. Comics are preferred over other types of visual narratives because they often include characters readers can relate to, short text that is easy to read, and a story arc that keeps their attention (Wang Z. et al., 2019).

In school and healthcare settings, comics are effective at increasing knowledge and awareness of health issues/conditions (Ohyama et al., 2015; Tekle-Haimanot et al., 2016). In one study, a comic about pediatric anesthesia helped reduce preoperative anxiety in children (Kassai et al., 2016). In another study, Leung and colleagues (2014) found that exposure to relatable characters in a detailed artwork comic can capture imagination and influence health behaviors. A comic combining concise text and detailed artwork that encouraged fruit intake increased self-reported self-efficacy and snack selection in urban minority youth ($n = 57$). This happened regardless of changes in knowledge. The youth who read the comic were also more absorbed in the content (they reported paying attention without getting distracted) than youth who read a newsletter. The researchers surmise that greater transportation into the narrative of the comic lead to the observed changes in health-related outcomes: "(N)arratives that transport readers

have been shown to change beliefs and motivate behavior change" (Leung et al., 2014).

Most studies have investigated the impact of visual narratives among younger audiences. However, there is early evidence that they can also help people of all ages. Health professionals are being encouraged to apply similar mediums—illustrated stories or comic strips—to communicate with older patients and their caregivers. According to behavioral science expert and RN Sarah Kagan, "(m)uch of what we provide as educational material lacks interest, overshoots reading level, and necessarily includes an enormous level of detail" (Kagan, 2018). Some researchers and science communicators have used visual narratives to engage people in preventing the spread of COVID-19. Igarashi et al. (2020) found that manga comics, as a form of visual storytelling steeped in culture and lived experience, can "provide the public with a deeper understanding of (scientific) messages through . . . characters and their "real-life" situations" (2020, p. 1).

Visual narratives in health education may be especially appropriate for individuals with low health literacy or limited prior knowledge about the topic being communicated (Mayer, 1997; Schnotz and Bannert, 2003). According to comic research expert Matteo Farinella, "the visual language of comics might make information, not only more accessible, but also help to overcome linguistic barriers" (Farinella and Mbakile-Mahlanza, 2020). The cartoon-like visual nature of comics and other visual narratives may also make scientific information less daunting and more approachable for people. When it comes to the communication of sensitive health topics or complex, unfamiliar, or scary topics like vaccines (Muzumdar and Pantaleo, 2017), people often prefer simplified, stylized, conceptual, or interpretational illustrations over photographs and realistic art (Haragi et al., 2019; Farinella and Mbakile-Mahlanza, 2020).

Despite the burgeoning research field around comics and other narrative visual formats, visual storytelling remains poorly studied in terms of its efficacy for health and risk communication among broader publics in real-world settings (Farinella, 2018). Lifeology "flashcard" courses provide opportunities for further research in this area. They are similar to graphic novels or comics in combining short text with relevant detailed visuals in cards that tell a story and often include characters. We wanted to see when or for whom the visuals in these courses mattered, which we explored through participants' self-reported content experiences.

Research Question RQ2: Which factors are correlated/associated with self-reported attention to the visuals in a visual narrative about COVID-19 or another health topic?

Heuristic-Systematic Model of Information Processing

Developed by Chaiken (1980), the heuristic-systematic model (HSM) stated that information can be processed *via* two approaches: systematic and heuristic. Systematic processing often occurs when an information seeker is highly motivated and capable of digesting data; thus, the individual pays more attention to message content (Metzger et al., 2010; Katz et al., 2018). Conversely, when an individual lacks motivation or the

ability to comprehend information, they may rely on contextual factors such as visual or vocal cues to make judgments (Wang X. et al., 2019; Kim, 2018; Lahuerta-Otero et al., 2018). Additionally, some researchers have found that heuristic processing is more dominant than systematic processing, because the former requires less cognitive effort (Chan and Park, 2015; Lahuerta-Otero et al., 2018).

In this study, we use HSM as a framework to investigate the impacts of visual narratives on health-related perceptions (attitudes and beliefs) and behavioral intentions. For example, individuals with lower health literacy or education (lower education is related to lower health literacy) may rely on and pay greater attention to the visuals in an illustrated flashcard course about COVID-19 to process the message. But even highly educated individuals could rely on and pay greater attention to the visuals in a more technical course about the mechanisms of COVID-19 in the body, because technical science and health information can be difficult for anyone to understand and apply in their own lives. Regardless, we would expect greater attention to visuals to result in improved engagement with the content/message and improved outcomes.

This idea—that greater attention to visuals in educational materials improves engagement and outcomes - is related to the concept of absorption (Oh et al., 2015), immersion, or transportation with content being related to associated outcomes. Absorption is defined as "the degree to which users experience temporal dissociation, focused immersion, heightened enjoyment, curiosity, and control over the computer interaction" (Agarwal and Karahanna, 2000; Oh et al., 2015, p. 740) when interacting with media. Greater absorption can improve behavioral intentions. Both attention and absorption can be conceptualized as components of content engagement. But in this study, we were particularly interested in attention to visuals as a key component of engagement—consisting of qualities like attention, focus, curiosity, interest (Webster and Ho, 1997)—with illustrated flashcard courses.

Research Question RQ3: Is greater self-reported attention to the visuals in a visual narrative about COVID-19 associated with increased self-efficacy, perceived threat, and protective behavioral intentions toward COVID-19?

Health Communication and the Extended Parallel Process Model

In this study, we also explored whether and how understandable and engaging visual narratives about COVID-19 can drive behavior change, either directly and by activating perceived threat and self-efficacy (Witte, 1994). According to the EPPM, external stimuli that increase perceived efficacy and perceived threat (including severity of the threat and one's susceptibility to it) along with fear can increase protection motivation, message acceptance, and behavioral intentions. People can respond to risk messages and fear appeals in one of three ways: 1) through danger control, for instance in the form of behavioral intentions in line with the message recommendations; 2) fear control (e.g., denial, avoidance); 3) no response.

It is important to note that during the global spread of SARS-CoV-2, fear and perceived threat from COVID-19 have generally been high,

especially among older adults. In May 2020, Pew Research found that in the U.S., 38% of adults total, 43% of adults between the ages of 50 and 64, and 49% of adults over the age of 65 see COVID-19 as a major threat to their personal health (Schaeffer and Rainie, 2020). Younger adults also tended to report high levels of emotional distress. In light of this, we expected that educational content that delivered empowering information about COVID-19 prevention and care would improve protective behavioral intentions through improvements in self-efficacy in particular. While perceived threat is key to motivating behavior change according to the EPPM, self-efficacy is key to a positive response. Some researchers have also proposed that "as perceived threat increases when perceived efficacy is low, people will do the opposite of what is advocated" (Popova, 2012, p. 463).

Based on the EPPM, risk messages that increase people's self-efficacy in the face of a health threat can help to drive positive behaviors that may protect them from that threat. Based on research we've reviewed above related to health literacy, highly health literate educational content (which is understandable, visual, engaging, actionable) should be best able to help improve people's understanding of the health threat, and their self-efficacy or knowledge of how to protect themselves and confidence in their ability to do so. We explore this idea through our final research question and corresponding hypotheses, which we analyze in *Means of Self-Efficacy, Perceived Threat and Behavioral Intentions Across Course Conditions* and *Course Impacts on Behavioral Intentions*.

Research Question RQ4: Can understandable and engaging visual narratives about COVID-19 improve self-efficacy and protective behavioral intentions?

Hypothesis H1: People who view a visual narrative about COVID-19 will have increased self-efficacy toward protecting themselves from COVID-19 than people who view a control narrative.

Hypothesis H2: People who view a visual narrative about COVID-19 will have improved protection behavioral intentions toward COVID-19 than people who view a control narrative.

Hypothesis H3: Self-efficacy and perceived threat will mediate the impact of viewing a visual narrative about COVID-19 on protection behaviors.

For all hypotheses, we planned to look at the impact of two illustrated flashcard courses about COVID-19 separately.

We did not predict that viewing an illustrated flashcard course about COVID-19 would increase viewers' perceived threat from COVID-19 compared to a control course. We did not predict this because we thought that perceived threat would already be high in general among study participants given the state of the pandemic in the U.S. at the time (late March). However, we did plan to explore whether the more technical "Mechanisms" COVID-19 course would raise perceived threat, as this course discussed risk factors of severe COVID-19 illness.

METHODS

Educational Platform—Lifeology "Flashcard" Courses

Lifeology's illustrated flashcard courses are self-contained digital and interactive online card decks, where each card contains a small amount of text (one to three short sentences) along with a custom illustration. The cards contain sequential art that, along with bite-sized text, tells a story. The course viewer allows users to swipe or click through the course flashcards. It also allows users to toggle between different language options, tap/click to see information sources, tap/click to learn more about the course creators, and submit feedback. The course viewer is optimized for mobile devices but is responsive and works in any smart-device or desktop web browser. Courses are free and often published under a CC-BY-SA Creative Commons license.

Each course is the product of a collaboration between one or more technical experts, one or more plain-language writers, and an artist. It is becoming increasingly important to incorporate diverse, creative, and non-technical voices in the creation of science and health educational materials. Diverse perspectives improve the accessibility and relatability of science and health information for broad audiences. Every course also goes through a collaborative creation process[4] that conforms to established health literacy strategies (Osborne, 2012). The process includes collaborative identification of one or a few key messages, card script-writing by a plain-language writer, visual storyboarding, fact-checking by external scientists, and listening to early audience feedback.

The courses evaluated in this study incorporate features that meet modern recommendations of health literacy experts (Osborne, 2012; "Principle: Understandable"; WHO, 2020a; Simmons et al., 2017; Mayer, 2003). These include: plain language and succinct sentences; definition of technical terms; conversational and positive tone; actionable information; narrative elements including characters and a story-arc; text in close proximity to related visuals. The visuals also incorporate features important for health literacy including: high detail but not hyper-realistic visuals; informative visuals that show characters/people at their best modeling desired behaviors; illustrations that communicate scale and context, as for cells or virus particles; storytelling.

Study Procedure

We conducted an online survey experiment. Participants were randomly assigned to one of three stimulus (flashcard course) conditions: a course about sleep; a Prevention Primer course about the basics of COVID-19 prevention and self-care; a Mechanism course about how the novel coronavirus impacts our body. The study was approved for IRB exemption by Louisiana State University (IRB# E11953).

Study participants first answered questions about whether their state of residence was under a stay at home order, their perceived knowledge about COVID-19, and attention to news about it. Participants were then instructed to open and swipe/click through "a series of health-related flashcards organized into a mini-course" and answer some questions about it. We used an opened-ended question asking participants what the course was about and what they had learned, to ensure that participants had opened and browsed through the course cards. Finally,

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[4]https://app.us.lifeology.io/viewer/lifeology/default/how-is-a-lifeology-course-created

FIGURE 1 | Above we've reproduced three of the "cards" contained within the COVID-19 Primer Prevention course, as they would be seen on a mobile device. The first is the title card of the course, while the others are example cards to demonstrate the visual style, informational content, and amount of text.

participants answered questions related to their perceptions of the course they had viewed, their perceptions of COVID-19 as a threat to their health, their self-efficacy and their behavioral intentions toward COVID-19 protection and care, and demographics.

Stimulus Content

The control flashcard course[5] covered why we sleep, sleep patterns of humans and animals, and sleep hygiene tips for brain health. It was illustrated in a storybook style by artist Ariella Abolaffio.

The COVID-19 Prevention Primer course[6] titled "What do I need to know about the 2019 novel coronavirus?" focused on explaining and clarifying basic information about COVID-19. It introduced and explained the viral cause of COVID-19 and the lifestyle and environmental changes that are recommended to keep people healthy and safe from infection. The content addressed what people could expect during the outbreak and what they might do if a family member were to get sick. The course used a detailed cartoon-like visual style and pictorial/representation visuals (Haragi et al., 2019) to illustrate preventative behaviors and processes people could adopt such as handwashing and social distancing (**Figure 1**). The course was illustrated by science artist Elfy Chiang.

The COVID-19 Mechanism course[7] titled "What does the coronavirus do in my body?" covered how the virus SARS-CoV-2

infects cells, infection mechanisms at the cellular level, how the body fights back, why some people are at risk for more severe illness and when they should seek care. This course followed a character from the Primer course but focused on providing a basic understanding of how viruses cause symptoms, how people recover from infection, and why there are differences in disease severity. This course used more interpretational (Haragi et al., 2019), metaphor-communicating visuals in a hand-drawn but digitized watercolor style to enhance understanding of the technical information about virology and the immune response (**Figure 2**). The course was illustrated by science artist Elfy Chiang.

We assessed whether the courses were health literate based on validated external tools including the SMOG (McLaughlin, 1969) online calculator, a tool for assessing reading level, and the PEMAT for printable materials (Shoemaker et al., 2014)[8].

The SMOG index was 9.2 for the Primer course and 9.3 for the Mechanism course, meaning they were both at a sixth grade reading level and "easy to read".

We evaluated PEMAT understandability and actionability scores for our COVID-19 courses, and we also had an independent reviewer submit scores—the independently derived scores matched our own. We evaluated the Primer course to have a 95% Understandability Score (14 out of 15 points[9]) and an 80% Actionability Score (4 out of 5 points[10]). We deducted one point for not providing a "tangible tool" for taking

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[5]https://app.us.lifeology.io/viewer/lifeology/default/why-do-we-sleep
[6]https://app.us.lifeology.io/viewer/lifeology/default/2019-novel-coronavirus
[7]https://app.us.lifeology.io/viewer/lifeology/default/what-does-the-coronavirus-do-in-my-body

[8]https://www.ahrq.gov/health-literacy/patient-education/pemat-p.html
[9]N/A scores given to items on headers and narration
[10]N/A scores given to calculations and charts

FIGURE 2 | Above we've reproduced three of the "cards" contained within the COVID-19 Mechanism course, as they would be seen on a mobile device. The first is the title card of the course, while the others are example cards to demonstrate the visual style, informational content, and amount of text.
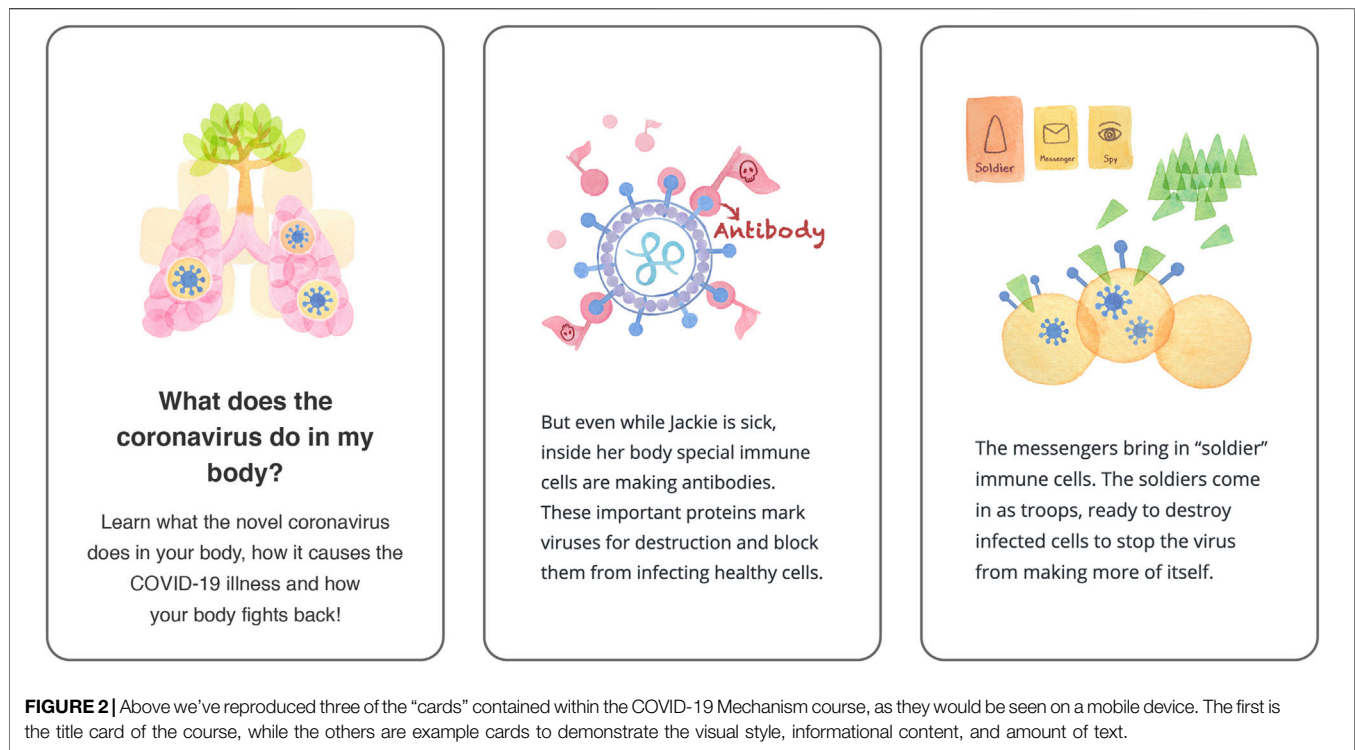
action, although we linked to WHO and CDC guidance and resources on home care and prevention for COVID-19. We evaluated the Mechanism course to have an 87% Understandability Score (13 out of 15 points) and a 60% Actionability Score (3 out of 5 points). We took a point away on Understandability for the Mechanism course for some technical terms like cytokines and antibodies, even though we defined them. We also took a point away on Actionability for "steps to action"—this course was more focused on informing people about COVID-19 risk factors.

Variables and Scales
Following News About COVID-19
We measured (pre-stimulus) how closely participants were following news about COVID-19 on traditional news media outlets in print, on TV, or online, on a 5-point scale from *not at all closely* to *very closely*.

Perceived Knowledge About COVID-19
We Asked Participants "*How informed would you say you are about COVID-19?*", measured (pre-stimulus) on a 5-point scale from *not at all* to *very*.

Understanding and Learning
We measured perceived learning or the degree to which people found courses informative ("*I learned a lot*"), and understanding ("*It was easy for me to understand the information*"), as single items on 5-point scales, based on level of agreement. We also explored how relatable the course was to people ("*The mini-course was created with people like me in mind*") as a single item on a 5-point scale.

We assessed basic COVID-19 knowledge with a 4-item quiz (Sum of items, mean score = 3.87, SD = 0.38). Its usefulness was limited by a low Chronbach's alpha of 0.21. Although Chronbach's alpha is not always a useful characteristic of knowledge instruments (Taber, 2018), we've only used the sum of knowledge items related to information presented across the two COVID-19 courses as an informal check and context for our self-reported learning measure.

The quiz consisted of true/false statements for the following: *Scientists are working on developing potential vaccines for COVID-19* (true); *Coronaviruses are found only in humans* (false); *Some people with COVID-19 have no symptoms* (true); *When practicing social distancing, 3 feet is the recommended distance* (false).

Attention and Absorption
We measured self-reported attention to the visuals and absorption in the content of the course based on items taken from Agarwal Karahanna (2000) and Oh et al. (2015). Participants were asked to indicate their level of agreement on a 5-point scale (*strongly disagree* to *strongly agree*) to statements "*I paid close attention to the graphics and visuals in the mini-course*" and "*The mini-course held my attention all the way through to the end*". These two variables are moderately correlated (Correlation = 0.48, $p < 0.001$) and used separately.

Perceived Threat
We evaluated COVID-19 risk perceptions as a 4-item scale (Chronbach's alpha = 0.67) based on level of agreement on a 5-point scale to statements reflecting participants' belief that they could get COVID-19, that they could get very sick, and that COVID-19 is serious; personal feelings of risk because of

COVID-19; belief that COVID-19 is serious. This measure and items represent threat in the EPPM and were taken from Witte et al. (1996) and Popova (2012).

Self-Efficacy

We evaluated self-efficacy for COVID-19 prevention and care as a 3-item scale (Cronbach's Alpha = 0.68) based on level of agreement on a 5-point scale to the following statements: "*I feel confident in my ability to protect myself from getting COVID-19*", "*I know how to protect myself from getting COVID-19*", "*I know what to do if I get COVID-19 and when to seek emergency care if necessary*". This measure incorporates both knowledge about COVID prevention and self-care and belief about one's ability to act on that knowledge. This measure represents self-efficacy in the EPPM.

Behavioral Intentions

We evaluated behavioral intentions as an 8-item scale (Chronbach's Alpha = 0.87). We measured participants' likelihood to engage in the following behaviors during the COVID-19 pandemic, on a 5-point scale from *extremely unlikely* to *extremely likely*: Stay 6 feet from others in public spaces, wash hands often, limit visits to public places or crowds, wear a face mask/covering in public, avoid visits with people I don't live with, follow government recommendations, stay at home as much as possible. All behavioral items were derived from official public health recommendations published by the CDC and other official sources.

Demographics

We measured demographic and other personal information including age, gender, formal education level, location (state), and existence of a stay-at-home order in the participant's state. Participants represented all 50 states and DC.

Data Collection, Cleaning, and Analysis

We collected data *via* a Qualtrics online questionnaire, which linked participants out to the courses in a new window that automatically closed upon course completion. Participants were recruited from two mobile health tracking apps—the LIFE Fasting Tracker (185k users received a study email) and the LIFE Extend mobile health applications (4,616 received a study email). To avoid recruiting too many participants, we recruited only participants that had 1) used the app at least one time within the previous 30 days, 2) a valid email address linked to their mobile application account, and 3) country of residence was the United States. An invitation to participate was sent to the eligible participant pool using an industry-standard mobile application data and analytics platform (MixPanel). The email outlined the study with a button/link to participate, the estimated time to complete, and a random reward for completion. All participants who clicked to participate received a follow-up "thank you" email and reminder to complete the questionnaire.

By May 22, 2020 (first email sent on May 8), 1,890 users completed and submitted the questionnaire, while 1,670 users had responses in progress. The completion rate was 53%. Based on emails opened (*n* = 37,581), the response rate for partial completions was 9.5% (1.8% based on total emails sent), while the rate of study invite emails open to completion was 5% (0.97% based on total emails sent).

We processed and analyzed all anonymous survey responses in SPSS. For data analysis, we only included partial responses where respondents completed more than half of the questionnaire and answered at least some of the post-stimulus dependent variables (starting with risk perceptions) (*n* = 65). We also removed responses (*n* = 115) where participants didn't correctly answer an attention filter question correctly or incorrectly answered what the course was about (responded "flu" as opposed to sleep or the novel coronavirus). We ended up with a total of 1,775 responses. The minimum time for questionnaire completion among these was 4.5 min.

To explore our research questions, we used ANOVA or ANCOVA tests to evaluate the impact of stimulus condition (categorical variable) as well as covariates that were not substantially correlated (typically age, gender and level of education) on interval data dependent variables. We assumed linearity, and normal distribution on dependent variables which we confirmed with histogram plots (understanding and behavioral intentions were most left skewed). We used conservative Bonferroni post hoc tests to adjust for multiple pairwise comparisons between stimulus conditions. Because Levene's test was sometimes significant in our ANOVA tests, we report the Welch F statistic (does not assume equal variances) for these tests.

White test for heteroskedasticity was positive in univariate tests predicting learning, absorption, and quiz scores. However, parameter estimates with robust standard errors (HC3 method) revealed no differences in significant results or differences between standard errors and robust standard errors (Hayes and Cai, 2007). Therefore, we report the standard statistics for ANOVA, ANCOVA and linear regression tests below. For ANCOVA tests, we report effect size as R^2.

We used linear regression to test our hypotheses with continuous interval outcome variables. In these regression tests, residuals for outcome variables (self-efficacy, threat, behavioral intentions) were normally distributed.

RESULTS

Demographics and Descriptives

Our final data analysis included 1,775 participants: 637 participants (36%) saw the control course about sleep, 546 (31%) saw the COVID-19 Prevention Primer course, and 592 (33%) saw the COVID-19 Mechanism course. Randomization was successful - there were no significant differences in participant age, education level, stay at home order status, self-reported previous knowledge about COVID-19, or attention to COVID-19 in the news across stimulus conditions.

Participants' age range was 18 to 90 years (Mean = 44.0, SD = 11.7). A majority of participants were female (80%, *n* = 1,423), reflecting the demographics of LIFE Apps users; 67% (*n* = 1,195) identified as White, 9% (*n* = 153) identified as Hispanic/Latino, 8% (*n* = 135) as Black; 4% (*n* = 68) as Asian. Participants were

highly educated with 30% (*n* = 528) having a graduate degree, 33% (*n* = 587) having a Bachelor's/4-year degree, 27% having some college education (*n* = 487) and only 6% (*n* = 108) having a high school GED or less. These demographics reflected the self-reported data we had for all LIFE Apps users, suggesting our survey respondents were representative of the eligible study population.

A majority of the participants (81%, *n* = 1,442) indicated that their state was under a stay at home order at the time of study participation. On 5-point scales, most participants reported feeling quite or very informed about COVID-19 (M = 3.99, SD = 0.91), and that they were following news about COVID-19 on traditional news outlets quite or very closely (M = 3.44, SD = 1.12).

Looking only at participants randomized to the control group (*n* = 637) as a baseline (these individuals had no exposure to COVID-19 information within this study), participants generally expressed moderate to high self-efficacy (M = 4.16, SD = 0.63), high behavioral intentions toward COVID-19 (M = 4.41, SD = 0.722), and moderate perceived threat (M = 3.67, SD = 0.81). According to their self-reports, a majority (> 70%) of participants said they were extremely likely to wash their hands often and practice social distancing. Fewer, but still many, were extremely likely to wear a face mask in public (68%) avoid visiting people they don't live with (46%), clean and disinfect frequently touched surfaces (49%), or follow government recommendations such as stay-at-home orders (59%). (For all but handwashing, the "extremely likely" intentions for these behaviors went up four to five percentage points among participants who saw a COVID-19 course.) While most participants (53%) somewhat agreed that they feel confident in their ability to protect themselves from COVID-19, only 23% strongly agreed; 38% strongly agreed that they know how to protect themselves. (These percentages increased *substantially* in the Primer course group, where 29% strongly agreed they feel confident in their ability to protect themselves and 53% strongly agreed they know how to protect themselves.) While most participants in the control group strongly agreed that COVID-19 is serious (60%), only 11% strongly agreed and 35% somewhat agreed that they personally feel at risk because of COVID-19.

Content Experiences—Course Understanding, Learning, and Absorption

To address RQ1, we looked at participants' experiences with the "flashcard" course content. We specifically looked at self-reported understanding of, learning from, and absorption in the courses. Participants generally reported that all the courses were very easy to understand (M = 4.59, SD = 0.67). See Mean results per course in **Table 1**. In an ANCOVA, course condition, age, gender, and level of education had no significant impacts on course understanding.

Participants who saw the control or Mechanism courses indicated learning ("*I learned a lot*") significantly more (Bonferroni post hoc test *p* < 0.001) than those who saw the Primer course (ANOVA, Welch F(2, 1,154.04) = 83.11, *p* < 0.001). See Mean results per course in **Table 1**. The Primer course was designed and written for broad audiences to learn the basics of COVID-19; it contained information that many participants observed in open-ended post-course reflections

TABLE 1 | Mean values of courses for Understanding, Learning, and Absorption.

Variable	Mean (Range: 1–5)	Standard deviation
Understanding		
Control/Primer/Mechanism	4.68[a]/4.69[a]/4.59[a]	0.62/0.68/0.69
Learning		
Control/Primer/Mechanism	3.59[a]/2.80[b]/3.60[a]	1.0/1.2/1.3
Absorption		
Control/Primer/Mechanism	3.97[a]/3.57[b]/3.87[a]	1.1/1.2/1.2
Attention to Visuals		
Control/Primer/Mechanism	3.50[a]/3.58[a]/3.92[b]	1.1/1.1/1.0

Notes: Superscripts designate statistically different means (p < 0.001), with Bonferroni adjustment for multiple comparisons.

that they were already aware of through information sources such as the CDC. The Mechanism course was also written for broad audiences but covered more technical information related to COVID-19 and how it works in the body. However, participants with lower levels of education indicated learning more from both of the COVID-19 courses (ANCOVA for COVID-19 conditions only with covariates age, education and gender; R^2 (effect size) = 0.14; Stimulus F(1, 1,083) = 137.18, *p* < 0.001; Education covariate F(1, 1,083) = 28.59, *p* < 0.001).

Although we focused on evaluating self-reported content experiences for RQ1, we did conduct a basic 4-item quiz of basic COVID-19 information following stimulus exposure. The quiz scores were generally very high, with over 90% of participants across all conditions answering correctly for each question. However, participants who viewed the Primer course scored slightly but significantly higher (M = 3.92, SD = 0.31; Bonferonni post hoc test *p* < 0.05) than did those who viewed the control (M = 2.84, SD = 0.44) or Mechanism (M = 3.87, SD = 0.38) courses (ANCOVA across all conditions with covariates age, education and gender; R^2 (effect size) = 0.02; Stimulus F(2, 1,680) = 6.6; *p* < 01). This result was largely driven by scores for the question of whether coronaviruses are only found in humans or not (significant differences were found across stimulus conditions for this question alone, which was covered in the Primer course), as well as the question about COVID-19 symptoms. Higher education also predicted higher quiz scores (Education covariate F(1, 1,680) = 24.80, *p* < 0.001).

Participants indicated significantly (Bonferroni post hoc test *p* < 0.001) greater absorption in the control and Mechanism courses compared to the Primer course (ANOVA, Welch F (2, 1,154.25) = 17.72, *p* < 0.001). See Mean results per course in **Table 1**. Absorption in the course and perceived learning are significantly and moderately correlated (Pearson Correlation = 0.58, *p* < 0.001).

We also explored whether participants found the course they viewed to be relatable ("*The mini-course was created with people like me in mind.*") (M = 3.53, SD = 1.21). Most people agreed (55%) or neither agreed nor disagreed (26%) that the course was created with people like them in mind. The Mechanism course was evaluated as more relatable (M = 3.73, SD = 1.17), significantly more so (Bonferroni host hoc test *p* < 0.001) than the Primer course (M = 3.26, SD = 1.30; ANOVA across all stimulus conditions, Welch F (2, 1,156.51) = 21.40, *p* < 0.001). However, as with perceived learning, lower levels of education were associated with greater evaluation of relatability (ANCOVA across all conditions with covariates age,

education and gender; R^2 (effect size) = 0.06; Education covariate F (1, 1,680) = 28.96, $p < 0.001$). Perceived relatability was significantly and strongly correlated with perceived learning (Pearson Correlation = 0.65, $p < 0.001$) and absorption (Pearson Correlation = 0.50, $p < 0.001$). It was weakly but negatively correlated with level of education (Pearson Correlation = −0.12, $p < 0.001$). The strongest correlation between relatability and level of education existed for those viewing the Primer course, suggesting that this course was particularly well suited to meet the informational needs of people with lower levels of education.

Based on these findings, the illustrated flashcard course format appears to make information about COVID-19 easy to understand for people with high and low levels of education alike. Individuals with lower levels of education indicated learning more from the course they viewed and perceiving it to be created with people like them in mind to a greater extent.

We relied on self-reported data of learning and absorption in the content, which limits robustness of the results. However, data on the time participants spent on the page that linked out to the Lifeology course can provide some context. Participants spent, on average, 3.3 min on the page linking to the sleep course (36 cards), 4 min on the page linking to the Primer course (49 cards), and 4.3 min on the page linking to the Mechanism course (47 cards). A minority (less than 1 out of 5) of participants spent less than a minute, and few spent more than 13 min. Based on previous user testing, a 30-card Lifeology courses takes around 4–6 min for a reader to read aloud. Most participants who completed the survey were engaged enough to spend a few minutes on the content, but didn't spend so much time that distracted reading (e.g., browsing off) was likely. Time spent was weakly but positively correlated with absorption (Pearson Correlation = 0.10, $p < 0.001$).

Attention to Visuals

Participants indicated paying significantly closer attention (Bonferroni post hoc test $p < 0.001$) to the visuals in the Mechanism course compared to the control or Primer courses (ANOVA, Welch F (2, 1,168.41) = 27.89, $p < 0.001$).

We were also interested in exploring predictors of attention to visuals (RQ2), so we ran a linear regression test predicting this variable with stimulus condition dummy variables, demographic variables, previous knowledge, and following of COVID-19 news (R^2 (effect size) = 0.06; F (8, 1,677) = 13.53, $p < 0.001$). See results in **Table 2**. People who viewed the Mechanism course, people with lower education levels, and people following COVID-19 news closely on traditional media paid closer attention to the course visuals.

Attention to visuals is significantly correlated with absorption in the course content (Pearson Correlation = 0.48, $p < 0.001$), perceived learning (Pearson Correlation = 0.38, $p < 0.001$) and relatability (Pearson Correlation = 0.35, $p < 0.001$).

Means of Self-Efficacy, Perceived Threat and Behavioral Intentions Across Course Conditions

We conducted a series of simple ANOVA tests with Bonferonni post hoc tests for multiple comparisons, followed by a serial mediation

TABLE 2 | Results of linear regression analysis predicting attention to visuals.

Model	Attention to visuals	
	β	99% CI of B
Constant	—	(−0.16, 2.35)
Primer Course	0.03	(−0.09, 0.24)
Mechanism Course	0.19***	(0.264, 0.583)
Stay at home order	0.01	(−0.15, 0.19)
Perceived knowledge about COVID	0.003	(−0.09, 0.10)
Following news about COVID	0.15***	(0.08, 0.21)
Age	−0.06	(−0.01, 0.00)
Education (degree)	−0.10***	(−0.18, −0.03)
Gender (1 = female)	−0.02	(−0.22, 0.14)
F total	13.53***	—
R^2	0.06	—

*Notes: β = standardized coefficient. B = unstandardized regression coefficient. CI = confidence interval. **p < 0.01, ***p < 0.001.*

analysis, to explore RQ3 and RQ4, and to test our hypotheses H1, H2, and H3. We hypothesized that people who view an illustrated flashcard course about COVID-19 will have increased self-efficacy and behavioral intentions than people who view a control course, and that self-efficacy and perceived threat will mediate course impacts on behavioral intentions. As a reminder, the self-efficacy measure was based on participants self-reported feelings of confidence in their ability to protect themselves from COVID-19, knowledge of how to do so, knowledge of what to do if they got COVID-19 and knowledge of when to seek emergency care. Perceived threat was based on participants' belief that they could get COVID-19, that they could get very sick, and that COVID-19 is serious; personal feelings of risk because of COVID-19; belief that COVID-19 is serious.

Participants who saw the Primer course (M = 4.35, SD = 0.56) had significantly ($p < 0.001$) higher self-efficacy for personal COVID-19 prevention and care than did participants who saw either the Mechanism course (M = 4.21, SD = 0.63) or the control course (M = 4.14, SD = 0.63). The means were significantly different overall: Welch F(2, 1,177.80) = 15.62, $p < 0.001$.

Perceived threat was slightly lower for the Primer course (M = 3.57, SD = 0.79) than for the Mechanism course (M = 3.68, SD = 0.78) or the control course (M = 3.67, SD = 0.81). But the means were not significantly different overall.

Participants who saw the Primer course reported slightly greater behavioral intentions (M = 4.51, SD = 0.64), followed by those who saw the Mechanism course (M = 4.47, SD = 0.69) and those who saw the control course (M = 4.41, SD = 0.72). But the means were not significantly different overall.

Course Impacts on Behavioral Intentions
Analytical Approach
We used the PROCESS macro add-on (Hayes and Cai, 2007) to conduct a serial mediation analysis[11] to test whether and how course viewing was causally linked (Hayes, 2012) to COVID-19 preventive behavioral intentions, both directly and indirectly through attention to visuals, self-efficacy, and perceived threat.

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[11]The sample size for the PROCESS analysis was 1765, the custom seed was 20200617

TABLE 3 | The serial mediation model of the effects of course types on preventive behavioral intentions via attention to visuals, self-efficacy, and perceived threat.

	Mediator = Attention to visuals		Mediator = Self-efficacy		Mediator = Perceived threat		Outcome = Behavioral intentions	
—	B (SE)	p	B (SE)	p	B (SE)	p	B (SE)	p
Constant	3.498 (0.043)	<0.001	4.031 (0.053)	<0.001	3.406 (0.069)	<0.001	2.355 (0.132)	<0.001
Primer	0.081 (0.063)	0.198	0.184 (0.036)	<0.001	−0.114 (0.046)	0.014	0.126 (0.035)	<0.010
Mechanism	0.424 (0.062)	<0.001	0.039 (0.036)	0.278	−0.029 (0.046)	0.526	0.026 (0.035)	0.459
Attention to visuals	—	—	0.037 (0.014)	<0.001	0.078 (0.017)	<0.001	0.064 (0.013)	<0.001
Self-efficacy	—	—	—	—	—	—	0.063 (0.024)	<0.010
Perceived threat	—	—	—	—	—	—	0.427 (0.018)	<0.001
—	$R^2 = 0.029$, $F(2, 1753) = 26.390$, $p < 0.001$		$R^2 = 0.020$, $F(3, 1752) = 11.872$, $p < 0.001$		$R^2 = 0.015$, $F(3, 1752) = 9.103$, $p < 0.001$		$R^2 = 0.256$, $F(5, 1750) = 120.201$, $p < 0.001$	

Note: B = unstandardized regression coefficient. Bootstrap resamples = 5,000. The level of confidence is 99%.

Preventive behavioral intentions was the primary outcome variable, course condition was the primary predictor entered as a multi-categorical variable[12], and self-efficacy and perceived threat were entered as serial mediators. We also included attention to course visuals as a mediator between course viewing and all other outcomes. Given the large sample size used in the present study, we opted for a more stringent level of significance ($\alpha = 0.01$). The results are presented in **Table 3**.

Attention to Visuals
Attention to visuals was a significant predictor ($p < 0.01$) in a series of regression tests predicting all other mediators and outcomes—self-efficacy (B = 0.037, SE = 0.014), perceived threat (B = 0.078, SE = 0.017) and behavioral intentions (B = 0.064, SE = 0.013). (Effect sizes are generally small; R^2 between 0.5% and 2%.) As we noted previously, people paid significantly closer attention to visuals embedded in the Mechanism course (B = 0.424, SE = 0.061, $p < 0.001$) compared to the control course (Model R = 0.17, F(2, 1753) = 26.39, $p < 0.001$). This addresses RQ3 and shows that greater attention to visuals in COVID-19 visual narratives predicts improved outcomes. See arrows connecting attention to visuals and outcomes in **Figure 3**.

Self-Efficacy
We hypothesized in H1 that people who saw a course about COVID-19 would have a greater sense of self-efficacy. Course viewing did have a significant relative direct effect on self-efficacy. Specifically, people who saw the Primer (B = 0.184, SE = 0.036, $p < 0.001$) as compared to a control course about sleep had improved self-efficacy in terms of protecting themselves from COVID-19. We controlled for attention to visuals (Model R = 0.141, F(3, 1752) = 11.87, $p < 0.001$). Attention to visuals was also a significant predictor in this regression model (B = 0.036, SE = 0.0136, $p < 0.01$). We found partial support for H1, based on the relative impacts of a COVID-19 Prevention Primer course. See arrows connecting the course stimulus condition to self-efficacy in **Figure 3**.

Perceived Threat
Course viewing did not have a significant relative direct effect on perceived threat. However, attention to the course visuals was a significant predictor (Model R = 0.124, F(3, 1752) = 9.10, $p < 0.001$; B = 0.078, SE = 0.017, $p < 0.001$).

Behavioral Intentions
As hypothesized in H2, people who saw a COVID-19 course as compared to a control course about sleep had greater behavioral intentions toward COVID-19. There was a significant relative direct effect of Primer course viewing on behavioral intentions, controlling for attention to visuals, self-efficacy, and perceived threat (Model R = 0.51, R^2 (effect size) = 0.26, F(5, 1750) = 120.20, $p < 0.001$). See the large arrow directly connecting course condition to behavioral intentions in **Figure 3**. People who viewed the Primer course had greater behavioral intentions toward protecting themselves from COVID-19 compared to those who viewed a control course (B = 0.126, SE = 0.035, $p < 0.001$, 99% bootstrap confidence interval: 0.035, 0.217). Attention to visuals (B = 0.064, $p < 0.001$), self-efficacy (B = 0.063, $p < 0.01$) and perceived threat (B = 0.427, $p < 0.001$) were all significant predictors in this regression model. We found partial support for H2, based on the relative impacts of a COVID-19 Prevention Primer course.

There was a significant indirect effect from Primer course → self-efficacy → behavioral intentions (B = 0.011, SE = 0.005, 99% bootstrap confidence interval: 0.000, 0.027). The bootstrap confidence intervals were based on 5,000 bootstrap samples.

There was a significant indirect effect from Mechanism course → attention to visuals → behavioral intentions (B = 0.027, SE = 0.007, 99% bootstrap confidence interval: 0.011, 0.047). The indirect effect from Mechanism course → attention to visuals → perceived threat → behaviors was also significant (B = 0.014, SE = 0.004, 99% bootstrap confidence interval: 0.005, 0.026).

As hypothesized in H3, both self-efficacy and perceived threat mediated the impact of course viewing on behavioral intentions. Self-efficacy was a key mediator of the impact of viewing a COVID-19 Prevention Primer course on behavioral intentions, while perceived threat was a key mediator of the impact of viewing a COVID-19 Mechanism course on behavioral intentions.

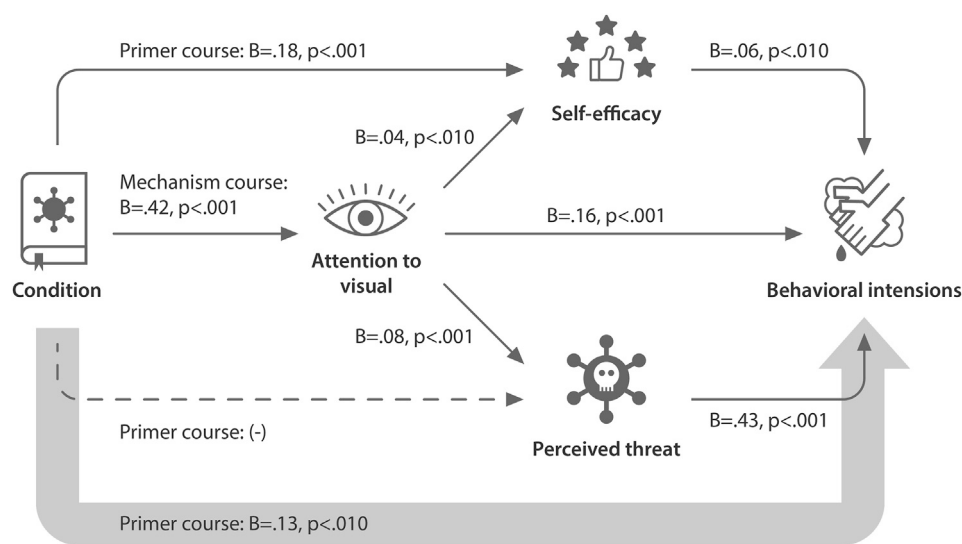[12]Entered as dummy variables relative to the control group

FIGURE 3 | Path diagram illustrating the relative direct and indirect effects of illustrated flashcard course viewing on behavioral intentions toward COVID-19. This path diagram visually represents a serial mediation model of the effects of viewing three different courses on behavioral intentions via attention to the course visuals, self-efficacy, and perceived threat. Solid thin arrows represent significant links between variables ($p < 0.01$), dashed thin arrows represent marginally significant links ($p < 0.05$). B, unstandardized coefficients showing relationship between variables. The larger arrow connecting condition directly to behavioral intentions denotes the path from predictor to outcome controlling for all mediators. See **Table 3** for full results of the regression analyses that this path diagram represents.

DISCUSSION

Visual narratives are a useful tool for engaging broad audiences in risk messages and public health precautions for COVID-19. We found that illustrated flashcard courses (visual narratives) about COVID-19 were perceived as understandable and engaging for a relatively broad audience, regardless of level of education. The effect sizes for these relationships were typically small but robust, where stimulus condition and other key independent variables often explained 1–6% of the variance in outcome metrics.

We also found that viewing an illustrated flashcard course about COVID-19 resulted in improved perceptions of self-efficacy and behavioral intentions. The stimulus condition, attention to the visuals, self-efficacy and perceived threat explained a substantial amount of the variance in behavioral intentions (over 25%). Visual narratives may improve health literacy, or capacity to understand *and* act on health information.

Interestingly, the COVID-19 Primer course impacted self-efficacy and behavioral intentions even though, on average, people indicated not necessarily learning anything *new* from the content. Participants viewing our COVID-19 courses had most likely come across similar information in other formats based on their existing knowledge of COVID-19, but these formats may not have made the information as accessible and relatable to their daily lives. Our results also suggest that visual narratives may improve health outcomes and disease prevention.

While both of the courses about COVID-19 had positive outcomes compared to a control course, they impacted self-efficacy and perceived threat to different extents. The Prevention Primer course was particularly effective in improving self-efficacy and behavioral intentions directly. This course visually told a story of a family's journey through a

COVID-19 outbreak in their city and their experience when a younger family member got sick. The course visuals showed characters expressing concern but ultimately modeling preventative behaviors such as handwashing for at least 20 s, social distancing, and safely caring for a sick family member. It also provided actionable takeaways. All of these features likely contributed to the course's impact on self-reported self-efficacy and behavioral intentions. On the other hand, the impact of the COVID-19 Mechanism course on behavioral intentions was primarily mediated by greater self-reported attention to the course visuals and perceived threat from COVID-19. This course explained how the coronavirus works in the body and why some people are at greater risk of severe illness, again with actionable takeaways.

Across both COVID-19 courses, greater self-reported attention to the visuals mediated the impacts of course viewing on self-efficacy, perceived threat, and behavioral intentions. We also found support for the idea that people with lower levels of formal education rely to a greater extent on visuals in these educational materials. This seems to be particularly true when the materials contain more technical science and health information. The more technical Mechanism course received slightly lower ease of understanding scores than the Primer and control courses. Participants who saw this course also reported paying significantly greater attention to the course visuals than did participants who saw the Primer course or the control course. Greater self-reported attention to the visuals in the Mechanism course in turn mediated a significant impact on perceived threat, and thus protective behavioral intentions.

Other factors beyond the level of technical content in the Mechanism course could also have contributed to the self-

reported attention to the visuals in this course. The course contained more interpretational visuals, defined as representing information associated with as opposed to directly representing the textual referents (Haragi et al., 2019). These types of visuals have previously been found to invite interpretation and elaboration of content, and to improve self-reported understanding, memorability, and interest (Haragi et al., 2019). However, future research is needed to explore whether it was the greater level of difficulty of this course that truly drove greater attention to visuals, or some other aspect of the visuals in this course.

Implications

This study fills a gap in literature looking at the real-world, holistic impact of health education materials that combine text, narrative, and visuals. The lack of research in this area may stem from the lack of health education materials that make effective, data-driven use of stories and visuals. But why are these materials missing from the media landscape? One of the reasons may be a dearth of collaboration between scientific and art communities. There are a growing number but still few resources and spaces that make it easy for scientists, artists, and communication experts to work together on such materials. However, calls for collaboration between scientists and creatives are increasing (Khoury et al., 2019; Botsis et al., 2020; Murchie and Diomede, 2020). Art-science platforms including Art The Science, Lifeology, the SciArt Initiative, and others are facilitating this collaboration through nascent online spaces that bring people from STEM and art fields together.

It is difficult today to assess visual quality or exactly how "good" illustrations improve information processing (McGrath and Brown, 2005). Different people have different tastes in the aesthetics of artwork that may stem from their cultural or social background. For this reason, it is important that the public have diverse options in terms of illustrated educational content available to them, created by diverse artists in diverse styles and cultural contexts.

Limitations

Participants in this study represented U.S. users of popular health tracking apps (the LIFE Apps). These apps have a broad user base with over 2.5 million users. Users of these apps are likely to be motivated to improve their health and adopt positive health behaviors; however, many join the app because they are struggling to achieve their health and weight loss goals. Most of the participants were highly educated. This does not necessarily mean that they had high health literacy levels, as even highly educated people can struggle to understand and apply technical health information. However, the results of our study are limited by this sample and the fact that we did not directly assess the health literacy level of our participants. While we did confirm that our courses were broadly understandable and had positive outcomes for a subset of our participants who had less than a high school education, outcomes could be different for people facing more substantial language, reading level, and internet access barriers.

Creators of visual narrative educational materials for science and health communication should always design their messages and content with target audiences in mind and evaluate their materials early among those target audiences. Future studies could target evaluation of visual narratives and illustrated flashcard courses in different languages within low-literacy populations, non-English-speaking populations, rural populations, racial and ethnic minorities, etc.

This study is also limited by not comparing the flashcard courses to the same messages presented in non-visual and/or non-narrative formats. We don't know how much the narrative elements of the courses (story, characters, emotions, etc.) distinctly contributed to the outcomes, separately from the visual elements and factual information presented. However, this would have been difficult to test in practice, as both the visuals and the text of the courses contained narrative as well as informational elements.

Another important limitation of this study is self-reported data. To measure learning outcomes, we would have needed to assess knowledge before and after viewing the courses (Jensen, 2014). However, we note that the COVID-19 courses had positive outcomes even though participants generally reported being quite informed beforehand. Self-reported behavioral intentions also do not fully predict behaviors (Sheeran and Webb, 2016). However, the self-reported data can still tell us a lot about people's experiences of the content and how prepared and motivated it helped them feel to protect themselves and others from COVID-19. Measures of enjoyment and absorption in content often rely on self-reports related to how much people enjoyed the content, whether it held their attention or if they were distracted by other things while viewing the content. However, real-world measured data for these variables would provide greater insight.

There was the possibility of bias in people's responses to experiences of the content. To try to prevent this, we assured survey respondents that their responses were anonymous, and we asked for honest evaluation to help us create better content for others. None of the content was branded by LifeOmic or LIFE Apps to avoid eliciting any identity with or loyalty to the LIFE Apps brand. LIFE Apps users also do not pay to use their apps and are often invited to join various other health research projects where strict privacy and HIPAA regulations apply. The risk that they joined this study because of any social pressure or experienced pressure to "like" the educational content displayed is no more likely than in other survey experiments, in our opinion.

Finally, we also acknowledge that we did not fully test or directly manipulate all factors of the EPPM in this study, particularly fear. We leveraged materials that had already been created and designed survey questions around the messages contained in these materials, with a focus on practical takeaways. While this approach has its strengths in terms of evaluating new educational resources at a high level in a real-world setting, it is limited when it comes to pinpointing effect mechanisms.

TAKEAWAYS AND RECOMMENDATIONS

New visual narrative formats have the potential to substantially improve engagement on issues of pressing public health concern. These formats are also ripe for future research.

In the process of conducting this study, starting with the collaborative creation the "flashcard" courses evaluated herein, we learned a lot about how to create effective visual educational materials science and health. We've curated some of what we learned into actionable tips below. (We are also leveraging lessons learned into a series of Lifeology SciComm "flashcard" courses[13] that help scientists and communicators learn evidence-based science and health communication practices.) This advice is based on our own process for and experiences in creating the materials evaluated in this study. It is based on factors that we think may have contributed to the impact of our materials. Future research should pin-point the role of these different strategies in making health education materials more effective.

1) Use plain language and non-clinical, narrative illustrations to improve understanding and relatability of science and health messages.
2) Assemble interdisciplinary teams in the creation of visual narrative materials. Collaborate with local professional artists and storytellers.
3) Use visuals that complement text. Avoid decorative visuals or ones that are either exact visual representations or conversely are unrelated to the text. Visuals might communicate helpful metaphors or help the viewer interpret or create accurate mental models of abstract concepts or hidden processes.
4) Include empowering stories of characters who face struggles, express relatable emotions, and achieve ultimately positive outcomes or a change in perspective through desired behaviors. Be compassionate when visualizing characters.
5) Be inclusive and illustrate a diversity of characters to engage a diverse audience.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Alex Cohen, Louisiana State University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomm.2021.712658/full#supplementary-material

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A Systematic Map of Inclusion, Equity and Diversity in Science Communication Research: Do We Practice what We Preach?

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Effective engagement with diverse stakeholders, combating misinformation and encouraging wider participation in science is core to science communication practice, and comprises much of the current focus of research in the discipline. Global events, such as the COVID-19 pandemic, have clearly shown that social inequalities also manifest within communication structures, including those of science communication. Practices which are inclusive of diverse audiences are key if we wish to engage diverse audiences in finding solutions to societal issues. Yet there is little available evidence to show which diverse, marginalised and/or excluded groups are being engaged within science communication, and *via* what means. This paper develops a systematic map of academic literature spanning 40 years to provide a preliminary evidence base of how diversity and inclusion within science communication research and practice is conceived and implemented. Although the discipline has shown an increased focus within the last 5 years, science communication must evolve further in order to develop a robust evidence base for understanding what constitutes inclusive science communication in both theory and practice.

Keywords: audience, diversity, engagement, equity, inclusion, intersectionality, science communication

INTRODUCTION

Modern science communication has a number of roles in society (Fischhoff and Scheufele, 2013; Davies, 2021), including – but not limited to – effectively engaging with diverse stakeholders (Weingart and Joubert, 2019), combating misinformation (Goldstein et al., 2020), and encouraging wider participation in STEM (Bevan et al., 2020). Since the emergence of COVID-19, "engaging with diverse stakeholders" and "combating misinformation" have been ever-prevalent roles. COVID produced an unprecedented demand for information, creating what the World Health Organisation termed an "infodemic"; "an over-abundance of information – some accurate and some not – that makes it hard for people to find trustworthy sources and reliable guidance" (World Health Organisation, 2020, p. 2). However, there were clear examples of how even "trustworthy" and "reliable" sources were not serving the needs of all community members. Park et al. (2020) found that over half of surveyed Australians had encountered COVID-19 misinformation at least "some of the time" – a figure likely underestimated as audiences need to recognise it as misinformation in the first place (Nurse et al., 2021). These unmet information needs were a major contributing factor to some of the detrimental outcomes for marginalised groups in Australia. The national multicultural broadcast network, SBS, reported that members of their audience were more likely to adopt

ineffective prevention, perhaps based on the belief they could ignore public health advice (Mara, 2020). The broadcaster argued that this could have been addressed by providing better, more appropriate, culturally targeted information (Mara, 2020). Minority groups are more likely to have difficulty accessing and understanding health information which can lead to gaps in communication (Blumenshine et al., 2008) and – at least in the case of COVID-19 – consequently a greater risk of infection and transmission (Tai et al., 2021) The challenges of the COVID-19 pandemic showed, in stark relief, the inequalities inherent within our societal and corresponding communication structures (O'Sullivan et al., 2020). Science communication also operates within these structures, and can reinforce some of these same inequities.

Science communication practitioners themselves note that the field tends to use a "Western, white, ableist and patriarchal" approach (Canfield and Menezes 2020, p 13), a description somewhat supported by a review of the existing science communication research by Guenther and Joubert (2017). Among attempts to address this problem, inclusive science communication has increasingly been suggested as a necessary framework (Bevan, Calabrese Barton and Garibay, 2020), bringing notions of inclusion and equity to existing science communication techniques and reflexive visions of how the field should progress both in academic and practical senses. Emily Dawson (2019) shows, in detail, ways in which science engagement continues to be inaccessible to many historically excluded groups. Earlier studies (e.g. Manzini, 2003) have similarly shown how well-intentioned inclusion activities fall into the trappings of the deficit model (Gross, 1994). This starts with the assumption that excluded groups have the "wrong" priorities around their needs, wants, interests and activities (Dawson, 2019) – an approach that disregards cultural history and nuance (Hogarth, 2017). Science communication, like science itself, is shaped by social forces including but not limited to gender, race, class, access to power and language (Lewenstein, 2019). As science communication researchers and practitioners, we bring our own cultural perspective to our practice and research, and it is useful to interrogate how our personal perspectives shape our work (Halpern, 2019; Polk and Diver, 2020). But do our personal perspectives allow us to be reflexive practitioners, capable of developing programs and initiatives that are truly inclusive and fit-for-purpose according to the needs of the diverse, and some traditionally underserved, audiences in our communities?

While the concept of inclusive science communication is not new (Massarani and Merzagora, 2014) there has been renewed interest within the last decade. Although the ideas of equity and inclusion are being more consistently raised in discussions of science communication theory and practice, there is little evidence to show exactly how science communication – and science communicators – define inclusion, whether they engage diverse audiences or not, and if so, how. This paper will present the results of a systematic map of 40 years of science communication literature, providing an empirical overview of how diversity and inclusion within science communication research and practice is defined and implemented.

Literature Review

Matters of equity and inclusion have received increased attention with 2020's Black Lives Matter movement coinciding with the COVID-19 pandemic and its inequities at local and global scales (Olzmann 2020). Academic interest in equity and inclusion as a starting place for high quality scholarly work across diverse fields has also recently increased to unprecedented levels (e.g. Khan et al., 2021). However, a significant historical limitation is the geography of scholarly work, with much study about inclusion and exclusion in science coming from North America, Western Europe and other Western countries including Australia and New Zealand, though this does not necessarily reflect the patterns of inclusive practice (Irwin, 2014).

Historical Exclusion

Feinstein and Meshoulam (2014) remark that equity – especially in practice – looks different for every organisation, with different contexts, local histories, challenges and individual perspectives influencing what is needed by the community. Attempts to address these needs are not always easy, or successful. Take gender equity in science as an example. Increased gender diversity without strategic underpinning has not resulted in major changes to the way science communication – or indeed science – operates in terms of progressing gender equity in leadership, policy or legislation (Rasekoala, 2019). Science communication, in contrast to STEM in general, tends to have a greater proportion of women working in the discipline, especially in lower ranked roles. Consequently the field is perceived as more feminine and lower status than science, yet men still tend to outnumber women at senior levels and in higher status roles (Rasekoala, 2019), mirroring what is generally seen in STEM disciplines more broadly. Despite decades of initiatives, research and attention to increase the attraction, retention and progression of girls and women in science, technology, engineering and mathematics studies and careers, inequities still exist and persist (e.g. Larivière et al., 2013; UNESCO, 2015; Holman et al., 2018; Potvin et al., 2018; Australian Academy of Science, 2019). The reasons are complex, including stereotypes (Steele, 1997), personal versus family and societal expectations (Sassler et al., 2017), and structural barriers (e.g. Miner et al., 2018), to name just a few.

While gendered exclusion from science is well-studied, women are not the only community who face barriers to participating in science. Science is subject to the Matthew Effect (Merton, 1968), where those with high science capital (Archer et al., 2015) have better access to science enrichment, including science education and careers (Holmes et al., 2018; Patfield et al., 2021). This includes class as a factor, with a study from the UK finding that the likelihood that students would persist with post-compulsory science study was stratified by class (Gorard and See, 2008). Literature examining how low-socioeconomic status individuals and communities have been excluded from science participation have generally looked at income as just one of several factors interacting to maintain exclusion (Dawson, 2014a, 2018; Medin et al., 2017). Exclusion due to race or ethnicity has been well studied (e.g. Asai, 2020), with research showing impacts on scientists of colour occurring and persisting

from childhood (e.g. DeWitt et al., 2011) through higher education (e.g. Avila, 2019), and into the workplace (e.g. Ginther, 2018).

Indigenous peoples have also faced exclusion, from traditional knowledge being regarded as inferior to Western scientific knowledge (e.g. Rigney, 2001; Singh and Major, 2017; Bang et al., 2018) though a limited number of outreach initiatives aim to remedy this with communities (e.g. Tzou et al., 2019). Doctoral study – a key transition to academic participation – can be a culturally unwelcoming experience for Indigenous peoples, as recounted in the personal perspective of Melitta Hogarth (2021), an Australian Aboriginal academic. Limited evidence from the UK (Sang et al., 2021) shows academic science participation for people with a disability can be similarly structurally limited, due to a number of factors including workplace policies and organisations' resources to implement them. People with a disability are under-represented in STEM, and generally take longer to find employment (Hawley et al., 2014). Sexual minority (for example, lesbian, gay, bisexual or queer-identifying) students are less likely than their heterosexual peers to complete tertiary STEM studies (Hughes, 2018), while LGBT+ STEM professionals in the UK reported that many felt unsafe, unsupported or excluded in their workplaces (Dyer et al., 2019). While women have been a fairly well-studied group in terms of gender as previously described, accounts of non-binary, transgender and gender diverse people's experiences in science seem to be limited to individual case studies (e.g. Barres, 2006; Pérez-Bustos, 2014).

English is recognised as the language of science (Gordin, 2015), and this dominance across both science and science communication excludes or disadvantages non-English speaking peoples (Márquez and Porras, 2020). Immigrants can find science communication inaccessible due to low literacy, low scientific literacy, and a poor understanding of the "rules" to be able to engage "correctly," each compounding exclusion (Dawson, 2019). This idea of multiple factors – or identities – compounding exclusion, and thus also increasing complexity in creating inclusive practice, will be further discussed later in this literature review.

Communicating With an Audience

Knowing your audience and responding to their needs is well established best practice in science communication, along with not simply taking what works in one context and applying the same strategy to a separate environment without scrutiny (Fischhoff and Scheufele, 2014). But this does not get to the deeper issue of engaging historically excluded and marginalised audiences. The term marginalised could be interchangeably used with minoritised, referring to groups that are actively diminished by others rather than existing as a minority (Gunaratnam, 2003). This goes beyond the often cited challenge of "engaging the unengaged" in science communication, instead encompassing the underlying and often systemic reasons for an audience's "unengagement"; specifically of not feeling that they are welcome, included or that the content will be relevant to them (Archer et al., 2016; Dawson, 2019; Humm and Schrögel, 2020).

Researchers have noted that some science communication activities may reinforce, rather than address existing societal inequities (Bevan et al., 2020). For example, common science communication experiences such as science museum visits can uphold perceptions that science is only for a certain type of person – often perceived by marginalised groups as "not for us" (Dawson, 2019, p. 61). Thus well-intentioned but poorly designed and delivered activities can perpetuate ongoing oppression and exclusion through "othering" and expectations of assimilation rather than meeting people where they are (Streicher et al., 2014) and accepting engagement on their terms (Boutte and Jackson, 2014; Dawson, 2019; Bevan et al., 2020).

Dawson (2014b) notes that while short-term science communication and engagement projects or interventions are a valuable testing ground for inclusive practice, they are limited in their scope and impact toward systemic change. Indeed, Banerjee (2017) found that one-off or short-term STEM enrichment and enhancement programs had no effect on whether school children went on to pursue STEM at higher levels. (Bevan et al., 2020, p. 2) note that the "celebrity status" of promising interventions belie their reliance on passionate individuals and unsustainable short-term funding. Dawson (2014b) asks how to move from relying on the more common short term projects to creating the kind of environment where they are redundant, and this question seems to remain largely unanswered.

Those with privilege and power to create change in the way that science communication is practised also need an evidence-based understanding of how to effectively create inclusive science communication. These understandings are less developed, however some notable progress has been made in the last few years. The 13th International Public Communication of Science and Technology Conference, held in 2014, featured *Science communication for social inclusion and political engagement* as the main topic, tapping into, at the time, emerging work in this area and bringing the relationship between science communication and social inclusion into sharp focus (Massarani and Merzagora, 2014). The Equity Compass, developed by The YESTEM Project UK Team (2020), is a good example of a practice-focused tool to support practitioners. Clear, directed reflection prompts guide practitioners to critically analyse, evaluate and increase equity and justice in science communication projects. The Equity Compass is just one part of the YESTEM equity model, which describes reflection and actions working together to influence outcomes for the individual audience, the practitioner, and the organisation (YESTEM Project UK Team, 2020). This idea of reflection and action working together is a key aspect of reflexivity (Salmon et al., 2017). A recent special topic in Frontiers in Communication has also shone a light on inclusive science communication practice and theory (Hayden et al., 2020) with a range of papers exploring ideas including, but not limited to, identity (e.g. Neeley et al., 2020), inclusive language (e.g. Bevan et al., 2020; Márquez and Porras, 2020), culturally responsive science communication (e.g. Carlisle, 2020; Gray et al., 2020; Landis et al., 2020), activity evaluations (e.g. Curry and Lopez, 2020; Polk and Diver, 2020), participant experiences (e.g. Smith et al., 2020), barriers to inclusive science communication practice

(e.g. Roca et al., 2020) and challenging the status quo (e.g. Bevan et al., 2020; Gray et al., 2020). This collection is all comparatively recent and contributes important information and insight to science communication research and practice alike. But are these the extent of inclusion focused work in the discipline? As a discipline, we require evidence that our research and practice is inclusive and equitable, enabling us to best serve our societal role for all people within our society.

Inclusion in Science Communication Research and Practice

While the type of major systemic and cultural change required to see equity and social justice in the science communication field is important (Canfield et al., 2020), it will take time, resources and collective will (Schell et al., 2020). This is a space where evidence-based science communication, bringing together the best of research and practice (Jensen and Gerber, 2020), could have a substantial impact. Clear, available data is one path towards equity, reform and justice (Ong et al., 2011). Although this literature review has already shown evidence of existing work aiming to identify barriers, gaps and opportunities, there does not appear to be a complete picture of how science communication has examined and incorporated inclusive practice to date.

Part of the problem arises due to the seeming lack of a consistent understanding or definition of terms such as equity, equality, diversity and inclusion. These phrases have somewhat varied and loaded meanings and understandings, that can cause struggle and confusion (Bisbee O'Connell et al., 2020). Putnam-Walkerly and Russell (2016) found that many organisations using equity as a guiding focus did not have a clear definition of what equity is, using a "gut feel" instead. Even the idea of inclusive science communication has varied names. Some authors specifically refer to "socially inclusive science communication" (Massarani and Merzagora, 2014, p. 1) but do not specify what this means in practice, whereas others use descriptors such as "effective science communication" (Manzini, 2003, p. 191) or "science for all" (Humm and Schrögel, 2020, p. 1), which are less specific again in a social inclusion context, yet similar ideas are presented.

Bringing a global south perspective to these matters from a public health background, Olusanya et al. (2021) define equality as understanding that all people are equal though unique and complementary – regardless of gender, race, disability, socio-economic status, or nationality – while equity is a commitment to specific action. Equity is a process of reprioritising opportunities and support to reduce or eliminate systemic imbalances and barriers to power, education, information or resources (Canfield and Menezes, 2020). With science communication as an important – and for some individuals and communities, the only – interface between science and society (Scheufele, 2013), equality and equity are critical considerations in who gets to participate in science.

Different groups within the science communication sphere understand "inclusive" to mean different things, especially around who – and what needs – should be catered to, in some cases distinguishing different identities of marginalisation such as disability, race or gender, while others do not (Canfield et al., 2020). Quick and Feldman (2011) argue that inclusion is more than successful participation, and similarly diversity is not simply having a range of demographics. Rather, Quick and Feldman (2011) instead define inclusion with respect to both process and outcome, where inclusion is shown within projects which are built and refined through collaborative, ongoing and iterative relationships. An intersectional (Crenshaw, 1989) perspective on inclusion would recognise that a given individual's identities would have complex interactions in the way that they perceive and feel about science, as well as how those in power in science environments will perceive the individual. For example, in the US, women of colour have been shown to experience barriers that are unique and compound their experiences both as women and people of colour, with the result being greater than the sum of the parts (e.g. Carlone and Johnson, 2007; Ong et al., 2011). In an increasingly complex world of diversity, and even "superdiversity" (Thomas and Macnab, 2019, p. 3), intersectionality – understanding that an individual's needs are unique, rather than determined by the stereotypes of a single aspect of their identity – is a useful foundation for considering inclusion (Avraamidou, 2020).

Within science communication, Canfield and Menezes (2020) describe inclusive science communication practice as being intentional, reflexive and reciprocal, linked throughout by equity. For the purpose of this study, the intentional focus of inclusive practice will be a key indicator. However, other key terms – such as inclusion, diversity, equity and access – are accepted in their broadest sense amongst the literature to capture the variety of ways they have been used with parallel intentions.

Study Aim

This thematic special issue calls for evidence-based science communication. Within science communication, academics and practitioners can both generate evidence of effective practice. For the purposes of this study, we will adopt Jensen and Gruber's (2020) stance that science communication research should be providing insights which practitioners can use. This study will examine the academic peer reviewed literature in order to gain an overview of the "best available evidence from systematic research, underpinned by established theory" (Jensen & Gerber, 2020, p. 2). This approach, while not exhaustive, aims to provide a systematic map of science communication studies over a period of 40 years to explore how issues of equity, inclusion and diversity have been incorporated in theory and practice. This time scale has been chosen as it encompasses the influential 1985 Royal Society report on the public understanding of science, and a period of advancement of research and publishing in science communication, including the launch (or relaunch) of the discipline's most dominant academic journals (Trench and Bucchi, 2015). We expect that the later years will show greater prevalence of research topics concerned with equity and inclusion, however will they be focused broadly on a range of minoritised audiences, or will the focus be on a few? The overarching aim of this study is to provide a preliminary evidence base for inclusive science communication practice

and research, examining which audiences are typically served, where, and how. This will provide the data necessary to inform areas of future effort and research to create a truly inclusive approach to science communication.

METHODS

This study will employ a systematic map approach (James et al., 2016). A systematic map uses methods similar to a systematic review – considered to be the gold standard of evidence in many fields – but a systematic map aims to survey what evidence exists, rather than synthesising the results of many studies (Bates et al., 2007). The advantages of using systematic methods include the ability to reduce biases due to the systematic approach to identifying and categorising literature, the ability to confidently discern trends in the literature, and, importantly, a systematic map has the ability to ask an open question (James et al., 2016). Systematic approaches also enable a rapid identification of the diversity and range of existing research (Pickering and Byrne, 2014), key to the aim of this paper. We used a streamlined version of the methodology proposed by Pickering and Byrne (2014), omitting considerations such as weightings given to papers based on sample size and methods, to conduct the systematic map as described following.

Search Procedure and Inclusion Criteria

Articles were sourced using the databases Web of Science and Scopus. Original research articles were used as these are a primary source which have been through a peer review process (Pickering and Byrne, 2014). The search terms were kept intentionally broad, and the journal options open as science communication related work is not published exclusively in science communication journals. We also wanted to ensure that we captured as many factors related to intersectionality and inclusion as possible, so terms and acronyms related to different characteristics and audiences were also intentionally broad. Searches were limited to journal articles published between 1980 and 2020 in English. We acknowledge that restricting the search to English is in itself a process of exclusion, mitigated only by the use of English as the "*lingua franca* in the field" (Trench & Bucchi, 2015, p. 2). Future studies should incorporate research published in languages other than English to gain a more complete overview. Searches used the following search strings:

Scopus

TITLE-ABS-KEY ((scien* W/1 communication) OR (science W/1 engagement) OR "public understanding of science" OR "communicating science" OR (scien* W/0 outreach) OR "informal science learning" OR (science W/1 participation) OR ("public engagement" W/3 science)) AND TITLE-ABS-KEY (inclusi* OR "leaky pipeline" OR disadvantage* OR discriminat* OR divers* OR equality OR equity OR exclusion OR intersectional* OR minorit* OR oppress* OR social OR female OR feminist OR gender OR girl OR woman OR women OR "English as a second language" OR "non-English speaking" OR "people of colour" OR "people of color" OR

"person* of colour" OR "person* of color" OR "wom*n of colour" OR black OR blak OR bipoc OR colour OR color OR cultural OR esl OR cald OR immigrant OR linguistic OR *migrant OR multicultural* OR race OR refugee OR regional OR rural OR socio-economic OR indigenous OR aboriginal OR first AND nation* OR disab* OR neurodiverg* OR neurodivers* OR autis* OR lgbt* OR queer OR lesbian OR gay OR bisexual OR transgender OR transsexual) AND PUBYEAR > 1979 AND PUBYEAR < 2021.

Web of Science

TS=((scien* NEAR/1 communication) OR (science NEAR/1 engagement) OR "public understanding of science" OR "communicating science" OR (scien* NEAR/0 outreach) OR "informal science learning" OR (science NEAR/1 participation) OR ("public engagement" NEAR/3 science)) AND TS=(inclusi* OR "leaky pipeline" OR disadvantage* OR discriminat* OR divers* OR equality OR equity OR exclusion OR intersectional* OR minorit* OR oppress* OR social OR female OR feminist OR gender OR girl OR woman OR women OR "English as a second language" OR "non-English speaking" OR "people of colour" OR "people of color" OR "person* of colour" OR "person* of color" OR "wom*n of colour" OR black OR blak OR bipoc OR colour OR color OR cultural OR esl OR cald OR immigrant OR linguistic OR *migrant OR multicultural* OR race OR refugee OR regional OR rural OR socio-economic OR indigenous OR aboriginal OR first AND nation* OR disab* OR neurodiverg* OR neurodivers* OR autis* OR lgbt* OR queer OR lesbian OR gay OR bisexual OR transgender OR transsexual) Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan = 1980–2020.

In each of the above search strings, the asterisk indicates a wild card search meaning that all possible variations of a word were included. For example, disab* would return results containing the words disable, disabled, disability, disabilities. W/n and NEAR indicates that the specified word (e.g. scien*) appears near or within the specified number of words to another specified word (e.g. scienc* NEAR/1 communication specifies that any word starting with scien is included if it appears within one word of communication; "informal engagement" W/3 science means the phrase informal engagement appears within three words of science etcetera). Searches used title, abstract and key words to identify relevant articles.

Initial searches yielded 2,280 articles from Scopus and 3,597 from Web of Science. A further 14 articles were included from additional sources identified by the researchers. The total 5,891 articles were uploaded into reference management system Mendeley and duplicates removed, leaving a total initial corpus of 5,455 articles. These were exported into Rayyan (http://rayyan.qcri.org) (Ouzzani et al., 2016), a web app designed to conduct collaborative systematic reviews.

Articles were then reviewed in two phases for inclusion or exclusion in the study. The initial review used the title and abstract to determine inclusion or exclusion. Articles were

FIGURE 1 | Overview of data collection process for systematic mapping.
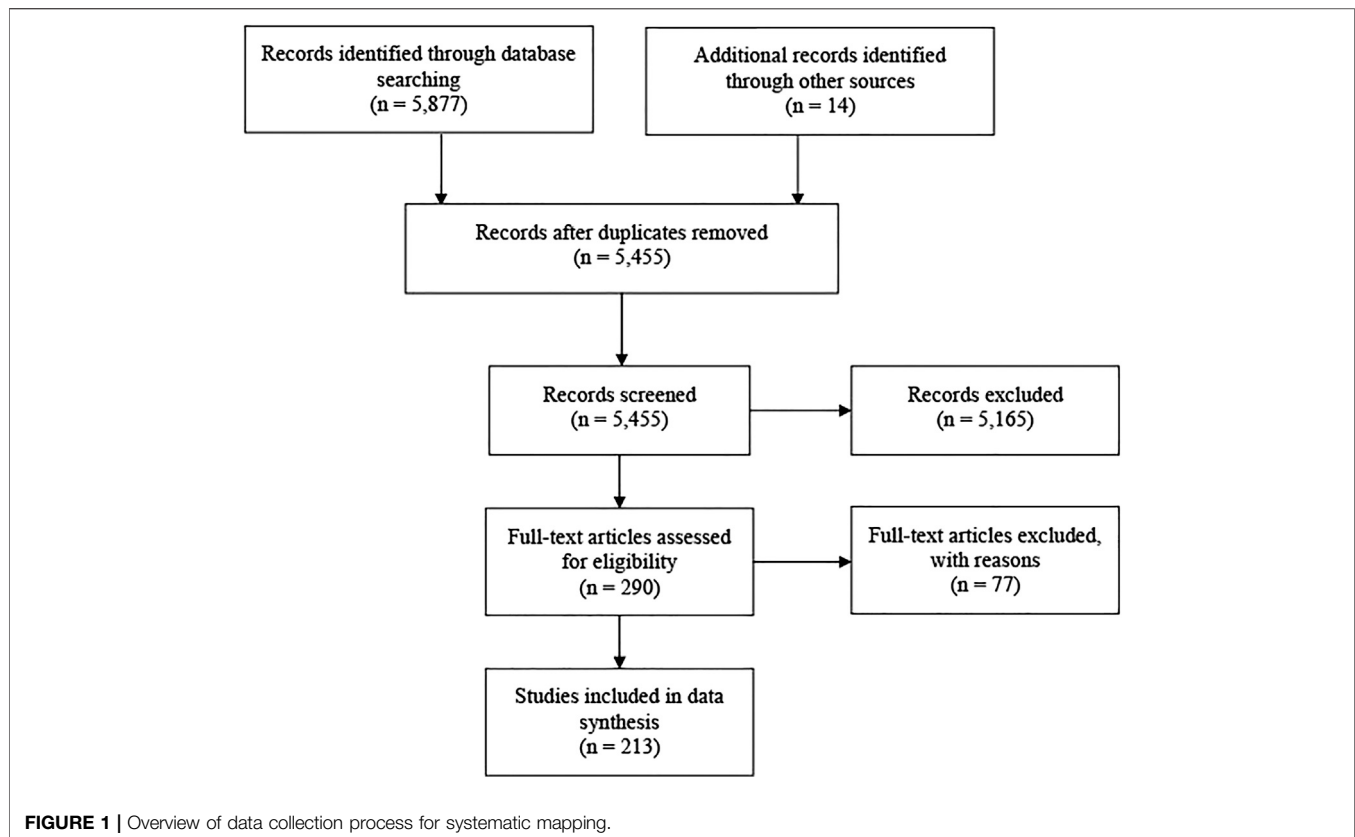
retained if they were about science communication within the parameters of the search strings (thus encompassed education, engagement, participation etcetera); if they related to the science/society interface; and/or if the study had an intentional focus on equity, inclusion and/or intersectionality. Articles were excluded at this phase if they were not articles published in peer reviewed journals, if they were published after 31 December 2020, not in English, if they were specifically about communication between scholars (e.g. open access publishing) or if the equity angle was not intentional (for example a general public survey that divided results by age and gender, but gender differences were not the focus of the study).

Both authors independently reviewed the articles. In the first phase, there was a conflict for 35 articles in the sample. These articles were discussed and resolved. At the end of the first phase, 290 articles were retained. During the second phase, the full texts of the articles were read. Articles were retained if they were intentionally focused on issues of equity, diversity and inclusion. The article had to have an intentional focus on a minoritised group, which could also be purely descriptive of their experience; and/or a science communication program/practice/other mechanism to support inclusion of minoritised groups. In this second phase, 54 articles were discussed and resolved. The number discussed was higher in this round as the intentionality of the study was not always easily identified, and a few studies were challenging to classify as "science communication" or not. For

example, two papers on the use of Indigenous names in taxonomy generated much discussion, with both subsequently included as the intention of the work was to include the Indigenous traditional knowledge and communicate that knowledge to a broader audience. After the second round of coding, 213 articles were retained for further analysis. A flowchart showing each step of the paper selection process is provided in **Figure 1**.

Data Analysis

The included article information was exported to a spreadsheet, with the full texts of the papers kept in both Mendeley and an online folder. A data extraction template was developed within Microsoft Excel to extract the key characteristics of each paper. These characteristics included the country where the study was located, the characteristics of the audience who were the focus of the paper (for example women, immigrants), the goals of the paper and the field of the paper (for example science engagement). The goals were developed inductively by one author, with a random sample of 10% of the dataset co-coded and verified by the other author. The paper fields were coded by the other author, with fields also developed inductively. Each paper was coded with one field (a primary field) and a secondary field was allocated to papers which may have spanned two fields (for example higher education and medicine). Each data extraction category code was continually refined throughout the extraction process, with both authors verifying the consistency and accuracy of the data.
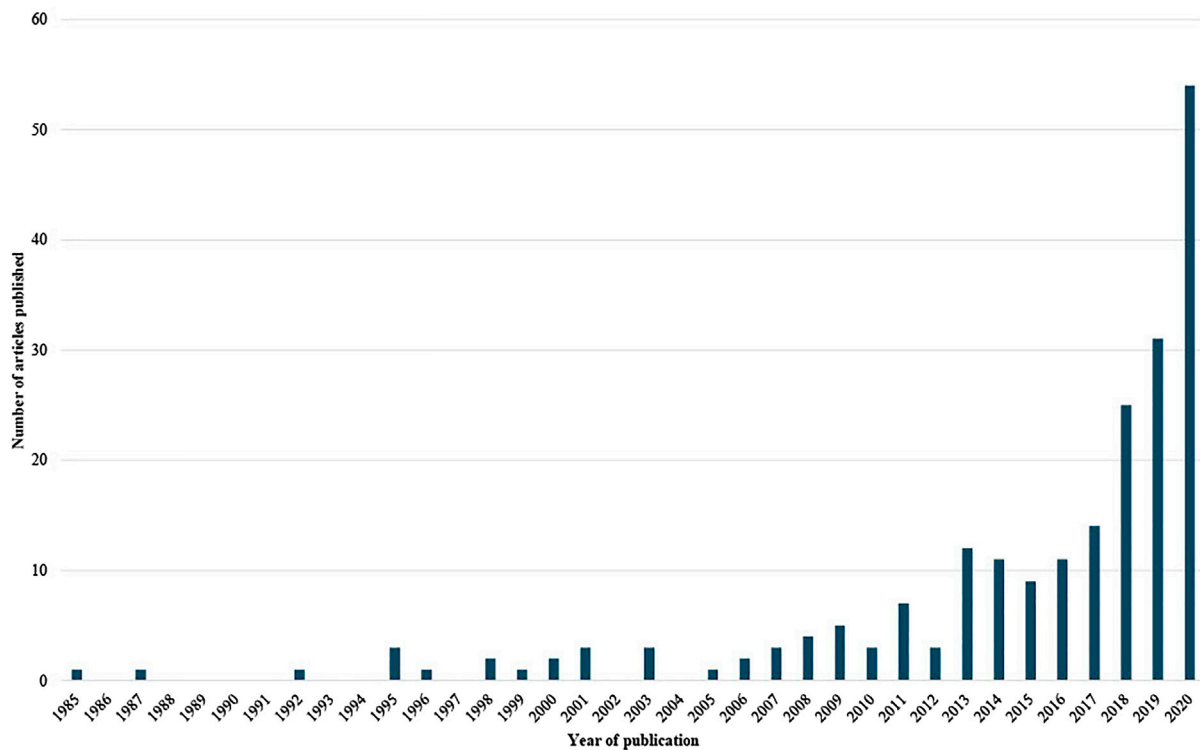
FIGURE 2 | Number of articles published each year during the 1980–2020 sample period (*n* = 213).

RESULTS

Included Paper Characteristics

A total of 213 papers from 117 journals were used in this analysis. Although the collection period was from 1980, the first included article was published in 1985. In the first 20 years of the sample (1980–2000), only 12 articles were published. Between 2001 and 2010 a further 24 articles were published. From 2011–2020, 178 articles were published, with the majority (*n* = 135) published between 2016 and 2020 (**Figure 2**). The majority (*n* = 15) of these articles were published in the Journal of Science Communication (JCOM), with the Frontiers in Communication and the Journal of Research in Science Teaching each publishing 11 articles, and Science Communication and Science Education publishing 10 articles each (**Figure 3**). The Public Understanding of Science was the last science communication focused journal in the top publishers, producing eight articles. The remaining "top" publishing journals all had an education focus, which extended into the remaining journals who published two articles in the sample period. The bulk of the sample (89 journals) published one article only during the sample period. The full list of journals and the number of articles published is available upon request from the corresponding author.

The geographic focus of each article was identified and coded. These are presented in **Table 1**. Articles were coded as "global" if they were reviews of a topic or used data from the internet such as comments on social media channels. The majority (*n* = 99) of articles were United States (US) focused, with global papers a distant second (*n* = 27). The United Kingdom (UK) had 22 papers. The sample included seven multinational papers that spanned several regions (for example North America, Europe, Southeast and East Asia) and the same number from Australia. All other regions had four or fewer publications. Taking geographic regions as a whole, almost half of the sample (102 articles, 47.89%) came from North America. Europe had the next greatest segment (31 articles, 14.55% of sample) closely followed by globally focused papers (27 articles, 12.68%).

Audience

For each of the included articles, audience categories were developed based on the stated aim of the paper or the description of the population sample. Papers could have more than one audience. For example, many papers from the US referred to under-represented minority groups. This typically included African American, Asian American, Native American/ Indigenous, Latinx and Hispanic people. Depending upon the paper context, some papers included women in their definition, or excluded Asian Americans. The included minority groups were usually (but not always) explicitly defined in a footnote or described in the method. These were not always consistent so individual groups within these minority groups were recorded. Where groups within the broader "under-represented minority" description were not specified, all groups listed above were considered to be included. Audience categories were added and refined as they were identified, leading to the following list:

FIGURE 3 | Journals with four or more inclusion focused articles published. Although the sample timeframe spans 1980–2020, all of the articles in the top publishing journals were published from 1995 onwards, therefore this graph shows only 1995–2020.
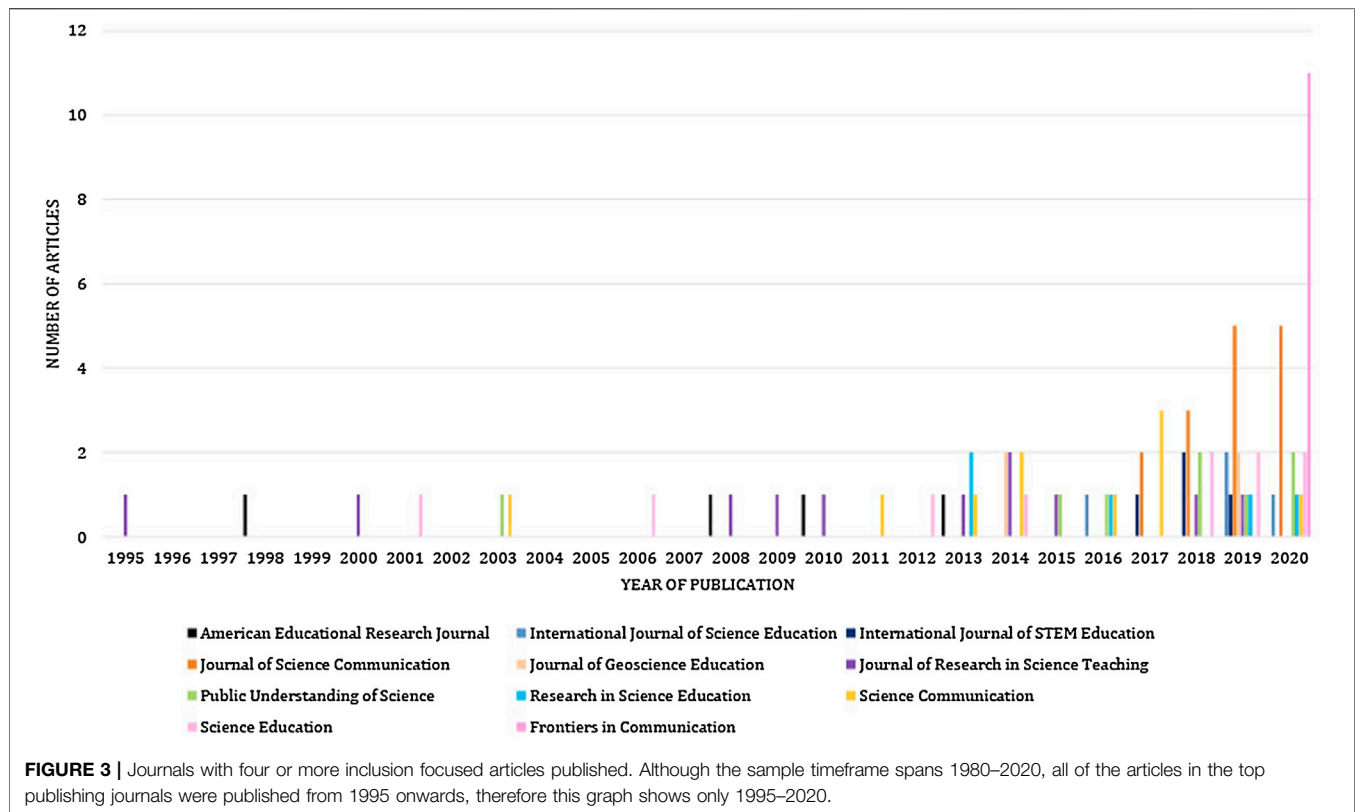
- Girls/women.
- Black – typically African American.
- Indigenous – Australian or Canadian Indigenous peoples, First Nations, Native American, Maori.
- Asian – often Asian American but also people of Asian backgrounds living in non-Asian countries.
- Latinx/Hispanic – People from Latin America and Spanish speaking nations, often – but not exclusively - in this sample referring to communities located in countries (e.g. USA) outside of this geographic region.
- Immigrant.
- Linguistically diverse – often appeared with immigrant
- Disability – physical, visual or audial impairment, developmental disability or neurodiversity.
- Religious groups/castes – groups with shared belief systems or socially stratified characteristics.
- Low socio-economic status – including schools/students who qualify for reduced or free lunches; included any papers referring to "working class" groups.
- Implementers – people with the ability to influence or implement the adoption of inclusive practice.
- Developing nations.
- Incarcerated people – groups living within correctional facilities.
- LGBTQ* - encompassing all forms and expressions of gender identity and sexuality.

Of all audience groups, girls/women appeared most commonly ($n = 97$, *see* **Figure 4**). Implementers were the

second most common audience, with 48 papers "speaking" to other practitioners and/or researchers. The "under-represented minority groups" appeared in similar numbers as many papers bundle these audiences together, with the exception of Asian audiences that were less frequently included. Papers from the UK in particular focused on communities from low-socioeconomic areas. A small number of papers looked at very specific – and arguably under-served – audience groups, namely those with disabilities ($n = 18$), developing countries ($n = 16$), religious or caste identities ($n = 3$) and those in prison ($n = 1$).

Paper Goals

Each article was read to determine what it aimed to present. Iterative development created the following categories:

Review – a synthesis of literature and/or data to provide an overview of the key issues, opportunities, and/or implications. Did not involve any data collection with specifically recruited participants.

Audience experience – original research exploring the experiences of audience/s in science communication practices such as presenting on YouTube or blogging. Could also include garnering input from particular communities or groups to inform practice or to develop research instruments (e.g. surveys). Can include testing of contributing/interacting factors which influence factors such as identity and beliefs. Does not explicitly aim to determine impacts or outcomes.

TABLE 1 | Comparison of country of focus for included articles.

Country of article focus	Number of articles	Regional total	% of sample	Total per region	% of sample
Africa					
Nigeria	1	7	3.29	7	3.29
South Africa	4				
Tanzania	1				
Multinational	1				
Asia					
Multinational within Asia broadly	2	18	8.45	18	8.45
Central Asia					
Tibet	1				
East Asia					
Japan	4				
Taiwan	1				
South Asia					
India	4				
Southeast Asia					
Timor Leste	2				
Thailand	2				
Vietnam	1				
Western Asia					
Israel	1				
Caribbean					
Multinational	2	2	0.94	2	0.94
Europe (including United Kingdom)					
Austria	1	31	14.55	31	14.55
Germany	3				
Luxembourg	1				
Norway	1				
Switzerland	1				
UK	22				
Multinational within Europe	2				
North America					
Canada	3	102	47.89	102	47.89
United States	99				
Oceania					
Australia	7	13	6.10	13	6.10
Fiji	1				
New Zealand	4				
Multinational	1				
South America					
Brazil	2	6	2.82	6	2.82
Multinational (Latin America)	2				
Colombia	2				
Multinational across regions (specific country focus)	7	7	3.29		3.29
Global (no specified geographic focus)	27	27	12.68		12.68
Total	213	213	100%		

Evaluation – research evaluating the impacts/outcomes of programs, projects or events on inclusion and identity formation, including those specifically designed to create an inclusive environment or prioritise inclusive practice.

Recommendations – Recommendations, toolkits for science communication practitioners to adopt/enhance inclusive practice and create inclusive environment. The recommendations are the specific focus and function of the research or case study presented.

Perspective – article describing perspective or opinion of a particular audience through a first-person narrative but does not provide recommendations for practice or present original research data.

The majority of articles ($n = 202$) were coded within a single goal category. The remaining papers typically belonged in two categories with one paper spanning three. Of all articles, the most common goal of a paper was to present the experience of an audience ($n = 76$; see **Figure 5**). This tended to be descriptive of students in classrooms or informal science education settings, particularly "identity work" and factors influencing interest and engagement. Sixty-six articles outlined some form of evaluation. This could be a long-term evaluation of student outcomes from a mentoring/pipeline support type program encouraging under-represented groups into health and science disciplines; the impact of mentors or role models on perceptions and stereotypes or the effectiveness of a particular pedagogical approach in engaging
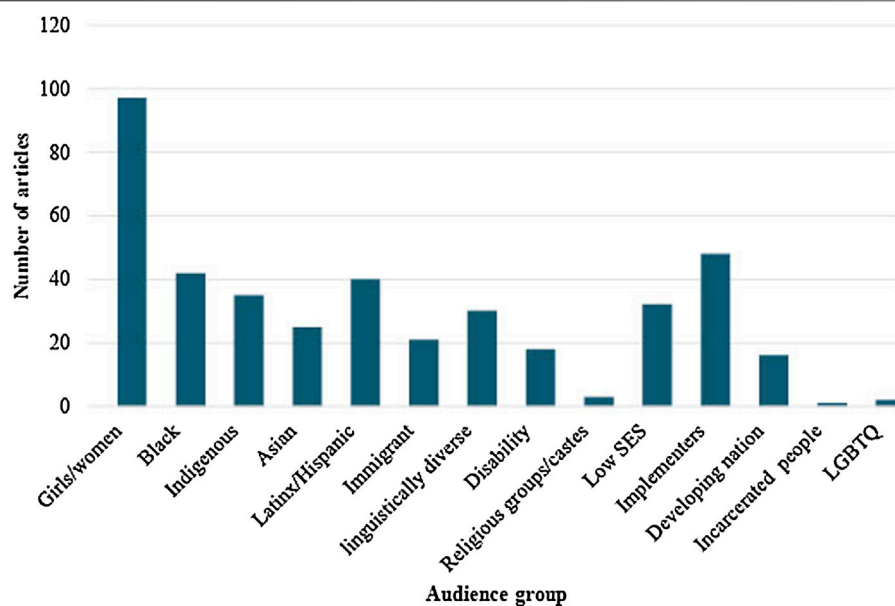
FIGURE 4 | Comparison of audience groups focused on in articles (n = 213). Articles could have more than one audience focus.
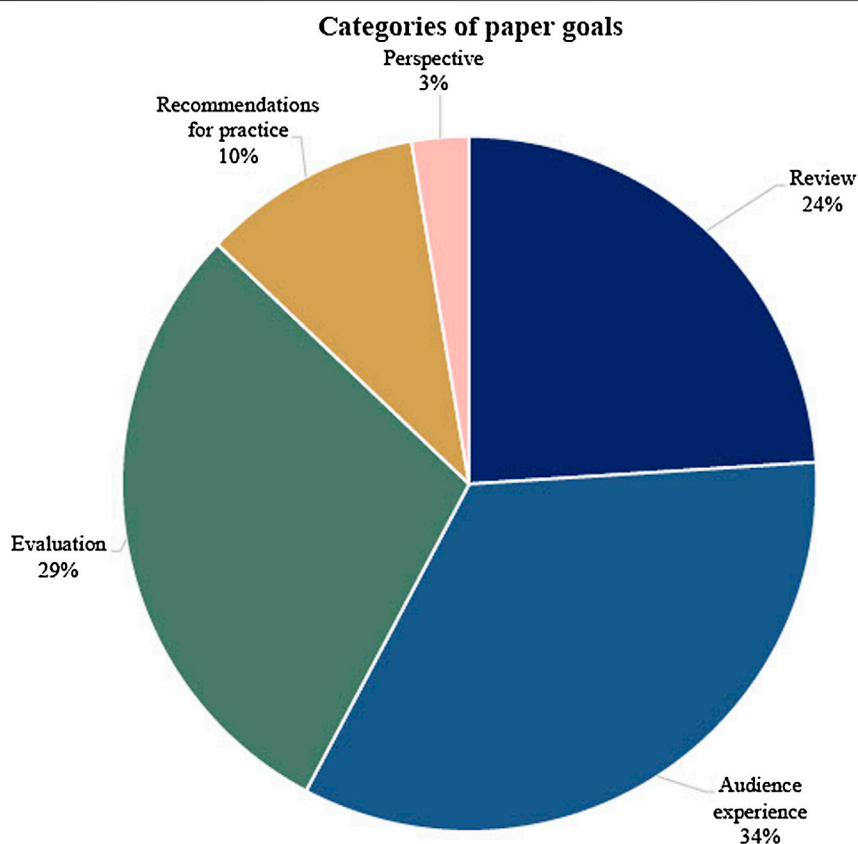

FIGURE 5 | Composition of paper goals within included articles. Eleven (11) articles had two or more identified goals, meaning the total count exceeds the sample size (n = 213).

TABLE 2 | Comparison of audience and paper goals.

Audience	Number of articles	Review	Audience experience	Evaluation	Recommendation	Perspective
			Paper goal			
Girls/Women	97	29	33	33	13	3
Black	42	5	15	24	0	0
Indigenous	35	9	12	13	4	0
Asian	25	2	11	12	0	1
Latinx/Hispanic	26	3	5	16	2	1
Immigrant	21	3	13	4	1	1
Linguistically diverse	16	3	13	4	1	1
Disability	18	2	6	6	4	0
Religious/caste	3	0	3	0	0	0
Low-socioeconomic status	32	7	11	14	0	0
Implementer	48	25	9	3	18	2
Developing nation	16	6	6	3	0	1
Incarcerated	1	0	0	1	0	0
LGBTQ*	2	0	0	1	0	1

students in formal or informal education settings. A smaller number of papers also evaluated workshops and conferences intended to build inclusive capacity in scientists and science communicators. About one quarter of the articles were coded as reviews of particular topics or issues, often using existing datasets of student enrolment or standardised tests, or presented literature reviews of issues pertaining to inclusion. While the majority of academic papers do make recommendations for future research or indeed practice, these tend to occur at the end of a paper and arise from the study rather than exist from the outset as the reason the study was done. The recommendations category is for those papers that had the sole focus on giving recommendations, aiming only to provide very practical, tangible guidance and suggestions for creating more inclusive environments and practice. Under 10% of the articles focused on making recommendations. This included papers which provided detailed guidelines on how to make spaces physically accessible, how to work with Indigenous community groups, how to present materials to ensure accuracy and accessibility for visually impaired people and how to run an inclusive conference.

Table 2 outlines how the different paper goals aligned with different audiences. Across all audiences, papers which focused on audience experience and evaluation were most common. Girls/women and implementers were most likely to be the focus of reviews. Perhaps unsurprisingly, papers aimed at implementers were also more likely to be recommendations. Girls/women also were the leading focus of recommendation papers with all other audiences the focus of less than a handful of recommendation papers, if they had any at all. Very few papers across all audiences were perspectives.

Paper Fields of Research

As observed in the journals represented in the final sample of articles, some fields and types of science communication were seemingly over- or under-represented. To quantify this, an additional round of coding sought to understand the types of work represented amongst the articles in this study. The iteratively developed list of categories comprised:

Science education (HE) – papers concerning science education in higher education settings, including student participation data, course evaluations, student mentoring programs and science achievement.

Science education (HS) – papers concerning science education in high/secondary school settings, including pedagogy, curriculum, science achievement and classroom dynamics.

Science education (PS) – papers concerning science education in primary, elementary or middle school and pre-school or kindergarten settings, including pedagogy, curriculum, science achievement and classroom dynamics.

Professional development – papers concerning employee upskilling opportunities, including mentoring for professionals, conference workshops, science communication or writing training for STEM professionals.

Science communication practice – papers concerning practical ideas, project descriptions or recommendations for public facing science communication including science centres and museums, science festivals or public science workshops (including for targeted communities). Includes work around public understanding of science or specific strategies for communicating scientific ideas. Includes science writing, including science blogging, science journalism and other science-related work in written media, and those who produce such works. Distinct from *STEM engagement* by the focus on practitioners and delivery rather than audience experience.

Science communication theory – papers concerning theoretical advances in science communication, including models or frames for understanding or analysing science communication work.

Science policy – papers concerning the making and communication of government policies concerning scientific content.

STEM workforce characteristics – papers concerning the makeup of the STEM workforce, including those who do science communication, STEM postdocs, and STEM professionals in academic or other workplaces.
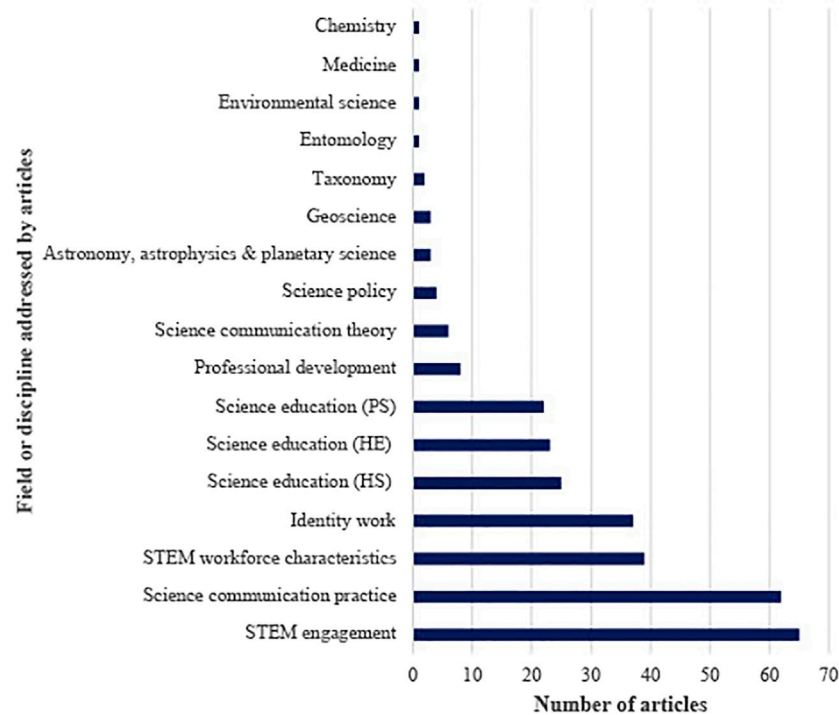
FIGURE 6 | Fields of study of articles in sample. Ninety (90) articles had both a primary and secondary field, with the remainder having only a primary field, so the total count of fields exceeds the sample size (*n* = 213).

Identity work – papers concerning the formation or understanding of individuals' identity or identities, including but not limited to science, gender or cultural identities, that generally draw on a combination of theoretical frameworks from fields such as psychology, sociology and anthropology.

STEM engagement – papers concerning a range of activities that aim or serve to understand or increase "engagement" in science, generally defined as attitudes towards science or desire to participate in future science activities such as attending a science fair or museum, or, especially for young people, aspiration or self-efficacy towards science careers or senior studies in science. Distinct from *science communication practice* by the focus on audience experience rather than practitioner experience.

A number of distinct academic fields were also included as codes:

- Environmental Science.
- Geosciences.
- Entomology.
- Astronomy, astrophysics and planetary sciences.
- Taxonomy.

Categories in this list did not include methods such as ethnography or econometrics.

Papers were assigned a primary and optional secondary field. Combinations of these two fields were also recorded, with both fields treated as equivalent.

The largest category represented was STEM engagement (65 articles or 30.52% of sample as either the primary or secondary field), followed by science communication practice (62 or 29.11%; **Figure 6**). Science communication theory was not as well represented, comprising only six articles (or 2.82%). Science education across all life stages was fairly equally represented in the sample with higher education (23 or 10.80%), secondary (25 or 11.74%), and primary and early childhood education (22 or 10.33%).

Articles with a clear single field were most common in the sample, with four of the five most frequent field codes having no secondary field (**Table 3**). Science communication practice (45 or 21.13%) was the most commonly occurring field code, followed by STEM workforce characteristics (27 or 12.68%), STEM engagement (15 or 7.04%), and Science education (HE) (12 or 5.63%; **Table 3**). The third most common combination of fields did have both primary and secondary codes - STEM engagement and identity work (18 or 8.45%). Most field code combinations were represented fewer than five times in the sample, with 18 of the 42 combinations only represented once.

DISCUSSION

This paper aimed to provide baseline evidence of how science communication has incorporated equity, inclusion and diversity in research and practice over the last 40 years. The systematic map process found that the attention paid to equity, diversity and inclusion matters has dramatically increased, with around 63% of

TABLE 3 | Fields of sample articles and their frequency (n = 213).

Field	No secondary field	Taxonomy	Astronomy, astrophysics and planetary science	Geoscience	Entomology	Environmental science	Medicine	Chemistry	STEM engagement	Identity work	STEM workforce characteristics	Science policy	Science communication theory	Science communication practice	Professional development	Science education (PS)	Science education (HS)	Science education (HE)
Science education (HE)	12			1			1		5	1	2		1					
Science education (HS)	9							1	9	3						3		
Science education (PS)	3								8	7				1				
Professional development	4										3		1					
Sci comm practice	45	2	1		1				4	3	3							
Sci comm theory	2																	
Science policy	2								1									
STEM workforce characteristics	27			1					2	1		1						
Identity work	4								18									
STEM engagement	15		1	1		1												
Chemistry																		
Medicine																		
Environmental science																		
Entomology																		
Geoscience																		
Astronomy, astrophysics and planetary science																		
Taxonomy																		

Primary and secondary fields are considered equivalent.

all articles published within the last 5 years. This is consistent with the timeline of the growing disciplinary awareness of the relationship between science communication and social inclusion assisted by the 13th Public Communication of Science and Technology Conference (Massarani and Merzagora, 2014). Certainly the dominant science communication academic journals are publishing articles about equity, diversity and inclusion. The Journal of Science Communication (JCOM) has been the most prolific publisher, although the recent (2020) research topic of "Inclusive Science Communication" in Frontiers of Communication could signal a further increase in focus of work in this area. Perhaps unsurprisingly, the majority of journals who publish articles with an intentional focus on articles related to equity, diversity and inclusion were education based, with articles concerning education at any stage, combined, the largest field represented. Arguably, classrooms create microcosms where differences created through circumstances beyond individual control can be seen in stark relief. This has long been recognised in teaching and requires an integrated inclusive approach which bridges both discipline and pedagogy (Stinken-Rösner et al., 2020). Perhaps there are lessons to be learned for science communication academics and practitioners from within the science education space.

Similar to the findings of Gerber et al. (2020), we found that papers from North America (especially the US) dominated our sample. Although likely a consequence of using only English language papers, this finding is consistent with previous studies showing the typical geography of scholarly work on equity and inclusion (Irwin, 2014) and reinforces the representation of science communication being predominantly white and Western (Guenther and Joubert, 2017; Canfield and Menezes, 2020). It may also influence the idea of who is considered to be minioritised and where. For example, in the US, Asian Americans may be considered an under-represented minority in STEM and the focus of science communication initiatives. But what of Asian science communication practitioners and researchers from other Asian nations? Although our study did find articles from Asian studies of science communication research and practice (e.g. Hopton and Walton, 2019; Ikkatai et al., 2019), and articles evaluating or describing activities in other countries, the authors tended to be those from the global north, not those from the country of study. As researchers, we could do better within our own practice. We echo previous studies which argue that researchers should make conscious and concerted efforts to increase the diversity of their collaborators, particularly in global or multinational studies where local people should make up at least part of the authoring team (e.g. Stefanoudis et al., 2021).

While most papers in our sample had excellent intentions and recognise the business and moral cases for diversity, equity and inclusion, the systematic map produced does not show a coherent and comprehensive body of work. This is likely a result of the disconnectedness of much of sample literature. Many articles in our sample were "one off"; single papers appearing in a broad catalogue of journals without a strong theoretical grounding consistently drawn from science communication literature. This perhaps also indicates that as a discipline, we do not yet have this strong evidence base. The findings of this mapping exercise suggest this could be the case. For example, the lack of guidance or evidence of best practice was evident in papers targeting implementers – those in the position to either advocate for, facilitate or implement more inclusive practice or policies. The papers aimed at this audience tended to be reviews and recommendations; very few were based on evaluations which specifically measured outcomes and impacts. Describing projects without sharing data about what works – rather than what simply sounds good – and what needs improving holds back the whole field and stymies attempts at reform (McKinnon, 2020).

The articles collected in this study show a disproportionate focus on girls and women. Although gender may be a visible characteristic, it is far from the only one which requires attention in the pursuit of equity, diversity and inclusion, and focusing solely on gender will not be enough to create the type of meaningful social and systemic changes needed. A Western, middle class, able bodied woman in biology would have a very different experience to a woman of colour, who is an immigrant, has a disability and works in engineering, for example. Focusing purely on gender would fail to identify and subsequently address these differences. There are small pockets of activity which recognise this, with some of the collected articles looking at populations with multiple factors such as gender, cultural background and socioeconomic status. It is this kind of intersectional approach which is necessary if we wish to develop systems, structures, policies and programs which are truly inclusive of the communities we serve (Thomas et al., 2021). Yet the results found in this study show that these kinds of studies are not yet common. In addition, minoritised groups, such as those with disabilities or from different cultural backgrounds, appear to also be overlooked in terms of research focus, appearing as the target audiences of a very small number of papers in our sample. While there is obviously scope for more work to be done with these communities, it is important to reflect on who is bearing the burden of research. Ashley (2020) comments on research fatigue, for example when minoritised communities don't see their contributions as having an effect, or are harmed through poorly designed projects. This could be, for instance, through unforeseen time or financial costs/commitments to be able to participate. Research fatigue has the potential to make communities reluctant to continue participating in studies, or from volunteering to participate in similar activities in the future. We believe this is an apt reminder of the importance for inclusion, equity and diversity interventions in science communication to be not just well-intentioned, but well-considered in their design, delivery and evaluation.

After science education, most of the papers in our sample were focused on STEM engagement and science communication practice, with theoretical work considering new models or frames for equity, diversity and inclusion in science communication somewhat lacking. Papers contributing to the development of science communication theory comprised under 3% of the entire sample. This may be related to the criteria of our search, with some known examples of this literature falling outside our inclusion criteria, such as books (e.g. Dawson, 2019) or reports (e.g. Canfield and Menezes, 2020; YESTEM

Project UK Team, 2020). This remains a gap that future research incorporating a broader range of sources could explore. It potentially also highlights an area where science communication researchers and practitioners could collaborate to make meaningful gains in developing an evidence base of what inclusive science communication is, does and for whom. Or even ascertaining if we are defining diversity, equity and inclusion in consistent ways across the discipline. This requires an integrated process of critical reflection at each stage of an intervention (Dawson, 2019). Some of this work is already in progress as seen in the YESTEM Equity Compass (YESTEM Project UK Team, 2020), an example of a practitioner-tested tool to guide reflection and reflexive practice, where reflection and action are interconnected (Salmon et al., 2017). As a discipline, we can do more, not only with our practice and research but also the communities we serve.

CONCLUSION

Forty years of literature shows that attention to equity, diversity and inclusion in science communication is entering a period of heightened awareness for researchers and practitioners alike. Yet this increased attention is not equitably distributed across historically under-served and minoritised audiences and does not go far enough to catalyse the societal, institutional and systemic changes required to create inclusive science communication theory and practice. Our results show that as a discipline, despite being aware of the white, Western, ableist and patriarchal nature of science communication (Canfield and Menezes, 2020), our theory and practice to date still largely reinforce these characteristics. Inclusive science communication must be intentional in its focus on under-served and minoritised communities, working *with* them as well as *for* them in both programs and in the development of theory. A robust evidence base of what constitutes best practice, for whom and how is vital if science communication - in theory and practice - wants to meaningfully fulfil its role in society, for all society members. Without a concerted focus on generating evidence and tracking progress, we will continue to tinker ineffectually at the edges.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

Both authors contributed equally to this work.

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A Repeated Measures Dataset on Public Responses to the COVID-19 Pandemic: Social Norms, Attitudes, Behaviors, Conspiracy Thinking, and (Mis)Information

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1 INTRODUCTION

The COVID-19 pandemic has highlighted social and cultural issues relevant to public health and the fundamental relationship between science and society. The pandemic has necessitated decision-making for individuals that can have life-or-death consequences. An understanding of these micro-level decisions can have social and ethical implications. For example, these decisions are affected by the socio-economic circumstances each individual faces, which collectively influence the wider course of this global pandemic. Research capable of showing valid evidence for such social and ethical dimensions may connect with improvements in public health communication, responses to emergency state measures, and efforts to mobilise pro-social behaviour. The need for evidence-based science communication has been pointed out by scholars (e.g., Jensen and Gerber, 2020). In response to this call, we provide evidence which may inform public health communication practices and improve individual decision-making in the COVID-19 and post-truth era.

Here, we present a longitudinal survey research dataset collected in Germany between October 2020 and September 2021. The social research producing this dataset was conducted as part of the Viral Communication project (viralcomm.info). The project has investigated the social and ethical dimensions of the COVID-19 pandemic in Germany. The longitudinal research has focused on attitudes, beliefs, and behaviours regarding the COVID-19 pandemic from a representative sample of individuals within the German public. The research topics specifically regard conspiracy beliefs about the pandemic, public health mitigation measures and government policies. By providing this dataset, we wish to facilitate the identification of key issues that affect recovery and resilience in response to public health crises.

2 METHODS

For this longitudinal survey research, we collected paired sample response data in Germany between October 2020 and September 2021. These methods used a repeated measures survey design conducted across three research phases. The survey instrument was developed as part of a wider range of qualitative and quantitative data collection methods employed by the Viral Communication project. Standard good practices in social research were employed, including informed consent, robust data management and anonymization procedures and use of appropriate statistical tests (see

Jensen & Laurie, 2016; Smith & Jensen, 2016). The full set of research protocols and procedures for this project were reviewed and approved by the Ethics Committee of Sigmund Freud University.

2.1 Data Collection

The research used a software solution designed for paired samples with matching between responses at the individual level, as well as automated email invitations and reminders for the questionnaires. All data collection used digital software for secure online and GDPR-compliant data collection and management provided by the research technology company Qualia Analytics. This software provides automatic matching for paired data across iterations of repeated measures within-person survey data collection by assigning each respondent a unique identifier and incorporating it into individual survey invitation links. This is a feature that was used to avoid the need to ask respondents the same socio-demographic information in each phase. This data report focuses on the repeated measures survey data collected at three separate project phases. Throughout this paper, Phase I, Phase II and Phase III refer to the first, second and third survey wave, respectively:

2.1.1 Phase I

Data collection for the phase I survey took place from October 30, 2020 to December 14, 2020. This first phase built the foundation for a wider range of data collection approaches and research methods used in the Viral Communication project by allowing respondents to opt-in to multiple research pathways. For the initial outreach of the survey campaign, postcard invitations were sent to a random population sample of 30,000 household addresses in Germany (using the German postal service's (Deutsche Post) address database), stratified based on relative population size across German federal states (DESTATIS, 2020). The postcards were designed to include instructions for how to access the respondent-facing survey, which included a request targeted at persons in the household to next have their birthday and who were at least 16 years of age to voluntarily complete the phase I survey. In total, 1,480 people responded to this initial survey resulting in a response rate of about 5%. The response rate for this survey is within the normal range for comparable sampling approaches and types of surveys (see e.g., Jensen et al., 2021b). Respondents received monetary incentives in form of prize draws to participate in each of the research pathways, including the phase I survey and both follow-up surveys.

2.1.2 Phase II

From the Phase I sample frame ($N = 1,480$), 687 eligible respondents who agreed to be invited in the Phase I survey were contacted *via* email and invited to participate in the follow-up surveys. Using the research methods for paired samples, automated email invitations were sent to those who voluntarily agreed to participate in the Phase II survey. This phase was conducted between March 02, 2021 and March 22, 2021. In total, 482 responses were collected in the Phase II survey.

2.1.3 Phase III

The same respondents who opted in for the repeated surveys were again invited to participate in the Phase III survey. This phase was conducted between August 1, 2021 and September 20, 2021. In total, 426 responses were collected in the phase III survey.

2.2 Survey Instrument

The survey instrument used closed-ended items (e.g., single- and multiple response questions, Likert-type scales, and semantic differentials). The Phase I survey instrument underwent one round of pilot testing prior to the official release in order to ensure high validity and reliability. Due to the length of the survey instrument, the online respondent-facing survey was split into two sections, including a longer main section that had the top priority variables and a shorter opt-in section. The mean time (5% trimmed) it took respondents to complete the Phase I, Phase II and Phase III survey was 33 min, 27 and 25 min, respectively. While most survey items remained identical in each project phase to enable comparisons of change over time, we implemented some changes to the survey instrument, such as removing or including new questions. These new questions were developed as a direct response to the unfolding context of the pandemic and the emerging socio-political factors relevant to pandemic mitigation responses.

2.2.1 Phase I

The initial Phase I survey included a range of socio-demographic questions aligned with the German (Zensus 2011, 2020) for weighting purposes. These socio-demographic questions included the following independent (predictor) variables: age group, sex, nationality group (German/other), migration background, federal state, highest school leaving qualification, and highest professional qualification.

The Phase I survey covered the following research topics as dependent (outcome) variables:

- Attitudes towards science
- COVID-19 infection history within the respondent's household
- Perceived effectiveness of voluntary COVID-19 measures
- Self-reported adherence to COVID-19 measures
- Risk perceptions and personal concerns
- Information seeking and use behaviours
- Trust in key governmental and scientific actors relevant to the pandemic in Germany
- Support for hypothetical mandatory and voluntary Influenza vaccination and COVID-19 vaccination as a pill and injection
- Ethical considerations in pandemic management
- General conspiracy-mindedness and belief in specific COVID-19 related conspiracies
- Information about respondent's household
- Political orientation and affiliation
- Use of digital devices and access to internet
- Influenza vaccination status

2.2.2 Phase II

In the follow-up Phase II survey, demographic questions were not necessary because of the use of paired samples with matching between responses that was enabled through the online survey software used for the study. This also meant that the Phase II survey was shorter in total length, focussing only on dependent (outcome) variables from Phase I. To account for unfolding aspects of the pandemic context, some survey items were removed and new questions were added. Most notably, in Germany, vaccination was a real option for some people at this stage (not a hypothetical scenario anymore), and public frustration over a long series of semi-strict COVID-19 regulations over winter were becoming increasingly visible (ZDF, 2021).

Compared to the original phase I survey, the following items or research topics were removed from the phase II survey due to reduced relevance:

- COVID-19 infection history within the respondent's household
- Support for hypothetical mandatory and voluntary Influenza vaccination and COVID-19 vaccination as a pill
- Information about respondent's household
- Use of digital devices and access to internet
- Influenza vaccination status

The Phase II survey added the following additional research topics as dependent (outcome) variables:

- Perceived effectiveness of wearing different types of masks, closing day-cares, kindergartens, schools, and non-essential shops
- Risk perception of variants worsening the pandemic situation
- COVID-19 vaccination status, experienced side-effects, and understanding of vaccination prioritisation (as this had become a real option for some socio-demographic groups)
- Experimental design to test effects of vaccines' national origins on vaccination willingness
- Experimental design to test effects of others' national origin on personal assessments of virus-related risk

2.2.3 Phase III

In the final Phase III survey, socio-demographic questions were again not necessary because of the use of paired samples with matching of Phase I, II and III responses. Research topics from Phase I and Phase II were used as dependent (outcome) variables, with removal of some items and new questions added in Phase III to adapt the survey instrument to emerging issues. Vaccination was still a major topic in Germany, particularly in light of the SARS-CoV-2 variants, the emergence of digital COVID-19 vaccination proof, the discourse of children's COVID-19 vaccination, and a potential fourth wave of infections in autumn.

We removed the following items or research topics for the Phase III survey:

- Relevant diseases in respondent's own household

- Experimental design to test effects of others' national origin on personal assessment of virus-related risk

Compared to the original Phase II survey, the Phase III survey added the following topics as dependent (outcome) variables:

- Risk perception about a potential fourth COVID-19 wave in autumn 2021
- Experimental design to test effects of different variants' national origin on personal assessment of virus-related risk
- Perception of how the delta variant's threat was represented in the media
- Support for hypothetical COVID-19 vaccination mandates on specific aspects of daily life and work
- Vaccination status and willingness to vaccinate for respondents' children
- Modification of the vaccine origin experiment (removing some vaccines and adding a more geographically diverse set of vaccines)
- Full COVID-19 vaccination status and use of digital proof of vaccination
- Respondents' participation in protests against COVID-19 regulations

3 ANALYSIS

Following each phase of data collection, survey data were cleaned and prepared for analysis, with the application of a range of inclusion criteria as filters. For example, valid cases needed to include responses for age group, sex, nationality group (German/other), migration background, federal state, highest school leaving qualification, and highest professional qualification. These inclusion criteria were strictly required due to the necessary application of weighting in subsequent analysis, which used available German census data as a reference (Zensus 2011, 2020). Weighting variables were calculated for analyses involving the main parts of the survey instrument as well as the opt-in sections.

In total, 1,480 survey entries were submitted for Phase I. However, 417 respondents were excluded for not fitting the inclusion criteria, leaving a revised sample frame total of $N = 1,063$ respondents ($\hat{p}_{\text{woman}} = 53\%$, $M_{\text{age}} = 48.9$, $SD = 18.6$ (weighted)). From the 482 respondents who participated in the Phase II survey, a total of $N = 433$ met the inclusion criteria ($\hat{p}_{\text{woman}} = 51\%$, $M_{\text{age}} = 48.1$, $SD = 17.9$ (weighted)). $N = 388$ from the 426 respondents who took part in the phase III survey met the inclusion criteria ($\hat{p}_{\text{woman}} = 51\%$, $M_{\text{age}} = 48.6$, $SD = 18.6$ (weighted)). The same inclusion criteria were applied for all three survey phases.

4 INTERPRETING THE DATASET

As the dataset involves three measurement points (i.e., Phase I, Phase II and Phase II), it is split into three sections, each of which can be identified by looking at the variable names. Variables

corresponding to the Phase I survey will have the prefix "PHASE1_", while variables from the Phase II and Phase III surveys will have the prefix "PHASE2_" and "PHASE3_", respectively. Exceptions to this are the socio-demographic variables from the main section of the Phase I survey.

Each questionnaire was additionally split into a main and an opt-in section, the cut-off points of which are located after the variables PHASE1_OI_AQ, PHASE2_OI_AQ and PHASE3_OI_AQ, respectively. Furthermore, three sets of two weighting variables were calculated. The first, second and third sets include weights for analyses involving Phase I, Phase II and Phase III variables, respectively. The appropriate weighting variable for analysis should be selected based on the latest survey and survey section involved. For instance, if an analysis involves a variable from the Phase II opt-in section and a variable from the Phase I main section, the appropriate weighting variable is the one for the Phase II opt-in section.

In the Phase II survey, we included two experimental set-ups. For each of the vaccination origin experiments, we included a grouping variable, PHASE2_HM_VACC_GROUP and PHASE3_HM_VACC_GROUP. The same was done for the risk assessment experiment, with PHASE2_RA_INF_GROUP being the designated grouping variable.

5 USING THE DATASET

The survey dataset provides quantitative data that allow investigation of relevant research questions for a representative sample of the population residing in Germany between 2020 and 2021 during the COVID-19 pandemic. Secondary research using this dataset may, for instance, reveal different predictors and behavioural outcomes of belief in the conspiracy that the COVID-19 pandemic is part of a global effort to enforce mandatory vaccination (Jensen et al., 2021a). By providing this dataset, we wish to facilitate the identification of key issues that affect recovery and resilience in response to public health crises.

The social research conducted to produce this dataset was part of the Viral Communication project (viralcomm.info), which focused on the following research questions:

- How do individuals and communities perceive risks and protective behaviours related to COVID-19 with regards to pro-social ethical duties and their own socio-economic situation?
- How do public understandings of the disease evolve?
- How do these public understandings vary across diverse socio-demographic groups?
- How are individuals in Germany experiencing stigmatisation and negative outcomes?
- What information are people in Germany seeking?
- What sources, (mis)information, and platforms do people in Germany regard as trusted/credible?

- How much confidence do they have in public health authorities and emergency state measures?
- What factors are associated with conspiracy theory beliefs relevant to the pandemic?
- How is conspiracy thinking affecting people's decision-making about pandemic mitigation measures?

Overall, the longitudinal research has focused on attitudes, beliefs, and behaviours regarding the COVID-19 pandemic from a representative sample of individuals within the German public. The research topics specifically regard conspiracy beliefs about the pandemic, the social and ethical dimensions of the COVID-19 pandemic in Germany which may influence public health mitigation measures and government policies.

The dataset is accessible on the open science publication platform Zenodo: https://doi.org/10.5281/zenodo.5546999. It is provided as an SPSS file and includes fully anonymised and cleaned survey data for the Viral Communication project. The dataset includes all quantitative variables and other computed variables necessary for performing analyses and comparisons with follow-up or related research.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://doi.org/10.5281/zenodo.5546999.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of the Sigmund Freud University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors contributed to the survey design. AP and LL set up the survey system. Data collection was conceptualized by EJ, BW, and MW, and implemented by LL. AP performed the data management. AP and LL wrote up the article. EJ, AJ, BW and MW did final editing.

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Taking Stock and Re-Examining the Role of Science Communication

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Eight science communication research projects have been funded by the European Commission since 2018. These projects are a response to one of the European Commission's 'Science with and for Society' (SwafS) funding calls — "SwafS-19: Taking stock and re-examining the role of science communication." Together these projects have received almost €10 million in research funding, and each has been affected to some extent by the COVID-19 global pandemic. This paper provides an overview of the eight projects, how they adapted to the challenges caused by the pandemic, and the subsequent implications for science communication policy and research funding.

INTRODUCTION

SwafS-19

Taking Stock and Re-Examining the Role of Science Communication is a Research and Innovation Action in Section 16, "Science with and for Society" (SwafS), of the European Commission's 2018–2020 Horizon 2020 Work Programme (European Commission, 2020). Previous iterations of SwafS, under the European Framework programmes FP6 and FP7, were titled "Science and Society," and "Science in Society," respectively (Delaney and Tornasi, 2020). SwafS-19 is dedicated to assessing science communication and its perception by citizens to construct a knowledge base that will support the ultimate aim of the Work Programme: to build trust in science and empower citizens through enhanced accuracy of information, more effective communication, and multidirectional knowledge flows between all stakeholders. This builds on two decades of scholars in the field highlighting the need for empirical research and resources to help improve and support science communication (Treise and Weigold, 2002; Nisbet and Scheufele, 2009; Trench and Bucchi, 2010; Fischhoff & Scheufele, 2013). The potential research agenda for science communication has included advocates for better evaluation of science communication (Jensen, 2014) and large-scale public engagement projects (Roche et al., 2017; Jensen et al., 2021), improved strategic communication (Besley, 2020), and the need to find synergies between science communication, science education, public engagement, citizen science, and related research fields (Stilgoe, Lock, and Wilsdon, 2014; Baram-Tsabari and Osborne, 2015; Roche et al., 2020).

The SwafS-19 funding call was launched in 2018 as part of the European Commission's eighth framework programme, Horizon 2020: the world's largest multinational research funding programme (Abbott, 2020). The SwafS-19 call was renewed annually for three years, with the final round of submissions invited in April 2020. The 26 applications received in 2020 represented a

TABLE 1 | All eight projects funded under the European Commission funding call H2020-SwafS-19: "Taking stock and re-examining the role of science communication."

Name	Timeframe	Partner countries	Budget	Website
CONCISE	01.12.18-31.01.21	Spain, Italy, Slovakia, Poland, Portugal	€1,198,337.50	concise-h2020.eu
RETHINK	01.01.2019-31.12.2021	Netherlands, Belgium, United Kingdom, Germany, Italy, Denmark	€1,198,771.25	rethinkscicomm.eu
QUEST	01.02.2019-31.07.2021	Italy, Norway, United Kingdom, Estonia, France, Ireland	€ 1,194,227.50	questproject.eu
TRESCA	01.01.2020 - 30.04.2022	Netherlands, Spain, Italy, Austria, United Kingdom, Germany	€ 1,199,601.25	trescaproject.eu
NEWSERA	01.01.2020-31.12.2022	Spain, Italy, Portugal	€ 1,299,250.00	newsera2020.eu
ParCos	01.01.2020-31.12.2022	Finland, Belgium, United Kingdom	€ 1,379,772.50	parcos-project.eu
ENJOI	01.01.2021-31.12.2023	Italy, Spain, Portugal, Netherlands, Belgium	€ 1,222,462.50	enjoiscicomm.eu
GlobalSCAPE	01.03.2021-28.02.2023	Ireland, Netherlands, Belgium, United Kingdom	€ 1,199,937.50	global-scape.eu

substantial increase from the previous years; six applications were submitted in 2018, and 18 in 2019. From 49 submissions over three years, a total of eight projects were funded, with an overall investment of almost €10 million (**Table 1**).

The relevance of the objectives of SwafS-19 was increased in the first instance by the challenges posed directly by the global pandemic, and further heightened by its ripple effects. By extension, the individual objectives of the eight projects assumed a new immediacy during an era marked by rapid and unprecedented change and marred by uncertainty and doubt. This article considers how these projects have contributed to evidence-based science communication in the COVID-19 era by outlining the aims of the eight projects and by contextualising them in light of how the world has changed in the wake of the most widespread public health crisis of the modern era.

INTERNATIONAL SCIENCE COMMUNICATION RESEARCH IN THE COVID-19 ERA

Three projects—CONCISE, RETHINK, and QUEST—were awarded funding in the first SwafS-19 funding call in 2018. Three more—TRESCA, NEWSERA, and ParCos—received funding in 2019, and were initiated in early 2020. The final two—ENJOI and GlobalSCAPE—were funded in 2020 and officially began in 2021. Each project is subdivided into interconnected tasks and work packages, with associated milestones and deliverables. The eight projects tackle the overall objectives of the SwafS-19 funding call in different ways.

CONCISE aims to gain greater understanding of, and insight into, the role of science communication in shaping public perceptions and opinions, and to assess citizens' trust in institutional sources and channels of information. The project gathered perspectives from 500 citizens across five EU cities on four pressing social and science issues: vaccines, complementary and alternative medicine use, food safety, and climate change. In view of the COVID-19 pandemic, these topics are more relevant than ever. Publications arising from the project findings explore participatory approaches to engaging the public with climate change communication (Dziminska et al., 2021); analyse how science communication is mediated (Delicado et al., 2021); and assess citizen trust in science (Brondi et al., 2021). Published in six

languages, the CONCISE Policy Brief is one of a number of open-access resources available.

RETHINK focuses on understanding the digital science communication landscape and how people navigate it in order to make it more open, inclusive, and adaptive. The project has established communities of practice, known as "Rethinkerspaces", in seven EU countries. The COVID-19 pandemic shifted these communities into digital spaces, and allowed RETHINK to explore public knowledge in the context of "science in the making" and the sources people turned to. RETHINK has produced publications that examine the ecology of digital science communication (Weitkamp et al., 2021); characterise the online practices of scientists undertaking public engagement (Roedema et al., 2021); and chart the implementation of a Delphi study of international science communication scholars (Fähnrich, 2021). Forthcoming work will address quality criteria for science communication in diverse contexts, and will produce training materials for science communicators in the context of COVID-19.

QUEST seeks to better understand the dynamics of contemporary science communication through the three strands of journalism, social media, and science museums. It brings together scientists, science communication professionals, and policy makers in designing tools to support quality science communication, and thus enhance public engagement and trust. QUEST responded to the pandemic by adapting its co-design methodology and moving its activities online, and the project was extended by six months in order to properly disseminate its results. QUEST has produced a number of publications, including an exploration of the fragmented landscape of European science communication (Davies et al., 2021); a study of quality indicators in science communication (Olesk et al., 2021); and insights into the tools created to support science communicators (Mannino et al., 2021). A collection of toolkits for scientists and science communication professionals are available online.

TRESCA focuses primarily on social science by exploring concerns about the effects of misinformation, disinformation, and over-information in relation to public trust in (social) science communication. The project employs large scale experimental survey research as well as qualitative, deliberative research in its methodology, with particular emphasis on addressing misinformation and digital safety; environmental health; automation and the future of skills and work. It responded to the global pandemic by specifically studying how increased online

consumption of health information affects trust in science communication and integrating those findings into a Massive Open Online Course to facilitate dialogue between the scientists, journalists, and policy makers navigating the digital environment *via* visual communication.

NEWSERA analyses and evaluates the complexities of science communication in citizen science as they pertain to data journalism and the quadruple helix of science, policy, industry, and societal stakeholders. The project's focus is on citizen science initiatives across Europe, taking into account iterative feedback loops and the multidirectional flow of information, as well as the specific tools and strategies required by different stakeholders. The COVID-19 pandemic has had a surprisingly positive impact on the project. The move from face-to-face to virtual events has facilitated a significant increase in the number of citizen science projects participating in #CitSciComm Labs—from four projects per lab to 38—as well as an increase in the number of representative stakeholders involved in the co-creation activities within each lab. The labs have also been delocalised to the countries involved, enabling the activities to be conducted in local languages.

ParCos utilises arts-based methods to create interactive stories and narratives from scientific data. Its central aim is to convert science communication into a widely accessible and cultural activity, and as such, the project adopts an iterative and co-creative process in order to change the manner in which science is communicated. The project is designed to enable audiences to interpret scientific data for themselves, and the contribution of diverse perspectives is encouraged. The outbreak of COVID-19 pushed ParCos to shift the majority of its activities online. Conducting data drama and other arts-based practices online was particularly difficult, because relationship-building and trust are crucial to the experience. ParCos was able to rise to this challenge by creating a fully immersive theatre experience that was streamed live to participants at home.

ENJOI centres on standards, principles, and indicators in science communication in order to address the prevalence of misinformation. Current issues, such as the global pandemic and the climate crisis are highlighted as key areas where misinformation must be tackled within a reliable framework of policies and actions that are grounded in science. Journalism is a core focus of the project, and the pandemic has underlined the significance of journalists as mediators in influencing and determining both public debate and public trust in science. Along with a series of public reports and research papers, the legacy of ENJOI will be a permanent platform for collaborative science journalism efforts, training, mutual learning, sharing of research outcomes, suggestions, and indications for policies. This 'Observatory for outstanding open science communication' aspires to become a reference point for innovations in science journalism and science communication, and their diffusion throughout the international community.

GlobalSCAPE uses diary studies to investigate the experiences of science communicators in parts of the world where their voices have been traditionally under-represented. Due to the pandemic, the project launch was delayed to plan for all aspects of the project to take place online if needed, including workshops, open educational resources, and policy briefings.

DISCUSSION

The inclusion of Science Communication as a topic under SwafS in the 2018–2020 Work Programme emerged from an interim evaluation of Horizon 2020, which demonstrated the need for greater engagement with civil society. In a subsequent report in 2020, science communication was recognised as central to the European Commission's goal of building trust between science and society in order to better meet societal challenges: "In essence, science communication entails presenting science related topics in a format which is designed for and understandable by the intended audience and remains faithful to the evidence" (Delaney and Tornasi, 2020, p. 15).

Since that report was published, at an early stage of the COVID-19 pandemic, the relationship between science and society has become increasingly salient. The initiation of the eight SwafS-19 science communication research projects during a public health crisis has provided a unique opportunity to explore how aspects of that relationship have changed. Perceptions of risk, uncertainty, credibility, and democracy have all received unprecedented attention in public discourse. The SwafS-19 objective of assessing science communication and its perception by citizens, with an underlying aim of building trust in science through clearer avenues of communication between all stakeholders, enhanced societal participation, and greater understanding of science, is tailor-made for confronting the challenges created by the pandemic.

The overall pre-pandemic goal of the projects in 2018 was to take stock of current changes in the landscape of science, innovation, and its communication, and from this basis, to empower citizens through enhanced accuracy of information and more effective knowledge-transfer. This goal has become far more pressing in the intervening years. With the outbreak of the pandemic and need for swift, drastic, and often contested decision-making, it has also become evident that effective science communication must be a fundamental component of policy-making, especially in terms of emergency and disaster management and climate communication (Kahan, 2012; Chinn et al., 2020; Koerber, 2021). The pandemic has also brought about dramatic changes to how large-scale research projects can be implemented, with wholesale conversion to online conferences and virtual events (Amemado, 2020; Klöwer et al., 2020; Niner et al., 2020; Roche et al., 2021a; Roche et al., 2021b). These challenges have highlighted that there is more need than ever for researchers and practitioners to harness their shared science communication expertise (Jensen and Gerber, 2020).

The SwafS-19 projects have produced research outputs to help reinterpret and rethink science communication in light of this ever-changing landscape (Kupper et al., 2021). Each project maintains a separate website so that project details, outputs, and data from the ongoing research remain publicly accessible. The links to the project websites are listed in **Table 1**. The projects

are not without limitations. To adhere to the guidelines of the Horizon 2020 Work Programme, each project consortium involves organisations from at least three European countries and all project budgets are kept below €1.4 million. A more restrictive constraint is the timeline for the projects, with the work for each project expected to be completed within two to three years. This provides a challenge for longitudinal science communication research in particular.

Although SwafS will not be included as a standalone pillar of research funding in Horizon Europe (the next framework programme of the European Commission) many of the same themes and topics will be addressed in Section 11 of the Work Programme: "Widening participation and strengthening the European Research Area" (European Commission, 2021). Dedicated science communication funding may be reduced from the previous funding programme, but public engagement may receive more broad attention throughout Horizon Europe (Gerber, 2018; European Commission, 2021). As the eight SwafS-19 projects continue to produce research outputs, support the field of science communication, and potentially influence future policy over the coming years, they will serve as an appraisal of whether the approach of funding large-scale science communication research projects is a worthwhile endeavour. Regardless of how the field is funded, the science communication community faces new responsibilities in how to communicate science in uncertain times. The pandemic

heralded a renewed call to rebuild trust between science and society, and it is up to researchers, educators, and policy-makers around the world to seize the opportunity to rebuild that trust (Andrews-Fearon et al., 2020).

AUTHOR CONTRIBUTIONS

JR, FS, KM, and LB led the conceptual design of the manuscript, while RA, MB, AF, AK, FK, JM, IMa, IMe, CM, JP, ET, MT, EW, and AW contributed to individual subsections. All authors reviewed the manuscript and provided comments and feedback.

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Methodological Considerations for Survey-Based Research During Emergencies and Public Health Crises: Improving the Quality of Evidence and Communication

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The novel coronavirus (COVID-19) outbreak has resulted in a massive amount of global research on the social and human dimensions of the disease. Between academic researchers, governments, and polling firms, thousands of survey projects have been launched globally, tracking aspects like public opinion, social impacts, and drivers of disease transmission and mitigation. This deluge of research has created numerous potential risks and problems, including methodological concerns, duplication of efforts, and inappropriate selection and application of social science research techniques. Such concerns are more acute when projects are launched under the auspices of quick response, time-pressured conditions–and are magnified when such research is often intended for rapid public and policy-maker consumption, given the massive public importance of the topic.

Keywords: survey, questionnaire, research methods, COVID-19, emergency, crises

INTRODUCTION

The COVID-19 pandemic has unfortunately illustrated the deadly consequences of ineffective science communication and decision-making. Globally, millions of people have succumbed to scientific misinformation about mitigation and treatment of the virus, fuelling behaviors that put themselves and their loved ones in mortal danger.[1] Nurses have told stories of COVID-19 patients, gasping for air, and dying, while still insisting the disease was a hoax (e.g., Villegas 2020). While science communication has always had real world implications, the magnitude of the COVID-19 crisis illustrates a remarkable degree of impact. Moreover, the crisis has demonstrated the complexity and challenge of making robust, evidence-informed policy in the midst of uncertain evidence, divergent public views, and heterogenous impacts. This adds urgency to seemingly abstract or academic questions of how the evidence that informs science communication practice and decision-making can be made more robust, even during rapidly evolving crises and grand challenges.

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[1]As just one example, Loomba et al. 2021 found that misinformation results in a decline of over 6% in vaccine intentions in the United States, or some approximately 21 million prospective American vaccine recipients.

There has been a massive surge of science communication-related survey research projects in response to the COVID-19 crisis. These projects cover a wide range of topics, from assessing psychosocial impacts to attempting to evaluate different interventions and containment measures. Many of the issues being investigated connect to core themes in science communication, including (mis)information on scientific issues (e.g., Gupta et al., 2020; Pickles et al., 2021), trust in scientific technologies and interventions, including vaccines (e.g., Jensen et al., 2021a; Kennedy et al., 2021a; Kwok et al., 2021; Ruiz and Ball 2021), and more general issues of scientific literacy (e.g., Biasio et al., 2021)—themes being investigated in a context of heightened public interest, significant pressure for effectiveness in interventions, and with highly polarized and contentious debate. Such survey research can be instrumental in informing effective government policies and interventions, for example, by evaluating the acceptability of different mitigation strategies, identifying vulnerable populations experiencing disproportionate negative effects, and clarifying information needs (Van Bavel et al., 2020).

However, the rush of COVID-19 survey research has exposed challenges in using questionnaires in emergency contexts, such as methodological flaws, duplication of efforts, and lack of transparency. These issues are especially apparent when projects are launched under time-pressured conditions and conducted exclusively online. Addressing these challenges head on is essential to reduce the flow of questionable results into the policymaking process, where problematic methods can go undetected. To truly succeed at evidence-based science communication (see Jensen and Gerber 2020)—and to support evidence-based decision-making through good science communication—requires that survey-based research in emergency settings be conducted according to the best feasible practices.

In this article, we highlight the utility of questionnaire-based research in COVID-19 and other emergencies, outlining best practices. We offer guidance to help researchers navigate key methodological choices, including sampling strategies, validation of measures, harmonization of instruments, and conceptualization/operationalization of research frameworks. Finally, we provide a summary of emerging networks, remaining gaps, and best practices for international coordination of survey-based research relating to COVID-19 and future disasters, emergencies, and crises.

SUITABILITY OF SURVEY-BASED RESEARCH

Social and behavioural sciences have much to offer in terms of understanding emergency situations broadly, including the COVID-19 crisis, and informing policy responses (see Van Bavel et al., 2020) and post-disaster reactions (Solomon and Green, 1992). Questionnaires have unique advantages and limitations in terms of the information that can be gathered and the insights that can be generated when used in isolation from other research approaches (e.g., see Jensen and Laurie,

2016). For these reasons, researchers should carefully assess the suitability of survey-based methods for addressing their research questions.

In emergency contexts, survey research can offer several advantages. Questionnaire-based work can:

- Allow for relatively straightforward recruitment and consenting procedures with large numbers of participants, as well as increasing the geographical scale that researchers can target (versus, for example, interview or observational research).
- Gather accurate data about an individual's subjective memories or personal accounts, knowledge, attitudes, appraisals, interpretations, and perceptions about experiences.
- Allow for many mixed or integrated strategies for data collection, including both qualitative/quantitative; cross-sectional/longitudinal; closed-/open-ended; among others.
- Integrate effectively with other research methods (e.g., interviews, case study, biosampling) as supplemental or complementary (see Morgan, 2007) approaches to maximise strengths and offset weaknesses that allow for data triangulation.
- Allow for consistent administration of questions across a sample, as well as carefully crafted administration across multi-lingual contexts (e.g., validating multiple languages of a survey for consistent results).
- Enable highly complicated back-end rules ("survey logic") for tailoring the user experience to ensure only relevant questions are presented.
- Create opportunities for carefully-crafted experimental designs, such as manipulating a variable of interest or comparing responses to different scenarios across a population.
- Deploy with relatively low costs and rapid timeframes compared to in-person methodologies.

At the same time, surveys can have significant limitations in the context of crisis research that can undermine their reliability or create temptations for methodological shortcuts. For example:

- Surveys face important limits in terms of what information can be reliably obtained. For example, respondents generally cannot accurately report about the attitudes, experiences, and behaviors of other people in their social groups. Likewise, self-reports can be systematically distorted by psychological processes, especially when it comes to behavioural intentions and projected future actions. Retrospective accounts can also be unreliable, particularly in cases of complex event sequences or events that took place long ago (e.g., Wagoner and Jensen 2015).
- The quality of survey data can degrade rapidly when there is low ecological validity (i.e., participants are not representative of the broader population), whether through sampling problems, systematic patterns in attrition for longitudinal research, or other factors.

- Seemingly simple designs may require extensive methodological or statistical expertise to maximise questionnaire design and data analysis (i.e., ensuring valid measures, maximizing best practice, and avoiding common mistakes).
- The limited ability to adjust measures once a survey has been released, without compromising the ability to develop inferences from comparable data, can be challenging in rapidly evolving crisis contexts where relevant issues are changing rapidly.
- Cross-sectional surveys can give a false impression of personal attributes that are prone to change if assumptions of *cross-situational consistency* are applied (e.g., factors that are expected to remain stable across time) (e.g., Hoffman, 2015).

Given these advantages and limitations, there are several appropriate targets for survey research in crises and emergencies. Alongside other methods—including observational, ethnographic, and interview-based work, depending on the specific research questions formulated—surveys can help to gather reliable data on:

- Knowledge: What people *currently* believe to be true about the disease (e.g., origin of the coronavirus, how could they catch it, or how they could reduce exposure).
- Trust: Confidence in different political and government institutions/actors, media and information sources, and other members of their community (e.g., neighbors, strangers) (e.g., see Jensen et al., 2021).
- Opinions: Approval of particular interventions to slow the spread; belief about whether policies or behaviours have been effective or changed the emergency outcome; or personal views about perceptions of vaccine efficacy or safety.

- Personal impacts: Reports from individuals who are exposed or negatively affected, such as with chronic stress or loss of loved ones, employment, health, and stigmatization.
- Risk perceptions: Hopes and fears related to the disease, end points of the emergency, and return to normalcy.

Even when aware of the limitations, launching and conducting survey research is a specialized skill that requires training, experience and mentorship. This expertise is comparable to conducting epidemiological, biomedical, or statistical research. Even when questionnaires appear 'simple' because of the skillful use of plain language and straightforward user interfaces, there are substantial methodological learning curves associated with proper research designs. In the next sections, we provide several project design, coordination, and methodological recommendations for researchers launching or conducting rapid-response research projects on these topics inherent with emergency contexts, in both COVID-19 and beyond. In the next section, we discuss overall research coordination, project designs, and specific methodological approaches.

PROJECT DESIGN

Researchers face important choices when designing survey-based research within the fast-moving context of disasters and emergencies. There can be a substantial pressure to conduct research *quickly*, including funder timelines, the perceived race to publish, or pressure to collect ephemeral data. Each of these factors can necessitate difficult decisions about project and research designs. At a high level, we recommend that survey-based projects on COVID-19 adopt the following standards (**Table 1**):

TABLE 1 | Key factors for effective COVID-19 survey-based research.

Key Factors	Explanation
Open access Make instruments, data, and research findings accessible to a wide base of researchers and non-academic audiences	Open access knowledge practices support practitioner access to research, enable future re-analysis and comparison of data, and facilitate more effective comprehensive and meta reviews. Paywalls are especially problematic for those in developing countries. Best practices include −making full instruments available for inspection. −anonymized datasets, including qualitative data, available for re-analysis. −pre-registering studies when appropriate and coordinating with similar projects (see *Research and Coordination*).
Integrating relevant social science expertise Engage experts in the design, administration, and analysis in survey-based projects	Emergency situations often increase the risk of mistakes in research design, sampling approaches, and instrument development. It is important to recognize that survey design is a specialist field with well-developed methods, longstanding challenges and potential for seemingly small errors to create problematic conclusions. High-quality survey research requires considerable training and experience. Most commonly mistakes arise with researchers who −are outside of the social sciences who lack training and expertise in survey research methodologies. −may have difficulty recognizing survey methods as a specialist social science domain. −publish in journals that struggle to find reviewers with extensive survey-based experience. This is particularly relevant to researchers from areas such as health, environmental, natural, and physical sciences who do not have extensive training and experience working with survey methodology. Of course, this does not preclude interdisciplinary, multi-disciplinary and transdisciplinary research: indeed, such approaches are *(Continued on following page)*

TABLE 1 | (Continued) Key factors for effective COVID-19 survey-based research.

Key Factors	Explanation
	most fruitful when collaborators' complementary expertise is respected. "Epistemic trespassing" (see Ballantyne 2019) in the form of disregarding either specialized methodological skills or topic expertise can undermine collaboration. Good practices include –Involving formally trained survey research experts in the project design and ensuring that their advice is heeded as much as possible. Survey experience alone is insufficient, if it is not accompanied by a familiarity with the literature on survey methodology and how that literature can be put into practice. –Recognising the relevant field-specific topics included in your project and involve appropriate subject matter experts (e.g., if measuring aspects of mental health, including someone with formal training in psychology and experience operationalizing psychological concepts in surveys).
Longitudinal research structures Collecting data in a way that tracks or monitors changes over time	Longitudinal research allows for understanding changes in individuals' experiences (e.g., see Wagoner and Jensen 2015) during emergency situations. This form of data has unique potential to yield valuable insights about effective emergency responses and relief efforts by showing unfolding processes and emerging attitudes. Moreover, because many of the measures used (e.g., risk perception) measure subjective perceptions, their results are of limited value without the ability to conduct temporal comparisons. Best practices include –developing funding and institutional mechanisms to enable pre-event data collection to establish baselines. –maximizing, where possible, both the duration and frequency of data collection. –minimizing, where possible, variation in sampling and instrument design throughout the project through careful planning and anticipation of future data needs.
Repeated measures design Rather than recruit new participants in subsequent rounds or studies, return to the same individuals	Emergency situations can produce rich information about individuals' development during that can occur in personal circumstances, knowledge, trust, opinions, impacts and risk perceptions. Consider –targeted "top-up" of under-represented demographic categories where necessary. – reporting on current experiences on a repeated basis delivers more precise data than asking someone to report retrospectively. –minor adjustments between data collection rounds such as adding a new item to the survey to account for emerging context, while avoiding unnecessary adjustments to existing items.
Probability sampling strategies Random sampling approaches that are *simple* and *stratified* allow population-level claims	In general, probability sampling must be used if making inferences about a wider population such as citizens of a nation or a city (Smith and Jensen, 2016). Careful consideration must be given to systematic sampling problems, which can be exacerbated in emergency contexts (e.g., economic disparities leading to under-participation by low income groups during times of additional uncertainty). When non-probability sampling techniques are used, such as **convenience** (e.g., recruitment via advertisements, mailing list, social media, etc.) or **purposive sampling** (e.g., deliberately perusing certain respondents rather than others), claims must stay tethered to the sample and should not be used to make inferences about the wider population. Great care should be taken to assess the representativeness of different potential sampling sources when using commercial providers. Many public opinion research firms offer access to respondent pools—useful for obtaining comparatively quick and cheap responses—which may not reflect the population in important ways. Researchers should be careful to identify the strengths, limitations, and appropriateness of such pools for a given research question.

METHODOLOGICAL CONSIDERATIONS

In emergency situations, avoiding common pitfalls in methodological designs can be challenging because of temporal pressures and unique emergency contexts. We recommend the following standards in methodological designs for COVID-19 research (**Table 2**):

We also encourage readers to explore other resources for supporting methodological rigour in emergency contexts. In particular, the CONVERGE program associated with the Natural

TABLE 2 | Key methodological considerations for COVID-19 survey research.

Validated measures Surveys designs should use previously validated measures wherever possible	Individuals go through complex psychological processes when answering survey questions (e.g., Tourangeau et al., 2000; Wagoner and Valsiner 2005; Smith and Jensen 2016). Validated scales offer accurate ways of measuring different dimensions of attitudes and behavioral intentions, where quality has already been established. In contrast, first attempts to generate quantitative survey measures (e.g., levels of trust towards the government) can often produce invalid or unreliable measurement. Indeed, building on existing validated measures can be the difference between having a process of quantifying public attitudes and interests through rating scales (e.g., level of agreement Likert-type scales) that is straightforward and effective or fraught with measurement error and other methodological issues.
	Research frameworks for surveys must be carefully **conceptualized** (i.e., "what are we measuring") and **operationalized** (i.e., "how will we measure it"). It is easy to make errors in conceptualization (e.g., not clearly defining the group being studied

TABLE 2 | (*Continued*) Key methodological considerations for COVID-19 survey research.

Research frameworks Align research questions, concepts, and operations	or the phenomenon being measured) and operationalization (e.g., choosing a sample that doesn't represent the conceptualized group or using a measure that captures something other than the phenomenon) when creating new measures or straying from pre-existing definitions of groups. Triangulation between results from open-ended and closed-ended survey items in a questionnaire can be helpful to provide more comprehensive coverage of a topic than would otherwise be feasible.
Standardized surveys and questions Ensure comparability with other studies	Survey items and scales should be **standardized to enable comparisons**, allowing for benchmarking and identification of patterns across research studies. For example, demographic questions can be aligned with census questions, the local equivalent of the General Social Survey, or other investigations being run on COVID-19 or related topics (e.g., influenza; see Kennedy et al., 2020 for an example of such coordination in a Canadian context and Jensen et al., 2021b in a German context). Moreover, outcome (e.g., attitude or behavior) measures can be aligned to prior studies to allow for comparisons and/or future meta-analyses.

Hazards Center at the University of Colorado Boulder maintains a significant community resource via tutorials and "check sheets" to support method design and implementation (see https://converge.colorado.edu/resources/check-sheets/).

RESEARCH COORDINATION

Research coordination during emergencies requires pragmatic strategies to maximise the impact of evidence from rapid-response research. Despite massive government attention and resulting funding schemes, the available funds for social science research are outstripped by research needs–a situation made worse through duplication of research, overproduction, and inefficient use of resources in some topics. This results in fewer topics and populations receiving research attention, and investigations spanning a shorter period. It also generates a "wave profile" of investigation that is temporary and transient, disappearing as funds become limited due to economic constraints or further displacements occur to new topics.

We recommend the following practical considerations to maximize the efficiency, coordination, and effectiveness of survey-based research efforts (**Table 3**):

TABLE 3 | Primary considerations for coordination of survey-based COVID-19 research.

De-duplication Avoid unintentional repetition across projects	Where possible, significant effort should be taken to avoid multiple projects investigating the same questions in the same populations, instead joining efforts to increase granularity and representativeness of data and extend duration of project. This will allow for greater prioritization of strategic replication and diversified inquiry.
Coordination Collaborating across regions and disciplines can help to reduce costs, increase data comparability, and improve long-term data utility	Given the unprecedented number of projects investigating COVID-19 topics, efforts should be made to coordinate with other investigations in similar jurisdictions to avoid public survey fatigue, reduce overhead expenses, and allow for richer data analysis. For instance, Kennedy et al. (2020, 2021b) used one probabilistic survey to collect data on behalf of four separate funded research projects, while aligning survey items with several other jurisdictions—thereby allowing each research team to investigate a wider array of interactions (e.g., mental health, stigmatization, and social determinates) and reducing overhead costs in survey administration. To aid coordination in the context of COVID-19, the Natural Hazards Center at the University of Colorado Boulder has launched a research registry and a series of COVID-19 working groups through its long-established CONVERGE program (funded by the National Science Foundation), which provides coordination and networking functions within the disaster research community. CONVERGE provides training for researchers, supports ongoing projects through networks and funding, and runs a social science data repository for research in the field of natural hazards and disaster studies.[2] Researchers should be attuned to coordination efforts within their fields of study. For instance, a collaboration between University College London and the University of Copenhagen has launched the COVID Minds Network for registering surveys, sharing protocols, harmonizing measures, and facilitating cross-national comparisons of results for projects focused on mental health during COVID-19.[3]
Harmonization Use validated survey measures to improve comparability	Where possible, harmonization on survey items should be achieved by using pre-existing and previously validated measures. For instance, Kennedy et al. (2021b) borrow from Statistics Canada, the General Social Survey, and several previous epidemic surveys. Coordination networks, as described above, provide a framework for identifying emerging harmonized approaches, although more must be done—including in the wake of COVID-19—to identify best practices going forward for establishing these standards in advance, rather than on-the-fly.
Evidence synthesis Invest in scholarship to clarify existing knowledge	Given the vast proliferation of COVID-19 survey research (dozens to hundreds of results being released daily), researchers and practitioners alike face a high degree of difficulty in conducting real-time literature and evidence reviews of the topics investigated. Significant investment should be made into efforts that make this research easily identified, navigated, and searched. Robust systematic reviews, rapid evidence reviews or even scoping reviews can assist practitioners and data users to gain an understanding of what has already been established about a topic. It is important for funders to invest in reviews and secondary analyses, rather than always expecting more and more new empirical data to be produced.

[2]*To view or add a project to the research registry, visit https://converge.colorado.edu/resources/covid-19/public-health-social-sciences-registry. To review opportunities and join a working group (including an international COVID-19 working group on survey research), visit https://converge.colorado.edu/resources/covid-19/working-groups.*
[3]*See covid-minds.org.*

CONCLUSION

Evidence-based science communication and decision-making depends on the reliability and robustness of the underlying research. Survey-based research can be valuable to supporting communication and policy-making efforts. However, it can also be vulnerable to significant limitations and common mistakes in the rush of trying to deploy instruments in an emergency context. The best practices outlined above not only help to ensure more rigorous data, but also serve as valuable intermediate steps when developing the project (e.g., meta-analysis helping to inform more robust question formulations; methodological transparency allowing more scrutiny of instruments before deployment). For example, by drawing on existing survey designs prepared by well-qualified experts, you can both help to enable comparability of data and reduce the risk of using flawed survey questions and response options.

In this article, we have presented a series of principles regarding effective crisis and emergency survey research. We argue that it is essential to begin by assessing the suitability of questionnaire-based approaches (including the unique strengths of surveys, potential limitations related to design and self-reporting, and the types of information that can be collected). We then laid out best practices essential to reliable research such as open access designs, engaging requisite social science expertise, using longitudinal and repeated measure designs, and selecting suitable sampling strategies. We then discussed three methodological issues (validation of items, use of standardized items, and alignment between concepts and operationalizations) that can prove challenging in rapid response contexts. Finally, we highlighted best practices for funding and project management in crisis contexts, including de-duplication, coordination, harmonization, and evidence synthesis.

Survey research is challenging work requiring methodological expertise. The best practices cannot be satisfactorily trained in the immediate race to respond to a crisis. Indeed, even for those with significant expertise in survey methods, issues like open access, de-duplication of projects, and harmonization between designs can pose significant challenges. Ultimately, the same principles hold true in emergency research as in more "normal" survey operations, and "the quality of a survey is best judged not by its size, scope, or prominence, but by how much attention is given to dealing with all the many important problems that can arise" (American Statistical Association, 1998, p. 11).

The emergency context should not weaken commitments to best practice principles, given the need to provide robust evidence that can inform policy and practice during crises. For researchers, this means creating multidisciplinary teams with sufficient expertise to ensure methodological quality. For practitioners and policy makers, this means being conscientious consumers of survey data–and seeking ways to engage expert perspectives in critical reviews of best available evidence. And, for funders of such research, it means redoubling a commitment to rigorous approaches and building the infrastructure that supports pre-crisis design and implementation, as well as effective coordination during events. Building resilience for future crises requires investment in survey methodology capacity building and network development before emergencies strike.

AUTHOR CONTRIBUTIONS

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Coming Closer to Citizens? Frustrated Dialogue on the Danish Health Authority's Facebook Page During COVID-19

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As the COVID-19 pandemic began, health authorities rushed to use social media to communicate information and persuade citizens to follow guidelines. Yet a desire to "come closer to citizens" often came into conflict with the very consequences of doing so—many social media interactions were characterized by complaint, resistance, trolling or misinformation. This paper presents a case study of the Danish Health Authority's (DHA) Facebook page, focusing on the initial phase of the pandemic and on posts about face masks. Face masks were chosen as an exemplar of the many topics where scientific research was being communicated as it unfolded, and where relations between science, policy, and politics were also evolving in public. In other words, topics where *what* should be communicated and *why* was unclear and unstable. A qualitative thematic analysis of the DHA Facebook page, grounded in the practice-based knowledge of one of the authors and feedback meetings with DHA staff, unpicks what kinds of engagements between authority and citizens occurred, both explicitly and implicitly. The analysis particularly looks for dialogue—as a mode of communication implicitly promised by social media platforms, and as a well-established ingredient of trust in relationships between experts and citizens. Drawing on Grudin's definition of dialogue as "reciprocal and strange," we argue that the DHA's Facebook policy limited such encounters, in part by practical necessity, and in part due to professional constraints on the ability to discuss entanglements between health guidelines and politics. But we also identify "strangeness" in the apparent disconnect between individual engagements and collective responses; and "reciprocity" in the sharing of affect and alternative forms of expertise. We also highlight the invisible majority of silent engagements with DHA information on the Facebook page, and ask whether the visibly frustrated dialogue that ran alongside was a price worth paying for this informational exchange. The paper also

serves as an example of qualitative research situated within ongoing practice, and as such we argue for the virtue of these more local, processual forms of evidence-based science communication.

INTRODUCTION

As the COVID-19 pandemic unfolded, health authorities worldwide raced to communicate effectively, quickly, and with as wide a reach as possible. But *what* they needed to communicate to citizens was much less certain and stable than in typical public health scenarios. Research was fast-evolving and uncertain, with the inevitable corrections, caveats and retractions that followed. On top of this, health authorities could not wait for negotiations between science, health strategy, and politics to be completed; these processes were unfolding live on the public stage. Expertise in such scenarios is necessarily multiple; power is dispersed in complex and opaque ways; and many different informational needs unfold in parallel. To make things even more complicated, the proper relation between science and politics was itself at stake, and could not serve as a stable frame for discussing contentious public health measures. So health authorities needed to communicate about science; about science-in-the-making; about the relation between science and public health guidelines; and about the unsettled relations between politics and knowledge (Arjini, 2020). And they had to do so quickly—making it harder to find time to draw on existing communication research or conduct formative research along the way (Frontiers, 2020).

As with all public health messaging in recent years, COVID-19 communication has taken place within an expanded media ecology dominated by the promises and threats of social media platforms such as Facebook, Instagram, and Twitter—"forms of electronic communication … through which users create online communities to share information, ideas, personal messages, and other content" (Merriam-Webster, 2022). Institutions have been both bewitched and bewildered by the idea of *coming closer to citizens* through social media (Heldman et al., 2013; Korda and Itani, 2013; Teutsch and Fielding, 2013). Health authorities have entered Facebook, Instagram, and other platforms, negotiating new relations as the messiness of peoples' reactions to health information plays out in public (Canel and Luoma-aho, 2019; Lovari and Valentini, 2020; Sesagiri Raamkumar et al., 2020). Citizens have always spread misinformation, torn up leaflets from the doctor, ignored public health posters, or shouted at TV infomercials, but these responses *come closer* to authorities on social media, and seem to demand a more immediate response. This is a proximity that seems to help overcome barriers of authority whilst simultaneously highlighting the reason those barriers are there: questions about who moderates public speech become a daily challenge, both in terms of what citizens are permitted to post, and in terms of what authorities' employees are permitted to discuss (Andersen et al., 2012; Myers West, 2018; Chadwick et al., 2021; Lovari et al., 2021; Tsao et al., 2021).

The communication situation unfolding around COVID-19 was christened by the WHO and others as an "infodemic;" "an overabundance of information—some accurate and some not—occurring during an epidemic, that […] makes it hard for people to find trustworthy sources and reliable guidance when they need it." (Tangcharoensathien et al., 2020). Misinformation spread on social media about the virus, the disease, its symptoms, prevention, transmission, and treatment, caused serious difficulties for authorities in implementing guidelines and restrictions—to some degree an unavoidable phenomenon in a novel disease scenario (Allington et al., 2021; Lovari et al., 2021). Calls were made to "treat the infodemic" with fast rollouts of informational inoculation, and researchers used the metaphor as a framing for research (Cinelli et al., 2020; Scales et al., 2021).

But what kind of treatment an infodemic requires is an open question. In addition to providing clear, accurate, and accessible information and managing the production and sharing of misinformation, we need to engage with citizens who hold opposing views or whose structural conditions restrict them from following accurate information and advice they might receive. Research on combating polarization and conspiracy theories on social media emphasizes the importance of recognizing participants' concerns and the community functions of these "bubbles" when addressing their members (e.g., Pariser, 2012; Harambam and Aupers, 2015; Del Vicario et al., 2016; Arceneaux et al., 2021), and recognizing that both those spreading and challenging misinformation can "behave badly" (Johansen, Marjanovic, Kjaer, Baglini and Adler-Nissen, in press).

This complex situation left health authorities with a dilemma. Health authorities increasingly recognized that "top-down" communication by experts needed to be supplemented by more reciprocal dialogue, but could they really provide the latter? What if the questions they were ready to answer were not the ones citizens want to ask? How could authorities balance the need to defend the status of their knowledge, with the need to recognize "unreasonable" concerns amongst resistant publics? How could they enact the transparency essential to building trust without airing too much uncertainty and "dirty laundry?" When is dialogue even appropriate—do people sometimes just want authoritative information, and is censure of dissent sometimes the most responsible strategy?

This dilemma is baked into social media, which were originally structured around notions of sharing, democratizing, and bottom-up community building, but nowadays host many groups whose communicative goals are far less democratic. Facebook contains what would earlier have been websites; constantly duplicates media from mass dissemination channels; and has been used to host helplines, Q&As, adverts and infomercials. As such it can be hard to navigate the relation

between what is promised by the form of the platform itself, and what producers are actually willing to deliver. It looks like dialogue—but is it? If people expect dialogue but receive the shutdown of dissent, how will they react? This dilemma is nothing new—it arguably characterizes the history of science communication and its academic critique (Nisbet and Scheufele, 2009; Bucchi, 2017)—but it comes into sharp focus in the current situation and on social media, and its detailed contours need to be understood in order to improve practice (Scheufele, 2014; Jensen and Gerber, 2020).

A Practice-Based Case Study

This paper addresses how health authorities navigated dialogical relations with citizens on social media with respect to a case study: the Danish Health Authority's Facebook posts about face masks during the first phase of the pandemic. The Danish Health Authority (DHA) entered Facebook just before COVID-19 emerged; a baptism of fire that meant practices were fresh and malleable. The DHA Facebook Strategy aims to provide citizens with important health information "at eye level," and to contribute to a greater knowledge of the DHA among citizens (Liebst, 2020).

Drawing from a unique data set of all the DHA's posts and citizen[1] engagements during the first year of the pandemic, we chose to focus on posts about face masks. Face masks were a contentious issue from the start of the pandemic, where scientific evidence was being gathered in parallel with the announcement of health guidelines and political arguments, exemplifying the challenges of communicating when relations between institutions are playing out live. As a *Nature* news article asked in October 2020; "The science supports that face coverings are saving lives during the coronavirus pandemic, and yet the debate trundles on. How much evidence is enough?" (Peeples, 2020). Face masks directly impact citizens' everyday lives and cultural beliefs, and thus give rise to a multitude of questions, opinions, and critiques (Martinelli et al., 2021; Steiner and Veel, 2021). They are designed to lower risk, but authorities worry that their use might also amplify risky behavior (see Jørgensen et al., 2021). Denmark also offers an interesting case in relation to face masks, as there is a high degree of trust in government and compliance with COVID-19 health measures, but also a history of controversial political resistance to the wearing of face coverings such as the niqab and burqa (Perolini, 2020). Indeed, the requirement to wear face masks in public arrived later in Denmark than in many other countries, and rather suddenly.

We present a qualitative analysis of the case supported by quantitative description of the Facebook engagements, aiming to provide a richer understanding of what happens when health authorities enter purportedly dialogical platforms. We hope that our research provides locally situated knowledge that might help to guide future practice. The case is further used to ground a discussion of more theoretical concerns about what dialogue is

and can be in such situations. The paper is thus an example of an interface between research and practice—but not one where the research was commissioned by the practitioners, or where the practice was directly and explicitly guided by the research. Rather, one of the authors (FM) was employed as a moderator on the DHA's Facebook platform at the same time as she was researching the platform for her master's thesis, which then became the present article in collaboration between researchers from three different faculties at the University of Copenhagen, including two (R A-N and NJ) who are involved in a wider research project How Democracies Cope with COVID-19 (HOPE)[2].

The research was thus grounded in practice-based knowledge, and questions and observations from the research fed back into the Facebook moderators' discussions, both formally and informally. We presented the findings to the DHA's communication team at several points, and at the end of the project held dialogue meetings with three leaders and three moderators, to ground our analysis in their perspectives on Facebook and the relevance (or not) of our findings. As we will consider further in the Discussion and in relation to Jensen and Gerber's call for evidence-based science communication (Jensen and Gerber, 2020), this is *research with practice*, more in line with qualitative traditions of participatory and action-based research or auto-ethnographic science studies, than with attempts to gather more rigorous and generalizable quantifiable knowledge about tightly characterized communicative scenarios. In the Analysis section of the paper, we weave together our quantitative characterization of the data, qualitative analysis of the post types and forms of citizen engagement, and comments from the DHA feedback meetings, along with our interpretation of the relationship between intentions and outcomes.

Dialogue in Science Communication

In this last introductory section, we situate the concrete dilemmas outlined above within the science communication literature. Science communication studies have produced many models of the relations between scientific experts and publics. Across diverse terminologies, three fundamental categories emerge: (1) information dissemination from experts to publics (often referred to as the "deficit model"); (2) experts listening to publics; and (3) a more reciprocal or two-way engagement, where the boundaries between expert and public are challenged and it is accepted that the topic under debate cannot be fully captured by any one form of knowledge. This classification was originally introduced as part of an argument for shifting from (1) toward (2) and then (3), fueled by social change as well as sociological studies emphasizing the failures of traditional dissemination for securing public support and for supporting robust, socially appropriate decision making (Wilsdon and Willis, 2004).

Following this important shift around the end of the twentieth century, a variety of more nuanced analyses of what takes place in science communication have unfolded—alongside a subtler critique of the normative dimensions of a desire for dialogue

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[1]We use "citizens" to refer to people posting on the DHA's Facebook page—instead of the more typical, consumer-oriented "users." This is in order to reflect the DHA's language and how the health authority imagines its relations with those they engage on social media. Note it does not imply that all those engaging with the Facebook page are legally Danish citizens.

(Broks, 2004; Bucchi and Trench, 2008; Einseidel, 2008; Trench, 2008; Irwin, 2009; Davies and Horst, 2016). Five key conclusions from this field guided us in the present analysis:

- First, that no form of relation is inherently good or bad; dissemination and dialogue can be appropriate in different scenarios.
- Second, that in many communicative situations all three forms of relation occur together and interweave—particularly over an extended period of time.
- Third, that the role of science communication in participants' identity and culture, and the interplay between cognition and emotion, is often crucial to the outcomes.
- Fourth, dialogue is a complex phenomenon and appearances can be deceptive; paying close attention to who says what, and with which affective content and epistemological consequences, is crucial to understanding a particular scenario.
- And fifth, "improper" engagement—where publics do not do what is expected, or fail to play by the rules—often reveals flaws in the producer's understanding of the scenario, and of the social context in which science communication unfolds.

Our analysis of the case study exemplifies all five principles, and the way in which nuance can emerge when they are taken as starting points, rather than starting from a normatively charged assumption that more reciprocal engagement is always good.

A key concept within these science communication models and for our analysis is *dialogue*, which has received many definitions, across disciplines and over millennia. We do not intend to contribute to the literature on dialogue itself, but instead interrogate the concept within our context. Within science communication practice "dialogue" has been too frequently uninterrogated, and requires deeper critical reflection within science communication scholarship too (see, e.g., Chilvers, 2013; Davies, 2014). It can be an overly flexible way of referring to a huge diversity of forms of interaction, highlighting the instability of the boundaries between the three forms of expert-public relation outlined above. Calls for dialogue can also indicate a desire for equality that is more tokenistic or instrumental than authentic, or which simply cannot be met in practice (Kerr et al., 2007; Einseidel, 2008). To understand an instance of science communication, we therefore follow Davies (2019) and Edwards and Ziegler (2022) in arguing for an STS-inspired approach that examines not just explicit exchanges between scientists and publics, but also "disassembles" the multiple hidden actors involved.

In relation to healthcare settings, Reid (2019) argues that "The characteristics of health dialogue include an equal, symbiotic health relationship between the patient and the healthcare provider, and reciprocal health communication toward reaching an identified health goal *via* a health message"—which seems like a far-away dream in the COVID-19 scenario. In this paper, when asking whether dialogue occurs, and then asking how this relates to ideas about the relations between experts and publics, we draw on Grudin's (1996) description of dialogue as characterized by reciprocity and strangeness:

By reciprocity, I mean give-and-take between two or more open minds or two or more aspects of the same mind. This give-and-take is open-ended and is not controlled or limited by any single participant. By strangeness, I mean the shock of new information—divergent opinion, unpredictable data, sudden emotion, etc.—on those to whom it is expressed. Reciprocity and strangeness carry dialogue far beyond a mere conversation between two monolithic information sources. Through reciprocity and strangeness, dialogue becomes an evolutionary process in which the parties are changed as they proceed. (Grudin's, 1996, 12)

This is also a high bar, and we do not use this definition in order to suggest that the DHA *should* be facilitating "strange and reciprocal" dialogue. Rather, we use it to sharpen our attention to what is actually desired, promised, and achieved in purportedly dialogical science communication. As a way of seeing what is missing, as well as what is present—and looking for this not just in the explicit back and forth between the authority('s proxies) and those engaging with Facebook, but also in interactions between citizens, and in invisible "reading" that leaves no trace in the comment threads (see also Davies, 2019; Edwards and Ziegler, 2022). We unfold the multiple forms of engagement present in this single case, and the diverse relations they imply. In the Discussion, we also consider the fragile conditions that supported this ecology of interactions—speculating about features of the face mask debate that allowed for a balance between authority and citizens that was later challenged when the dominant question became vaccination.

MATERIALS AND METHODS

We first did an initial quantitative descriptive analysis to explore and characterize the data, and help select material for an in-depth qualitative analysis (Creswell and Plano Clark, 2007; Hollstein, 2014). As described in more detail below, the qualitative thematic analysis was developed through an initial pilot study of a key DHA post, and then developed iteratively on a larger subset of 13 highly commented posts.

The analysis was grounded within FM's work as a moderator on the Facebook platform; her situated knowledge (Haraway, 1988) of how moderators experienced working with citizen engagements inflected the developing research questions and thematic categories. And finally, a more explicit dialogue between research and practice informed our interpretations; the authors presented to the DHA during the study and then conducted interviews at the end with three leaders ("leaders meeting") and three moderators ("moderators meeting") in order to enrich and sense-test the analysis; the leaders also read the final manuscript.

The DHA Facebook Page Data

This study originated with the unique opportunity to gather all Facebook posts, comments, and replies to comments (collectively "engagements") from the DHA's Facebook page between February 29th and October 11th, 2020. This was conducted under a data agreement between the Danish Health

Authorities and the HOPE project[3] at the University of Copenhagen, which includes a commitment to use the data only for scientific purposes, not share it outside of the team and ensure full anonymity.

At the start of our data collection period the Facebook page was relatively new, and the number of followers increased during the period—by the time of the leaders meeting, they reported 175.000. The data included 748 DHA posts, 31,535 comments, and 44,945 replies. This does not include 564 citizen engagements that contained only visual elements, as our analysis was only of written text. Of the combined engagements, the DHA were responsible for 14%, suggesting that they are active in responding to comments as well as producing posts. There was a mean of 2.44 engagements per user, with only seven citizens engaging more than 100 times during the data collection period. Only 4.6% (3,538) of the engagements were hidden by DHA moderators. We delimited the data set by selecting all engagements mentioning "face mask" or common Danish synonyms ("mundbind," "mundble," "mb," "fjæsble," "maske," "mundvand," "mundværn," "bundbind," "mundbeskyttelse"), which yielded, 7,895 engagements. This was then used to select key posts for the qualitative analysis (see below).

Figure 1 reconstructs and translates into English a typical Facebook post, consisting of a capitalized title, brief paragraphs of text often including short bullet points, and sometimes further supplemented with infographics, a picture, or a video. Comments are entered below the main post, and replies can be made to comments and to each other. The DHA posts on face masks included recommendations, regulations, how-to guides, or a combination, and the title was typically a question such as "What type of fabric mask can I use?" or "Should you wear a face mask to school?", or an informative heading such as "This is how you use a face mask" or "Face masks are required on public transportation." **Figure 2** reconstructs an excerpt of a (translated) comment thread, showing several citizens engaging in a back-and-forth exchange with occasional input from a DHA moderator.

An engagement was *hidden* by the DHA moderators if it could be characterized as dangerous misinformation, if it had a racist attitude or aggression toward other Facebook users. Engagements that only or mainly contained a link or were considered spam were also hidden. In extreme cases the employees could *delete* engagements—if the content was particularly offensive, insulting, or racist in a way that they considered could not be tolerated. If the engagement included sensitive personal data, the content was also deleted to protect the person [practice as stated in appendix to Liebst (2020), DHA internal document]. As was explained by one of the DHA communication leaders: "We cannot delete misinformation. We can delete if someone is throwing a bunch of middle finger emojis, but if someone is trying to convince with information or links to other pages then we cannot delete it," (Leaders Meeting, 2021), though as we discussed at the leaders and moderators meetings, there is a grey zone between dangerous or insulting content, and persuasion or misinformation that the

DHA might disagree with. Facebook itself also can hide and delete engagements without knowledge from the DHA, so we are not able to provide statistics on this. But despite the challenges of this work, the moderators and leaders also talked of their commitment and excitement at being involved. For example, one moderator said; "It was exciting to get going and see if we could go into dialogue, AND we can! It's so cool when it works … I also think it's fascinating to try and understand how on earth they can be so far from what I think is reality" (Moderators Meeting, 2021).

Quantitative Analysis

The face mask engagements were analyzed using Python Programming for Data Science, with two purposes. First, giving a better description of the data set by characterizing the frequency of engagements, by which user, and how this unfolded over time, giving general information about the pattern of posting on the Facebook page. Second, this descriptive quantitative analysis was used to help select posts for the primary qualitative analysis, where we investigate the character of dialogical exchanges between DHA and citizens in more depth.

Pilot Study and Qualitative Analysis

We carried out a pilot study prior to the qualitative thematic analysis (Braun and Clarke, 2006) using the DHA Facebook post "Frequently asked questions about the use of face masks" from July 23rd, 2020. This post was chosen as it occurred at a key point in the evolution of face mask guidance—shortly before face masks were made mandatory and the DHA updated its guidelines—and also as it generated many engagements (437 in total, 221 of which mentioned face masks at least once). In the pilot study we searched for phrases relating to the guiding interests outlined in the introduction, coupled with an openness to emerging themes. The primary interest was how citizens and the DHA engaged with each other—we looked for when and how citizens provide, seek, contest, or co-create information; for signals of trust or distrust; for dialogical patterns or their absence; and for markers of expertise and (dis)respect for expertise.

The full qualitative analysis was then conducted on 13 key posts relating to face masks, including the pilot study post. In the period February 29th–July 8th, before the DHA explicitly posted about face masks, 7 posts with the highest number of mentions of face masks in the comments and replies were selected. In the remaining period, a subset of 6 of the DHA posts directly relating to face masks were selected by hand, choosing posts with high numbers of engagements but also in order to give good coverage across the period, and capture responses to key changes in the guidelines. We used the pilot study to initiate the recursive development of a thematic coding tree, working through each post and its engagements chronologically and cycling back through the material as the themes evolved and new elements emerged. The tree was structured according to key DHA-citizen engagement patterns, which also structures the Analysis section below.

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[3]https://politicalscience.ku.dk/research/projects/hope/

The Danish Health Authority ✓
August 25, 2020 · 🌐

WHAT TYPE OF FABRIC FACE MASK CAN I USE? 😒
It is new for us Danes to wear face masks in public spaces. With the mandate to use a face mask on public transport, we all need to consider what kind of face mask to acquire.

We primarily recommend CE-marked disposable face masks because the degree of protection is documented. If you buy a fabric face mask, the degree of protection is not subject to the same quality standards, but a good fabric face mask is still better than no face mask.

If you are getting a fabric face mask or sewing one yourself, there are a few things you should be aware of:
■ The face mask should sit close to the face and preferably be made of three layers of fabric.
■ The material must be dense enough to create filtration, whilst still breathable. It can be, for example, tightly woven cotton.
■ It is a good idea to choose light colored material so you can see if it is dirty. The material must also be washable at 60 degrees.

How to use a fabric face mask:
■ Face masks are personal. Do not share with others.
■ Face masks should be changed when dirty or damp and washed at least once a day.
■ Fabric face masks must not be reused. When you're on the go, it's therefore a good idea to bring more than one with you in a sealed bag.

Six tips on fabric face masks

FIGURE 1 | Exemplar post about face masks from the Danish Health Authority's Facebook page. Translated into English.

The coding was conducted in NVivo by FM, and the development of the codes and the coding tree were continuously discussed in relation to excerpts with other authors. The conceptual interpretation of the themes was also developed in dialogue across the author group and refined through discussion with colleagues in the DHA Facebook team. The data material was in Danish, but quoted engagement extracts are translated into English.

Relations Between Research and Practice

This research builds on a unique collaboration between research and health institutions. Author FM was both employed in the HOPE project at the University of Copenhagen and at the DHA. FM's key task at the DHA was to monitor the Facebook platform and she was thus both producer and researcher of the same phenomenon. This situated position requires reflective consideration of its impact on

Citizen A
I can't believe it!!!! Since all this started you've said we should cough and sneeze in our sleeves to avoid infecting others, and now 5 months later you say it might be better to use a face mask, as it probably works better???? A kindergarten teacher would have managed the situation better than you. Unbelievable that you get paid for this unbelievable mess!

22

The Danish Health Authority
Hi Citizen A,

We still recommend that people cough and sneeze into their sleeves. But in certain situations, one can consider wearing a face mask. For example if you have symptoms or are infected with the novel coronavirus and need to go to hospital, if you are on your way back home from the airport, or if you can't stay distanced from a person who is at high risk.

We still do not recommend that healthy people moving around in public spaces use face masks.

Best regards [name], The Danish Health Authority

28

Citizen B
Citizen A don't people have the right to improve, we're constantly learning something new right?

14

Citizen B
And that goes for all points, one is ALWAYS learning

4

Citizen C
Citizen A where does all this anger comes from? I think when you consider that no one has tried a situation like this before, they did damn good across the board. It could have gone much worse. I think we should applaud all the people - some of them with their lives at stake – who have taken their turn in this situation. Thanks to all of them.

25

Citizen C
Citizen D they've been saying that all along. That's one of the reasons they were testing everyone, even those who had no symptoms.

5

Citizen E
Citizen A http://www.sst.dk/.../recommendations-on-infection-prevention...

SUNDHEDSSTYRELSEN | SST.DK
Recommendations for preventing infection have been supplemented with specific situations where you can use a face mask...

2

Citizen A
No Citizen B they should not be learning all the time, they should be at the forefront - always! They are the ones who should guide us in such a situation, and not slur their words about the importance of how to protect yourself and others. It's simply pathetic!

3

Citizen F
They haven't slurred their words on anything, I think they have reacted quickly and so far the strategy has worked against an unknown enemy. You could blame lots of people, but what do you get out of it...

9

Citizen G
Citizen A you seem out of educational reach. Get a grown up to teach you.

2

Citizen H
Citizen A where on earth did you read that a face mask is better? At least it doesn't appear in this article

2

FIGURE 2 | Exemplar comment thread from the Danish Health Authority's Facebook page. Reconstructed and translated into English. Please note, this figure is split across two pages.

Citizen A
In Slovakia Citizen H the face mask has been mandatory from the beginning. They have 28 deaths from Corona and a population similar to Denmark! http://ekstrabladet.dk/.../danske-myndigheder.../8080002

> EKSTRABLADET.DK
> Danish authorities stand firm: Face mask do not help against corona

👍 2

Citizen I
Citizen C what nonsense. These people sit where they do for exactly ONE reason: Because it is EXPECTED that they act right in any situation, even UNKNOWN situations. Otherwise, you could just follow a procedure book. I hope the whole gang gets thrown out, especially the Minister of Health, the power-hungry man with too much power to intimidate, which he (funny enough) won't relinquish now. EW!

👍😡 5

Citizen J
Citizen A Exactly

👍 1

Citizen K
Citizen A You can choose to think for yourself. But easier to shoot at others

👍 1

Citizen L
The Danish Health Authority I guess you mean Covid19?

Citizen M
Citizen A Why isn't The Danish Health Authority allowed to develop their instructions gradually, as experience builds up worldwide? Should one always stick to the first thing one knew, or could it be that we should develop existing knowledge?

😆 2

Citizen M
Citizen A you use Ekstra Bladet [ed. a Danish tabloid newspaper] as your source! A medium which consistently reports on the truth in distorted ways to appeal to emotions and trigger outrage. It would be more convincing if you were linking to real peer-reviewed research so we can avoid the fake news that is currently flooding social media.

Citizen N
Citizen A well, take it easy!!!

Citizen O
The Danish Health Authority face masks are not safe because microparticles can enter from the sides. They do not provide 100% protection. For them to work 100%, we would all need custom-made masks…

Citizen P
Citizen A if the Danish Health Authority doesn't have to learn all the time it makes no sense. They must make the best possible assessment on the basis of what we currently know. As this is constantly changing their assessments will of course change over time. At the same time, it is important that they do not flutter from one recommendation to another as it's challenging for us as citizens to deal with rapidly changing recommendations ...

👍 2

The Danish Health Authority
Hi Citizen D,

It is true that you can be infected with new coronavirus without developing symptoms. Therefore, it is important that everyone continue to follow our general advice for preventing the spread of infection, which you can read more about here on our website:
https://www.sst.dk/da/corona/FAQ#corona-faq-raad

Best regards [name], The Danish Health Authority

FIGURE 2 | Continued

the work, but has had several valuable impacts. FM's dual role brought insider knowledge about how the Facebook platform worked and evolved throughout the research period, and enabled us to refine our analysis through dialogue with and in practice, not just with FM but also with her colleagues.

Throughout the research period, FM and others from the HOPE project shared preliminary findings and open

FIGURE 3 | Number of engagements concerning face masks on the Danish Health Authority's Facebook page, posted by the DHA and by citizens, from March 1st to October 11th 2020.
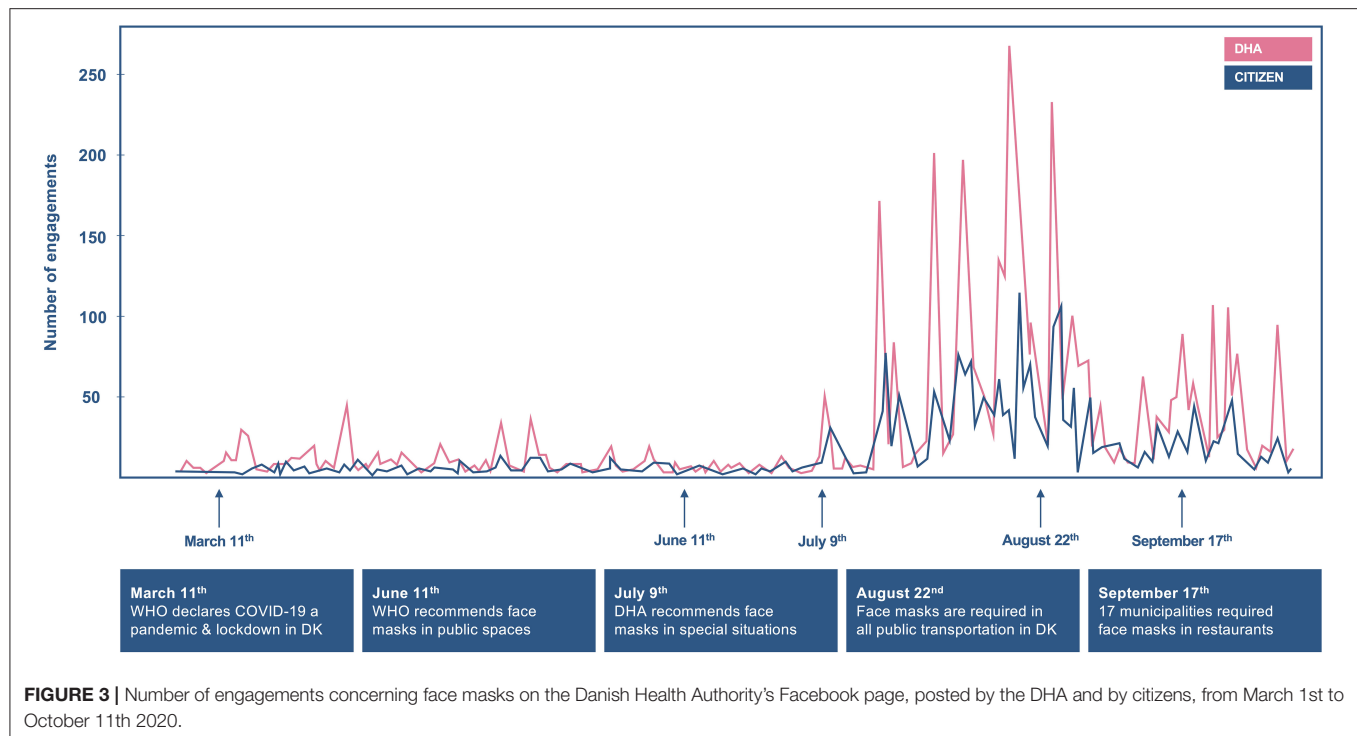
questions with DHA communication staff. At the end of the project we conducted two more formal meetings, which were audio-recorded and transcribed. First, a 1 hour "leaders meeting" with three senior staff members from the DHA communication department. In addition to presenting our findings and asking for feedback on our ideas about DHA-citizen engagement patterns and their perspectives on misinformation, we discussed how the DHA had experienced the communication challenge presented by the pandemic, how their responses evolved, and what future steps were planned or wished for. Second, we carried out a 1.5 hour "moderators meeting" with three DHA student assistants employed to monitor the Facebook page. Specific additions for this conversation were to discuss their experiences monitoring the DHA Facebook page, and their views on the DHA communication, information flows and practical work.

ANALYSIS

In the Analysis section of the paper, we weave together our quantitative characterization of the data, qualitative analysis of the post types and forms of citizen engagement, and comments from the two DHA feedback meetings, along with our interpretation of the relationship between intentions and outcomes. Quotations are from citizen engagements, unless indicated as from the "leaders meeting" or "moderators meeting," and all quotes are from 2020, unless otherwise indicated.

Engagements Over Time

Figure 3 illustrates the incidence of engagements that mention "face masks" over the period, divided by whether engagement was by the DHA or citizens. The vertical lines on **Figure 3** indicate key

announcements, DHA recommendations or new government regulations (see **Table 1** for a summary list). Face masks were mentioned throughout the period, including prior to the first formal face mask mandate on July 9th and the DHA's first post about masks. There was an average of 7.45 engagements per day before the first mask recommendation was posted on July 9th, and an average of 73.36 engagements per day after that date and until October 11th. There is no consistent relation between key announcements and frequency of engagements, but there are noticeable peaks when face masks were made mandatory in new situations. There is clearly some correlation between the peaks of DHA and citizen engagements (Kendall-Tau correlation coefficient 0.599), hinting that back-and-forth communication is occurring.

Goals of the DHA Facebook Page

At the leaders meeting it was explained that the DHA had entered Facebook because there "has been a desire to be much more citizen oriented and much more at eye level" and that "There has been no doubt that the DHA should be represented on Facebook, because it is the biggest social media platform in Denmark and it is where one meets the citizens." This reflects a general sense that institutions must use social media, and the often rapid way in which they have to launch such platforms. The nascent Facebook platform was then rapidly overtaken by the COVID-19 pandemic, and the DHA's communication role and resources were greatly expanded:

> We have never ever had such a prominent role in relation to the entire population. We used to manage it ourselves in connection with efforts or campaigns or something else, where we of course

TABLE 1 | Danish face mask recommendations and regulations, July–October 2020.

Face mask recommendations and regulations in Denmark, July—October 2020

July 9th. The DHA changed their recommendation from face masks not being needed in public spaces, to recommending that people wear face masks in special situations to protect others. The special situations were described as: if one had to break self-isolation when travelling to hospital, transportation from the airport after arriving from a high-risk area, if one is a close contact to an infected person and needs to travel to get a test, and if one has a relative at risk of getting seriously ill with COVID-19 and cannot keep the recommended distance.

July 31st. The DHA expanded their recommendation to use face masks on public transportation when crowded, as increased infection rates were expected due to the summer holidays ending, people getting back to work and school, and expectations of people spending more time indoors in Autumn.

August 7th. Face masks became mandatory on public transport in the city of Aarhus due to locally high infection rates. Infection rates continued to increase across the country and on *August 15th.* people at increased risk were advised to wear a face mask in all situations where it was not possible to keep the recommended distance, and everyone was advised to wear a face mask on public transport at all times, prior to it becoming mandatory on *August 22nd*.

September 17th. Mandatory face mask wearing was expanded to restaurants, bars, cafés and similar venues in 17 municipalities.

September 28th. The DHA intensified their recommendations for the use of face masks in the health and senior care sector, and in some parts of the social care sector.

October 23rd. Face masks were required in all indoor areas with public access.

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have reached out and entered into dialogue and everything, but we have never been as 'available' to the population as we have been during this pandemic. (Leaders Meeting, 2021)

The Facebook page was driven by two key imperatives, to "answer questions" and "be present" (Leaders Meeting, 2021), and to do so informed by professional expertise. The DHA thus chose to employ internal moderators, who draw on experts to develop an answer catalog that evolves as questions change, rather than employing an external company to moderate the site. This was only possible due to the unprecedented budgets allocated to COVID-19 communication—and described at the leaders meeting as a luxury, offering citizens an unusually responsive service to citizens.

The DHA see their readiness to answer questions and respond to comments in this relatively direct way as dialogue. Yet despite the huge investment in the platform during COVID-19, capacity was still limited relative to demand. The description on the Facebook page indicates that during busy periods, individual citizens can expect a maximum of one to two responses per week, and that questions on posts more than 4 days old will not be responded to Sundhedsstyrelsen (n.d.). There were also serious limits on what the moderators could enter into dialogue about. In the leaders' meeting they drew a distinction between political decisions that moderators cannot comment on, and professional recommendations and guidelines, which are the appropriate remit of a health authority. Moderators were also instructed to give only general and official guidance, not individual or personalized advice. Here we see a restricted practice of dialogue developing, shaped by the institutional role of the platform as well as by resources—questions concerning certain matters can be

responded to in certain ways, and without sustained interaction or personalized contact with individual citizens.

Forms of Communicative Engagement

So how did citizens engage with this offer? The overall impression from our analysis and from talking with the DHA staff was one of intense demand, in the context of citizen confusion and frustration around multiple and shifting sources of information. As one user wrote early in the pandemic:

> I follow the Danish guidelines because I live here, and I have confidence in the Danish health care system as they are more competent than we are – but I will not hide that I am gradually becoming more and more frustrated by directly opposing orders all around – March 12th

As outlined in the Methods, we selected 13 key posts and responses for the main qualitative analysis. This thematic analysis focused on forms of communicative engagement between the DHA and citizens engaging on Facebook, asking when citizens provide, seek, contest, or co-create information; how expertise and trust are indicated, and whether and how dialogical engagement occurs. We were sensitized by the five principles outlined in the introduction that emerge from critical engagement with traditional science communication models— acknowledging that multiple forms of communication often coexist, that their normative status is contextual, that key actants may not be visible in the explicit exchanges, and that affective responses and unruly "misbehavior" are not just mess but a critical part of what occurs (e.g., Horst and Michael, 2011; Davies and Horst, 2016; Davies, 2019). The three key categories that emerged are outlined below. Each is a more explicit description of the "top layer" of what is going on—but we also discuss the multiple layerings of forms of communicative engagement present within each. We then conclude with a fourth cross-cutting theme looking at the link between strong emotion and dialogical patterns.

Seeking Information and Justification

Citizen engagements categorized as "seeking information" posed questions or requested clarification or further detail. For instance;

> I am wondering if it is true that disposable face masks can be reused if microwaved?—August 5th
> Is the use of a face mask required when visiting one's general practitioner?—September 19th

These are typical examples of citizens asking detailed questions, trying to "do the right thing" and follow restrictions and recommendations, as they ask for help on how to navigate in their daily life during the COVID-19 pandemic. Notably though, the questions asked were not always related to the topic of the original post—an indicator that agendas can be shifted by "non-experts" even if they are requesting information from experts.

Not all questions were as clear and precise however, and many engagements appeared as an informational request but where the question posed could be read as rhetorical, sarcastic, or used in

order to express an opinion about the perceived inconsistency or irrationality of a particular guideline or regulation. For instance;

> Could the Danish Health Authority soon take a stance on their opinion regarding the use of face masks among the Danish population?—July 23rd

> Why is one required to wear a face mask in restaurants but not in retail shops 😒 This makes no sense to me 🙄—September 19th

The first example should be read in the context of the DHA taking longer to make a decision on their face mask guidelines than most other European countries, a gap that allowed debate and uncertainty to flourish. These "pseudo-questions" seem to express frustration, but they are *also* requests for information, *and* commentary; they offer affective information to the DHA about how citizens feel, as well as requesting facts or actions.

Citizens who seek information behave roughly as the DHA describes in their strategy. They place the DHA as the expert, either implicitly by seeking guidance or explicitly by saying that the DHA should know how to guide citizens. Such engagements were typically easy to answer by the moderators as answers were available on the DHA webpage or answer catalog, falling within the DHA's self-defined area of responsibility. But in another looping between traditional science communication models, this apparently clear example of "expert informs citizen" was also a route by which the DHA learnt from citizens about what they wanted to know. Thus, from the perspective of information *on COVID-19*, the engagements were classic dissemination, but from the perspective of information *on what citizens want to know*, the engagements were also an example of experts listening to publics.

Giving Feedback and Lack of Response

This category describes citizens who give feedback on the DHA and their guidelines. Most feedback was negative—as expected on social media, where approval is often expressed as a simple "like" or silence, whilst negative emotions are more likely to result in extended expression. Feedback is characterized by being evaluative rather than information-seeking. For instance;

> Thanks to the Danish Health Authority for the great work you are doing—August 5th

> Good to know about the optimal use of face masks and how best to store them—September 19th

> No thanks 👆😐👆—August 15th

> I will not wear that shit—September 19th

A lot of the engagements in this category gave feedback specifically about how the DHA *changed its position* on face masks. Some citizens defended the work of the DHA, often contextualized with reference to the complex situation, but many were angry and even aggressive. One citizen wrote:

> I can't believe it!!!! Since all this started you've said that we should cough and sneeze in our sleeves to avoid infecting others, and now 5 months later you say it might be better to use a face mask, as it probably works better???? A kindergarten teacher would have managed the situation better than you. Unbelievable that you get paid for this unbelievable mess! – July 9th

The DHA replied with:

> Hi [name], We still recommend that people cough and sneeze into their sleeves. But in certain situations, one can consider wearing a face mask. For example if you have symptoms or are infected with the novel coronavirus and need to go to hospital, if you are on your way back home from the airport, or if you can't stay distanced from a person who is at high risk.

> We still do not recommend that healthy people moving around in public spaces use face masks. – July 9th

The citizen points out inconsistency over time, and interprets it as incompetence, with a sense of being let down by a well-funded institution. The interpretation of changing advice as incompetence was commonly expressed, both by citizens who were pro- and against the use of face masks.

How to manage shifting knowledge is a long-standing challenge for public health authorities, where frequent changes of guidance can reduce trust—for example, as advice around drinking in pregnancy or healthy diet composition changes. This has been used to argue for communicating honestly about the limitations of knowledge—so that when guidelines change, publics will be less likely to lose trust (e.g., Irwin, 2008). In the case of COVID-19, guidelines changed regularly, and uncertainty surrounding the scientific knowledge on which they were based was unusually public. Nonetheless, we still saw emotional reactions to this "shifting ground"—and it is unclear whether more explicit transparency about uncertainty would have helped or hindered peoples' positive feelings toward the DHA (though see Petersen et al., 2021).

The reply from the DHA follows a classic pattern, answering with dissemination of information as if the citizen had asked, "Should I wear a face mask and when should I wear a face mask?", rather than reacting directly to the feedback and frustration that is clearly expressed. Here we see the severe limitations of dialogical engagement—the moderators are not able to acknowledge the feelings of the citizen nor defend the DHA. Rather, they perform their informational, "non-political" function, addressing the collective "people" rather than the individual citizen, and deliver whatever they best can within the constraints of this role. To return to Grudin's (1996) definition of dialogue as characterized by "reciprocity and strangeness," this exchange inverts reciprocity—it is controlled and closed down by the expert. However, there is certainly something "strange" about it. Not the "strangeness" that might be generated by the DHA openly (and thus vulnerably) engaging with the citizen's feelings, but there is an "emotional shock" generated by reading and perhaps receiving this exchange. We learn something about what is possible for the parties, even if they do not engage in learning more about each other's opinions.

Until July 2020 the DHA insisted that there was not enough evidence to recommend that face masks be worn in public. They then changed their opinion, stating that new scientific knowledge and experiences from other countries pointed toward face mask use by healthy individuals reducing infection rates. In addition to the more emotional reactions discussed above, there were also many citizens accusing the DHA of being overly influenced by politics in this shifting guidance;

> A true shame to witness how you constantly change your opinion in accordance with the desires of politicians in Christiansborg [Danish Parliament] – August 15th

And 5 days after the CEO of the DHA, Søren Brostrøm, was announced as a nominee to a seat at the WHO committee (to which he was appointed a month later), a citizen wrote:

> Unbelievable how you have changed your mind regarding the effect of face masks. Funny to see how moving up the ranks can change one's opinion. I am wondering whether you [Søren Brostrøm] sleep well at night? – September 19th

Many of the engagements giving negative feedback about the DHA's political role revealed a lack of knowledge about how the health authorities, the state virological institute, and government differ in their duties and are meant to interrelate—a perception also expressed at the leaders meeting:

> Citizens believe that it is the DHA who decides why there should be a Corona passport, assembly limits, and that everyone has to get tested all the time – and it is not. (Leaders Meeting, 2021).

In this engagement, a citizen gestures toward politics as a rather amorphous phenomenon, expressed by the lack of agreement between the different institutions:

> One day face masks are not necessary at all and the next day it is absolutely necessary. What happened in 24 hours? Unfortunately, this is a lot of politics. We need answers to a lot of things. And why do the State Serum Institute and the Danish Health Authority not agree with each other, and then the Minister of Health is of a third opinion? – August 15th

The DHA and other authorities thus face the extra challenge of communicating what it is they are meant to do and what they cannot; where their power lies and why scientific and political considerations do not always align. It is tempting to suggest that the "feedback" discussed in this section should not just be read as a comment on the DHA's official actions, but also on the presentation of what the DHA *is*. Citizens "behaving badly" here show us cracks in the foundations on which a more "proper" dialogue about guidelines could be conducted. Negative feedback is not an explicit invitation to dialogue—but it could be a prompt for Grudin's (1996) "strangeness;" to discussions about how politics and science entangle. Whether social media would be a good place for this is of course a complex question.

Giving Information and Claiming Expertise

The third category of citizen engagements we identified were those where the citizens themselves shared knowledge and information, either positioning themselves or others as having competing expertise. This sometimes overlapped with the previous category of giving feedback, but has a distinct sense of offering *content* to the DHA and/or other readers, and often with apparently good intent. As one of the DHA employees at the leaders meeting said; "they are convinced that they can help others." For instance, in this engagement a citizen responds to the post on face mask recommendations, questioning the medical-scientific knowledge of the DHA;

> DHA - face masks are not safe because microparticles can enter from the sides. They do not cover 100%. If they were to do so, we would each require custom-made masks… – July 9th

The second excerpt below is addressed to a general "you" rather than to the DHA, and offers a lively description of the user's beliefs about the dangers of face masks:

> For a short time, the mask provides protection, but the mask quickly fills with your exhaled air, moisture and your own bacteria and virus – coronavirus, if you are infected. And you inhale all of that deeply into your lungs with each breath. And the breathing is deep due to the greater amount of carbon dioxide and the lack of oxygen. You are actually infecting yourself. At the same time, the now saturated mask is a pure infection bomb, causing you to also infect your surroundings. The masks are a bigger part of the problem than they are of the solution. Everyone is better off without. Of course, changing the mask often could work for you but everyone can certainly not afford so many masks – July 9th

This explanation circulated widely in the early phases of the pandemic, expressed by citizens and some politicians and even medics. It draws on everyday intuition—it sounds sensible— and on situated knowledge about how people use face masks in the context of limited resources or supply. This engagement has a conciliatory yet insistent tone that might make it more palatable than the shouty exclamation marks and capitalized sentences seen elsewhere (see examples in the section "Emotional Off-Loading in Broken Dialogical Chains" below). As such, it is arguably more worrying to the DHA, and exemplifies the huge grey zone of misinformation-in-the-making that unfolded as people combined everyday knowledge with other information sources whilst scientific studies were unfolding.

The writer of the previous engagement acted implicitly as a bearer of knowledge while others were more explicit about their source of expertise and how it related to that of the DHA: coming from personal experience, professional background, or repeating the claims of other public figures or authorities. In the following two excerpts, citizens provided information to the DHA and other readers based on their personal experience;

> Have you [The DHA] or the politicians been out in society? In the places I'm moving around in 7 out of 10 people (approx.) use face masks wrongly. No matter how much information you provide.

They touch it constantly, put it on and off, e.g., when talking on the phone, etc. – August 15th

Many of us living with anxiety cannot wear anything in front of our face as we, in certain situations, can't breathe in the first place. – August 15th

These citizens either explicitly or implicitly criticized the DHA's ability to understand how their communication is received, or challenged the applicability of DHA recommendations to daily life. These posts often highlight a disconnect between authority and society, a situation that works fundamentally against Grudin's "reciprocity." It is still clear that the DHA is in control, and the citizens seem to be attempting to better inform the authority rather than requesting more control for themselves.

Other citizens positioned themselves as holding and being closely in contact with relevant professional expertise.

It is not true – a face mask is protective equipment that protects in both directions… I was employed at the epidemic section at 'Riget' [National Hospital] and have never been infected during my 7 years there 😊 – August 5th

"IS IT HARMFUL TO THE LUNGS TO WEAR A FACE MASK?" "No, there is nothing suggesting that" [text from the DHA post]. Then why are security personnel at my workplace advised not to wear them for more than three consecutive hours, as the body needs to recover beyond that? (…) It is contradictory information and I have more faith in what I am told by the security personnel – July 23rd

These claims to authority were potentially influential and arguably even relevant during this phase of the pandemic. At the time, there was no scientific consensus on how or whether face masks influenced infection rates in different settings, and different national health authorities drew different conclusions about the way to balance potential benefits and risks in relation to supply issues, potential behavioral impacts, and political pressure. However, the competing professional positions presented in these engagements were often unstable, and hard to evaluate. Does a surgeon know about the value of wearing a face mask in public based on the knowledge of wearing a face mask in the operation room? Is that specific information useful to the non-scientific citizen? Does it enlighten citizens to know the details or is it obscuring the message from the DHA to a population it needs to act quickly? These engagements are potential openings to dialogue—they stage a more equal relationship between the authority and the citizen—but they can only be responded to by the DHA in a way that affirms the authority's position and informational role, further restricted by the need for clear action.

A final kind of expert positioning was when citizens referred to or argued with statements from other persons or groups presented as experts—for example, informing the DHA that "some researchers are of the opinion that COVID-19 is airborne and for that reason it might be more infectious than initially anticipated" (August 5th). It was common for posts to link to

other media articles, Facebook stories or webpages, either as an isolated engagement or as part of an argument or exchange. More often than not, the links went uncommented, but sometimes citizens react to each other's links, as in this excerpt;

You use Ekstra Bladet [Danish tabloid newspaper] as your source! A medium that consistently distorts the truth to appeal to emotions and trigger outrage. It would be more convincing if you were linking to real peer reviewed research so we can avoid the fake news that is currently flooding social media. – July 9th

Citizens also referred to and/or linked to scientific articles from peer-reviewed journals, often including a significant amount of detail. Whether they were scientifically correct in their argumentation was often unclear, but they were clearly making a claim to expertise and trustworthiness. As above, we might wonder whether this information is useful to other readers, and whether the DHA should censor the "wrong" interpretation of potentially influential scientific claims.

More obviously false information also flourished, with the repetition of common COVID-19 conspiracy theories about, e.g., the pandemic being fake and the vaccine being a vehicle for Bill Gates to inject people with ID chips (Tjekdet.dk., 2020a,b). Yet even these claims were often allowed to sit on the page—the DHA needs to maintain an appearance of openness to dialogue, even if their capacity to engage dialogically is severely limited. There's a wicked problem here—in order to try and maintain the trust so crucial to citizens following health guidelines, the authority feels it has to host information that directly contradicts those guidelines and the knowledge on which they are based. This problem cannot be easily solved with censorship. Citizens claiming expertise and actively attempting to participate in the circulation of knowledge suggests a more reciprocal dialogue, but this is not what we observed. Thus, citizens often appear to be engaged in a fruitless reverse dissemination toward the DHA—though our discussions with DHA staff suggested that these engagements did have impact, if not in the way intended.

Emotional Off-Loading in Broken Dialogical Chains

Across the three categories outlined above, many engagements had a highly emotional tone—using multiple exclamation marks, capitalization, swearing, and emphatic language;

I cannot believe it!!!!

BUT FOR FUCK'S SAKE, THINK ABOUT THE REST OF US; SOME OF US ARE EVEN IN THE RISK GROUP OF A PRETTY SEVERE COURSE OF DISEASE – THINK ABOUT US

DAMN, how difficult can it BE to understand this.

Negative affect and emphatic statements are fundamental features of social media communication, especially around controversial topics, but are sidelined in the DHA's Facebook strategy. The moderators are trained not to engage with negative affect directly, but instead respond *as if* the user is making a reasonable request for information—a strange negation with a paternalistic flavor. We should not assume, though, that

this is a *bad* response—or that citizens get nothing positive out of such behavior. Perhaps these explosive contributions are a kind of emotional "off-loading" that does not need a response. An exclamation as much to the self as to the imagined listener. Perhaps they are rather toothless in terms of their ability to persuade other citizens—the slightly misinformed referencing of scientific articles is arguably more dangerous for the DHA's agenda.

Many emotional engagements appeared in isolation, a kind of "hit and run." As discussed above, the DHA often responded in an incongruent way to highly emotional posts. But citizens also often responded incongruously to what came before, or failed to respond to the answer they were given. This patterning became clear early on, and challenged our expectation that we would be analyzing *dialogue*—what we found was far more chaotic and fragmented. People seem to pass by, maybe respond, and then leave again. As noted earlier, the average citizen engaged 2.44 times over the course of the 7-month period, supporting the impression that extended and repeated dialogue from individuals was not occurring. Citizens thus seem to be using the engagement function on the platform for either quick informational needs, or for emotional release.

Emotional off-loading can also significantly impact those working for social media platforms—especially when directed personally at them. At the moderators meeting, one of the students said "If I can be completely honest, then I have to say that it was really rough working on the Facebook platform, that there was so much hate, and yeah citizens can be personal and we sign the replies with our name." Here again we see a tension between wanting to explain and defend one's position—whether as an individual or an institution—and the feeling that it will do little good. A sense of fragmentation and disconnect infused the material we analyzed, but along with a feeling that this was the "price to pay" for the symbolic value of a dialogical platform and the undoubtedly huge reach it offered for what was ultimately rather restricted and traditional dissemination and Q&A formats.

DISCUSSION

We will begin this Discussion by summarizing key findings, contextualized in our discussions with DHA staff. We will discuss how this relates to classic models of expert-citizen relationships in the science communication literature, and how a more critical perspective on the assumptions behind these models reveals a perspective-dependent understanding of when dialogue occurs and to what purposes. A vignette from the end of our study period—as citizen engagements shifted toward the topic of vaccination—will be used to raise questions about the conditions necessary for dialogue. We conclude by reflecting back on the value of research-in-practice.

In the theme *Seeking Information and Justification* we saw the most straightforward fulfillment of the DHA's desire to come closer to citizens while still retaining their expert role—citizens asked questions about face masks that the DHA felt were in their remit to answer. In this sense, the Facebook page

provided a fast, personalized Q&A—requiring greater resources than a regularly updated FAQ page. However, not all citizen questions were clear in their motive; rhetorical or sarcastic "pseudo-questions" were also common, and layered together requests for information, expressions of frustration, and/or commentary on the DHA. Whether this counts as top-down dissemination or bottom-up citizen engagement depends on what the *object* of communication is, and which *outcome* is of interest. From the perspective of communicating information about COVID-19, the engagements were classic dissemination, if often failing to answer more difficult questions. But from the perspective of understanding what citizens *want to know*, the engagements were a source of learning for the DHA. The answer catalogue was adjusted in the light of popular questions, and the moderators learned about effective replies from observing citizen reactions. As discussed in the Introduction, traditional models of science communication that focus almost exclusively on whether knowledge is transferred can miss these kinds of nuance—seeing communication as also about needs, desires, and identity excavates new perspectives.

The theme *Giving feedback and lacking response* captured a large group of citizen engagements giving feedback on the DHA's posts—not just asking for information, nor providing their own new content, but evaluating the DHA's actions. In practice these three categories often overlapped—a question can be used to pass judgment, and an evaluation can be used to share new information. The negative evaluations—and we must remember that positive evaluations often go unmarked on social media and thus recede from view—were often focused on the changing nature of advice; the instability of the DHA's expert knowledge base. This was to some degree inevitable in a pandemic, where scientific knowledge was changing fast and where negotiations between research, health institutions and authorities, and government played out live and more "in public" than ever before.

The last decade of science communication scholarship has highlighted the need to communicate science in process; to build trust *via* transparency and increasing literacy about the way scientific knowledge evolves (Arjini, 2020; Petersen et al., 2021). Our case study emphasizes both the need for transparency (any sense of hidden interests or hiding new knowledge was angrily derided) but also its difficulties. While recent research suggests that playing out the development of guidelines live in Denmark increased public trust on a general level (see Petersen et al., 2021), it led to many critical questions on the DHA Facebook page. One frustration for the DHA moderators was that they were not permitted to comment on "political" questions, but many of citizens' enquiries concerned science-politics-institutional hybrids. Face masks is a case *par excellence* of this kind of hybridity—no-one could prove quickly enough exactly what effects different masking practices would have in different contexts, yet decisions still had to be made that took into account social, economic, and political factors. Negative citizen feedback was often unfair or misplaced—but the DHA was not always free to explain *why* this was the case. Thus, "bad behavior" revealed cracks in the foundations that would be necessary for dialogue about the "real" matters at hand.

As mentioned in the Introduction, this echoes arguments by other science communication scholars that we should treat bad behavior as a valuable source of information about the structures that shape what purposes communication (can) serve for the various actors involved (e.g., Horst and Michael, 2011; Davies and Horst, 2016; Davies, 2019).

When sarcastic questions were posed, or negative judgments about the political role of the DHA were made, moderators sometimes gave a standard answer to whichever common question best approximated the theme of the citizen's feedback. This reads strangely—a kind of "non-response" that seems to refuse the reciprocity Grudin's (1996) insists is part of dialogue. Yet the very incongruity of these exchanges also generates a kind of "strangeness" that could perhaps be read as an affective dialogue. A shock of emotion followed by the refusal of the DHA to become emotional, which may not transmit any information, but arguably communicates something about what is meaningful and possible for both parties.

In the section *Giving Information and Claiming Expertise* we enter the more classical territory of reciprocal dialogue—citizens share their own knowledge, and on matters and in modes that challenge the authority of the DHA. They do not just gently "fill in the gaps" in how policy translates into real-world contexts, but challenge the meaning of those contexts for policy itself. Or they intervene with contradictory theories, references, and sources of information about matters of policy such as the wearing of face masks. Citizens position themselves, their friends or colleagues as holding competing expertise, and give links and references to a huge diversity of sources. Conspiracy theories and misinformation are also posted, and often allowed to remain—though we speculate that this is perhaps less concerning in relation to the DHA's goals than the more "reasonable" posts of unverified or decontextualized scientific findings or expert testimony. This section also reminds us that it is as much citizens as authorities who can shut down "strange and reciprocal" dialogue—and both DHA leaders and moderators were very clear about the limitations of social media persuasion with certain groups of citizens. As one of the leaders said when talking about vaccinations, "there is a tiny group, where the reality is that they opt out—they are totally against it," and another commented that these citizens "are *completely* convinced that we are all sheep."

The DHA seeks with its Facebook page to provide an authoritative and trustworthy source of information—as soon as citizens start sharing unvetted scientific articles and other expert sources, the stability of this position is thrown into doubt. But what should the DHA do? The DHA cannot disrespect citizen's positions if they wish to give the appearance of dialogical openness. It would also bring additional practical challenges if moderators had to make more "grey area" judgments—as Facebook has discovered repeatedly in recent years. In discussing this aspect of the findings with DHA leaders and moderators, we were again reminded of the silent majority who do not argue with what is presented, but simply absorb the DHA posts and ignore the noise of other citizen engagements. Indeed, some of their informational posts reached a third of all Danish citizens. Is the anarchic bubbling in the comment thread, then, a reasonable

price to pay for the wide reach of the Facebook page, boosted by its appearance of proximity to citizens and offer of a rapid Q&A function?

In the last Analysis section *Emotional Off-Loading in Broken Dialogical Chains*, we tied some threads together across the different patterns of engagement. Engagements were often highly emotive, as expected on social media and around a controversial topic. As discussed above, the negative engagements visible on the page are a slim slice of the total usage—most people are invisible and simply take what they need. But the negative engagements take up a disproportionate amount of the "public space" of the page and indeed of the time of the communication staff. What we discovered was that—at least during the period we studied—even these negative engagements appeared to be primarily "hit and run." People burst into a comment thread, off-load, and leave again. Here a dialogue is not unfolding between the individual and the DHA, though weakened, second-hand exchange is arguably occurring as others read the threads and as the DHA constructs future responses influenced by the "improper engagement" of these individuals.

This theme of the individual citizen vs. an implied citizen group is one we would like to draw out in these concluding reflections. The DHA wishes to come closer to citize*n*s in the plural, *via* an engagement with individuals—not to engage directly in the unique individual concerns of lived experience, which inevitably drag along undisciplined knowledge and context that muddy the waters of generalized guidance. On the Facebook page this was seen when individual "bad behavior" was met by a generic group response—an arguably paternalistic strategy, but not necessarily a bad one. The DHA's Facebook policy is intentionally structured around limiting personal engagement; the page is rather a portal for general information and redirection to individualized services. The strangeness this creates on a supposedly dialogical platform like Facebook is jarring to observe—especially from our perspective as researchers—and was stressful for many of the moderators, but is not necessarily jarring for citizens. We speculate that emotional off-loading may perform an important affective function for the citizen and other readers of their comments. Further research could delve into the ways in which silent users, emotional off-loaders, and other engagers experience such phenomena.

The image we think we are building up here is one of a compromise; a balance between appearance and reality to satisfy underlying motives; and a displacement of dialogue from individually open minds onto representative entities and into a more affective than cognitive register. There is plenty of strangeness here—and plenty of learning by the DHA about the citizens they engage. However, we would argue that in straightforward terms, what is desired is not really dialogue about COVID-19, and the desire to get closer to citizens is a one-way mirror—the DHA is not able or willing to be "known" in the open and vulnerable manner that they hope citizens' interests can be known. We see this analysis as an example of what happens when we attend to science communication not just in terms of explicit exchanges of knowledge, but also attempt to "disassemble" the multiple actors involved—and how these

actors imagine themselves and each other (see Davies, 2019; Edwards and Ziegler, 2022).

In the case of face masks, the balance between opening up for citizen engagement and opening the floodgates to misinformation seemed to hold—a lot of citizens got timely, accurate information; were reassured; were able to make contact and feel seen. The misinformation-in-process unfolding on the Facebook page was judged by the DHA staff to be manageable; "hit and run" engagements likely ignored by most. However, when the dominant issue shifted to vaccination, things changed. This lay outside the period of our empirical analysis, but was a strong theme in our meetings with the DHA at the end of the project. With the advent of vaccination programs, trolls appeared—more determined, more repetitive and persistent, less open to engagement than the earlier emotional citizens. The DHA staff described their appearance of being highly coordinated, of using the Facebook page opportunistically as part of a wider campaign, rather than engaging with it as a specific authority. As one of the moderators noted; "There have been critics on the facebook page the whole time. In the beginning the subject was the reopening of schools, the mothers 'went' on us, then there were the face masks and now it is the anti vaxxers. The anti vaxxers take a lot of space and are well-organized." And as another described; "there are no real questions anymore, I feel it's more just… angry, sour people."

In this challenging situation, the moderators were restricted in their responses, and had to make repeated judgment calls. They could hide links they considered misleading, but could not delete posts unless they were intolerably insulting. These tools are also used sparingly, as users noticing that comments have been deleted or hidden can damage the appearance of transparency. When we discussed with the leaders and moderators what should be done if this continued, opinion was split—some favored just shutting down the comment thread—one moderator said "I think the idea is good, to enter dialogue with the citizens, but not the way it is now." Whilst others saw the comment thread as essential to the identity of a Facebook page—for example one of the leaders said "I think that social media is about dialogue and I would never recommend turning off a comment option."

For our purposes, what this anecdote highlights is the crucial importance of context for judging the appropriateness and even the possibility of dialogue for health authorities on social media. It is not just the DHA who is responsible for whether dialogue occurs; citizens can also facilitate or close down reciprocity and strangeness. In the face mask period, both DHA and citizens refused the rules of reciprocal dialogue in various ways, but this still allowed many of the goals of engagement to be met. In the vaccine trolling period, the "refusal" was harder and more disconnected, and the fear was that this would swamp the silent masses' ability to continue to use the page as intended. Our discussions with DHA staff about this again highlighted the difficulty of dealing with political matters—face masks and lockdown were in a period of greater emergency, and decisions were seen by the DHA staff as more evidence led, whilst reopening and vaccination were seen as more politically-inflected. It seems that when institutions are more separated (and sedimented) in their roles, it is easier for them to communicate about controversial topics. But we would argue that even in the calmer period, a key citizen concern was exactly the relation between institutions, and that communicating about these relations is critical to the flourishing of dialogue about the decisions institutions wish to explain and defend.

In the last 2 years there has been intense research focus on all aspects of COVID-19 including its public communication, already resulting in journal special issues such as this one and, e.g., Massarani et al. (2020a,b) and Nan and Thompson (2021) and an edited volume by Lewis et al. (2021). This study aims to contribute to this expanding field by providing an in-depth, qualitative analysis of what actually occurs when health authorities pursue laudable aims of opening up dialogue with citizens who desire it. Our analysis does not deliver advice on which communication strategies to deploy on Facebook, but instead aims to illustrate the importance of asking questions about the complex configurations of purpose, need, constraint, and identity that characterize dialogical communication between citizens and authorities.

This project was an example of a close relation between science communication research and practice, grounded in FM's dual role as DHA moderator and University researcher, and the relationship-building and formative feedback this allowed. Being able to share our evolving findings and questions about how they relate to DHA strategy has grounded our analysis in context, and helped to expand our attention from the nitty gritty of Facebook engagements to the invisible users, other platforms, and wider communicative contexts in which they occur (Davies, 2019). It also heightened our understanding of the dilemmas faced by health authorities in communicating about COVID-19 and in making compromises inevitable when these expert positions enter dialogical, individually-driven social media platforms.

By situating this research/practice relation in a specific DHA project, we saw by contrast the lack of resources usually available for drawing on science communication research. Moderators get minimal training, and are not instructed through academic research; staff of all levels of seniority were interested in research, but did not have working hours to engage with it. Decisions were made based on the expertise of experience, but missteps were made that could perhaps have been diverted within a research-based frame. In emergency situations, it is unclear whether slower, research-based communication design would be more efficient and effective than a more intuitively led process with running correction. But in general, we think our case shows some of the virtues of embedding research processes within the development of new science and health communication projects. The movement for evidence-based science communication (e.g., Jensen and Gerber, 2020) makes important calls for more generalizable, rigorous and experimental knowledge about the impacts of particular communication strategies. Inspired by a more STS-informed approach to science communication, we would like to add to the list of desired outcomes a focus on embedding qualitative research within local, situated case studies.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because the raw data consists of Facebook posts and citizen engagements on the Danish Health Authority's Facebook page, as part of the HOPE project (see manuscript). The current agreement does not allow for general sharing of this data, which is very hard to anonymise and contains sensitive information, but future collaborative agreements may be entered into that involve sharing of the data. Requests to access the datasets should be directed to RA-N, ran@ifs.ku.dk.

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A New Frontier in Science Communication? What We Know About How Public Audiences Respond to Cinematic Scientific Visualization

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Presenting data in visually appealing formats has long been a useful science communication technique. Millions of people around the world have encountered scientific visualizations through documentary films on giant and small screens. Visual effects software from the film industry can increasingly be used to visualize scientific data. Such cinematic scientific visualization should be (a) based on real data, (b) understandable, and (c) entertaining for a public audience. To investigate what is known about how audiences respond to this type of science communication, this essay presents an overview of the literature on this topic, highlighting key findings, gaps, and directions for future research. The sprawling nature of the theoretical and empirical research literature on audience responses to cinematic scientific visualization makes it difficult to achieve comprehensive coverage of relevant studies and theoretical models. Recurring methodological limitations present further challenges to establishing a foundation of reliable knowledge on this topic. Nevertheless, prior research has identified several factors that affect how public audiences respond to cinematic scientific visualizations. Here, we discuss findings relating to intelligibility, film content, and immersion. These results offer a basis for hypotheses to be tested by future confirmatory studies of audience responses to cinematic scientific visualizations.

Keywords: science communication, scientific visualization, public engagement with research, public engagement with science and technology, data visualization, science education, informal learning, planetarium

INTRODUCTION

Presenting data in visually appealing formats has long been a useful science communication technique. Its earliest vestiges can be seen in depictions of astronomical phenomena over 2000 years ago (e.g., Friendly, 2008). Using charts to present scientific data in a recognizably modern way gained ascendancy in the nineteenth century (e.g., Friendly, 2005). The advent of computing made it easier for scientists and science communicators to create more complex visualizations of three-dimensional, time-evolving data in the form of video, starting around the 1970's-80's (Johnson, 2004).

Scientific visualization is a subset of data visualization (**Figure 1**) which focuses on the creation of images from spatial data (e.g., galaxies, tornadoes, molecular structures) rather than relational data (e.g., bar charts, scatterplots, networks). While there has been some variation in terminology in the literature referring to similar phenomena, the term cinematic scientific visualization is used to describe an aesthetically oriented, cinematic-quality presentation of spatiotemporal datasets.

The use of artistic techniques from the world of film production with the aim of delivering effective science communication to public audiences sets this kind of scientific visualization apart.

> Cinematic scientific visualizations turn complex scientific phenomena and concepts into stunning graphics and make them easier for the general public to comprehend (Shih et al., 2019, p. 1).

These public audiences encounter such cinematic scientific visualizations in leisure-oriented settings such as movies, television, science centers, and planetariums. The science films that feature such visualizations can reach millions of people worldwide, and often have lifespans of 10+ years. For example, the fulldome show "Black Holes: The Other Side of Infinity" was released in 2007 and is still playing in theaters in 14 languages. As of March 2021, "Solar Superstorms" (2015) was played on international television in 16 countries, played in 68 planetariums, has 4.6 million views on YouTube alone, and is additionally available for streaming on Amazon Prime and MagellanTV.

The topic of audience reception of cinematic scientific visualization therefore sits at a crossroads in the academic literature, with relevant research published in several distinct subject areas:

- Data visualization, with strong ties to computer science and data science
- Public engagement with science through entertainment media
- Informal science learning, including in science centers, planetariums and museums
- Science communication using visual methods
- Visual communication

In addition to these specific domains, key theories associated with the related academic disciplines tied to each of these domains have also been brought to bear to a limited extent to study this topic. Relevant theory from art and design, psychology, communication, media research, and other relevant fields can help to clarify likely audience impacts associated with cinematic scientific visualization.

Borkiewicz et al. (2019) argue that scientific visualization aimed at public audiences should take advantage major advancements in the quality of computer-enhanced graphics seen in movies, television, and video games:

> The aim of cinematic visualization is to be not only educational and compelling but also aesthetically pleasing and entertaining in order to have broader appeal... (1) Experts can make use of these
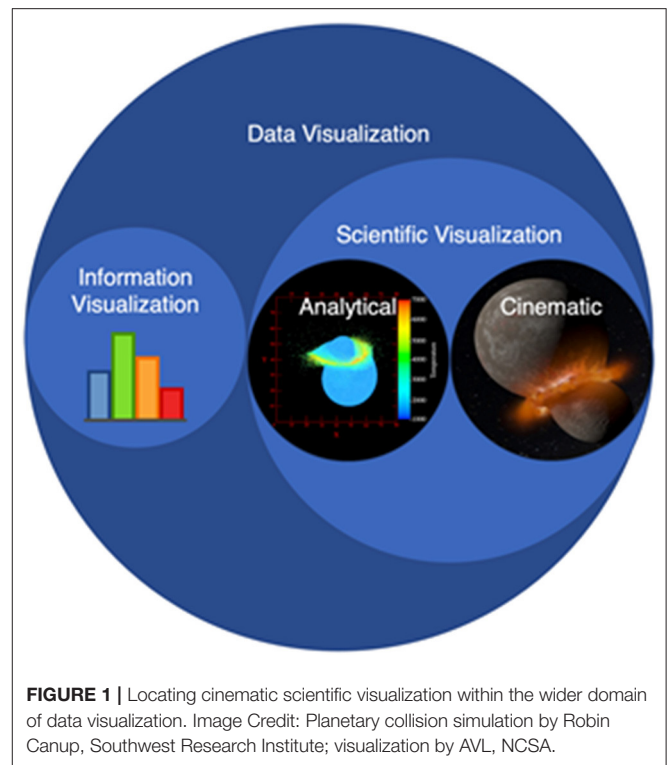

FIGURE 1 | Locating cinematic scientific visualization within the wider domain of data visualization. Image Credit: Planetary collision simulation by Robin Canup, Southwest Research Institute; visualization by AVL, NCSA.

tools to better communicate with those not in their field, and (2) scientific visualization will look increasingly anachronistic if we cannot keep pace with advancements in the arts (Borkiewicz et al., 2019, p. 1, 11).

Cinematic scientific visualization is defined by (a) its use of authentic research data, (b) its aim of achieving intelligibility for a general public audience and (c) its entertainment value. In other words, cinematic scientific visualization should be (a) based on real data (b) understandable and (c) entertaining for a public audience. Given that (b) and (c) can only be accurately assessed from the audiences' perspective, the impact of this kind of visualization on public audiences is of overriding concern.

WHAT IS THE ROLE OF CINEMATIC SCIENTIFIC VISUALIZATION IN PUBLIC SCIENCE COMMUNICATION?

The importance of visual aspects of science communication is self-evident. Yet, this is a relatively under-developed dimension of the empirical research literature, with much more focus on the content aspects of television, film and newspapers. This pattern of limited coverage is even more evident with a specific topic such as cinematic scientific visualization, despite its history and the large audiences it has been used to engage.

Relevant research must be drawn from a diverse set of cognate areas to piece together an understanding of the likely role of cinematic scientific visualization in public

science communication. A meta-analytic study focusing on the summative evaluations conducted for 10 National Science Foundation-sponsored films focusing on students came to a set of positive conclusions about the educational value of giant screen films (Flagg, 2005). Flagg (2005, p. 66) points to evidence from these evaluations to conclude that education-oriented giant screen films increase science understanding while reducing stereotypes about scientists. These optimistic conclusions are drawn from the assessments of knowledge conducted by the summative evaluations analyzed: "measured by paper-and-pencil tests, using true/false, multiple choice, and short answer questions" (Flagg, 2005, p. 52). All the films assessed showed "increased student knowledge of the content assessed" (Flagg, 2005, p. 53). Beyond knowledge, Flagg (2005, p. 65) noted that "giant screen films can successfully push viewers to broaden their image of scientists beyond the stereotype of white-coated lab researchers" (Flagg, 2005, p. 56). Yet, on the question of science attitudes, there was insufficient evidence available: "Giant screen films may influence attitudes, but we have little information on the success of such efforts" (Flagg, 2005, p. 56).

A meta-analysis looking more broadly at adult informal science learning through media brought together research studies and evaluations assessing the outcomes of educational programs using television, radio, film/IMAX, and web (Rockman et al., 2007). This larger review was far less optimistic in its overall assessment:

> The preponderance of studies have failed to find significant, consistent, and meaningful impacts of the treatments they have studied (Rockman et al., 2007, p. 22).

Yet, studies zooming into the specific dynamics of audience response to scientific visualizations that are more or less cinematic have identified measurable effects in audiences, as well as factors driving those effects.

KEY FACTORS IN CINEMATIC SCIENTIFIC VISUALIZATION'S SCIENCE COMMUNICATION ROLE

Prior research has identified several factors that affect how public audiences respond to cinematic scientific visualizations. Here, we discuss findings relating to the narrative voice, content and framing, immersion, annotation, and intelligibility.

Narrative Voice, Content, and Framing

There is some evidence that the specific narrative focus of the content is critical to the audience outcomes.

> Science media should focus more on science as a process than providing information on an interesting phenomenon or fact. Public understanding of science and science literacy may depend more on people learning that science is a complex activity, building on past learning and being willing to change based on new information (Rockman et al., 2007, p. 29).

Indeed, going beyond "fun facts" or phenomena to instead center the content on valuable "take away" points may be an important factor, in line with prior research on informal learning settings (e.g., Land et al., 2020).

Aside from the scientific content, Heimlich et al. (2010) found that the cultural content and framing in scientific documentary films can play an important role in affecting audience reception. The finding from this study that content can have differential effects for audiences coming from different cultural backgrounds, depending on the framing of the narrative, is also in line with prior research and theory in informal learning settings (Dawson and Jensen, 2011; Jensen et al., 2011).

Moreover, the way that the narrative voice is presented can also be important. A study ($n = 514$) asking for audience feedback on different practices in narrative visualization of scientific documentary films to investigate the use of "voice-of-god" narration and other storytelling techniques. This study found "participants preferred having a strong voice narrating the presentation of evidence regardless of topic or video presentation" (Bradbury and Guadagno, 2020, p. 348). More specifically, the "audible voice of god commentary…was found to be a significant variable outperforming the alternative video without voiceover narrative. Participants preferred the observational videos with voice-of-god narrative 66.84% (113/169) over the second observational video without voice-of-god narrative 33.14% (56/169)" (Bradbury and Guadagno, 2020, p. 348).

A qualitative follow-up question in this study by Borkiewicz et al. (2019, p. 348) inquired about the reasons for preferring a particular factual documentary film. This qualitative aspect of the research highlighted the importance of "narration" in general and the voiceover in particular. Another identified preference was for having the narration come from a participatory character in the documentary and the presentation of the data visualizations. Moreover, there was a clear preference for an "entertaining" style and "better production quality" (Bradbury and Guadagno, 2020, p. 348). Qualitative responses also pointed to audiences valuing learning from the films (Bradbury and Guadagno, 2020, p. 348). These findings have clear implications for cinematic scientific visualization.

Immersive Experience

Existing literature indicates that immersive shows and experiences can have a distinctive impact on audiences.

> It appears that heightened levels of immersion allow learners to more easily understand scientific concepts (Fraser et al., 2012, p. 182).

The most well-established indicator of immersion's importance is the research on audience responses to scientific visualizations on different sizes of screen. An experimental study by Yu et al. (2016) tested the importance of screen size as a driver of science learning, in this case focusing on undergraduate students in an introductory astronomy course. This study employed a complicated design, with all of the groups (treatment and control) receiving a lecture designed to target common

misconceptions about astronomy. Learning was evaluated using a multiple-choice test administered on a repeated basis. The evidence gathered by the study indicates that the treatment group that viewed the accompanying film offering a virtual tour of the Solar System in the Planetarium showed the greatest learning impact. The authors contend that this is because immersion is greater with larger, more expansive screens, the level of impact, there is also greater learning impact from the same film viewed on a larger screen.

> We propose that visual immersion itself has benefits for learning by reducing cognitive load and increasing attention (Yu et al., 2016, p. 102).

However, the experimental design employed in this study did not control for the novelty effect of an outside-the-classroom field trip to a Planetarium, given that the control group remained within the classroom setting throughout. Nevertheless, Yu et al. (2016) note that their conclusion has support in the empirical research literature on how different screen sizes affect audiences (e.g., Lombard et al., 2000) as well as the research on giant screens and learning (e.g., Fraser et al., 2012). Indeed, Heimlich et al. (2010) came to the same conclusion based on a separate experimental study comparing different screen sizes used with the same film.

The emphasis on immersion's value for science communication and informal learning comes from a variety of angles. For example, research investigating audience responses to virtual reality has also highlighted the value of immersion within informal learning experiences (Yu et al., 2015, p. 43). Another study also went a step further than the typical cinematic immersion, exploring the effects of introducing interactivity into educational visualizations integrated into a game engine:

> As our results showed that adding interactivity increased our participants' enjoyment of the visualization, and game engines are well-established for developing interactive applications, our finding suggests that there is value in developing interactive cinematic scientific visualizations in a game engine for educational purposes (Shih et al., 2019, p.2).

Such convergent findings in the literature suggest that the feeling of immersion could be an important factor in audience responses to cinematic scientific visualization.

Annotation

One of the key unanswered questions in this domain is regarding the impact of labeling or annotation of cinematic scientific visualizations on audiences. A priori, there are good theoretical reasons for thinking the annotations will be important drivers of learning, for example, drawing on concepts such as scaffolding from Vygotsky. Prior research is also generally supportive of the importance of priming or contextualizing scientific film content for audiences.

> It would appear that presence can be enhanced by an audience's previous familiarity with a topic or by priming the audience prior

to the film experience through stimuli such as sounds and images related to the topic (Fraser et al., 2012, p. 185).

While labeling is a default practice in conventional data visualization, its use in entertainment-based public oriented cinematic visualizations is more contested. This contestation focuses on the issue of whether the immersive experience of cinematic scientific visualizations- and the audience impact associated with that immersion- is undermined by labeling.

While no studies have directly examined this issue in the context of *cinematic* scientific visualization, there have been some relevant research published on audience responses to still images of space phenomena. Smith et al. (2015) conducted a study of labels in a museum exhibition of still deep-space images using an experimental design. This study investigated what kind of label information museum visitors were looking for when they encountered these images. This study reported the following categories of interests expressed by those viewing these deep-space images: "the most common question that people asked was: 'What is it?' or "What is it made of?" after that, the next most asked questions were about how the images were made (p. 290).

Smith et al. (2015) conclude that the comprehension of the underlying science for space images and appreciation of those images increases with the addition of informative labels. A similar finding is apparent from the much larger web-based study conducted by some of the same authors. Smith et al. (2017) further reinforce their argument that images should not be left to "speak for themselves," but rather require explanations, including "information about colors used, size, scale, and location of the object" (p. 1) represented in the visualization. Smith et al. (2010) highlight the importance of annotations but complicate the picture by showing differences in outcomes depending on how expert or novice an audience member thinks they are.

Clearly, the use of annotations must be targeted to avoid distracting viewers with non-essential details. Moreover, prior research in other contexts suggests that there may be differential responses to annotations depending on the audience's level of prior knowledge about that topic. Those with greater knowledge of the topic were better able to take in the additional detail offered by annotations (Hurzlmeier et al., 2021). This raises the idea that annotations may come with tradeoffs between broad accessibility and precise understanding for non-technical audiences. Therefore, finding the right balance in the use of annotations is a key practical challenge for the professionals producing cinematic scientific visualizations.

Intelligibility

Whether audience members can make sense of a scientific visualization- cinematic or otherwise- is the ultimate de facto arbiter of success in this science communication game. The extent to which intelligibility is a primary or secondary factor in audience response remains unresolved in the literature. For example, Smith et al. (2017) argue that non-expert public audiences "work from an initial reaction to an image of "WOW!" to questions about the science" (p. 3). Rockman

et al. (2007) on the other hand view the intelligibility of a scientific film is a primary factor, affecting the nature of the audience that a film can attract, as well as downstream outcomes such as impact: "Accessibility has an impact not only on types of viewers and listeners, but also on the total audience size and frequency of their viewing and listening" (p. 4).

There is no systematic research available on the relative priorities of the makers of scientific films destined for giant screens, but Rockman et al. (2007) infer that entertainment is being privileged over depth in general: "IMAX and similar types of giant screen films shows are more likely to go for excitement and delight, rather than in-depth, issue-oriented science concepts" (Rockman et al., 2007, p. 7).

CONCLUSION

There are multiple developments pointing toward the increasing potential for high quality, entertainment-industry standard scientific visualization. For example, in informal learning spaces such as museums, there is an ever-growing focus on developing immersive media experiences, extending beyond the giant screen shows that already heavily feature cinematic scientific visualizations. In the context of research, Borkiewicz et al. (2019, p. 11) have argued that science should "make use of visual effects tools [that] will allow for the creation of higher-fidelity visualizations that meet the high bar set by modern cinema." Because the outer limits of practice in this domain are extending every year with the technology, cinematic scientific visualization is a perpetual frontier in science communication for public audiences.

Audiences are central to cinematic scientific visualization, as they are in science communication more generally (Jensen, 2011, 2014, 2020). This in turn makes the question of how producers of such visualizations can most effectively create audience impact equally central. Indeed, producers of cinematic scientific visualizations and scientific documentary films agree on the paramount role of the audience (e.g., Nucci, 2018). Yet to date, studies have provided only a limited picture of how public audiences perceive cinematic scientific visualization in

different settings, with the most extensive literature available in the context of informal science learning and giant screen (dome) shows. This disconnect between the audience focus of professional practice and the under-developed research literature on audience responses to this means of science communication is yet another example of the multi-faceted research-practice divide in the various fields working on science communication topics (Jensen and Gerber, 2020).

The sprawling nature of the theoretical and empirical research literature on audience responses to cinematic scientific visualization makes it particularly difficult to achieve comprehensive coverage of relevant studies and theoretical models. While there is limited evidence available on the details of how audiences respond to cinematic scientific visualization, this essay has identified factors that are likely to be relevant to the question of audience impact. Key issues remain under-explored, such as the effects of specific storytelling techniques when overlaid on a cinematic scientific visualization and whether audience outcomes may differ for ethnically or culturally diverse audiences (Kennedy et al., 2018; Jensen et al., 2021).

At the same time, it is evident that major gaps remain in knowledge about this science communication pathway that has already reached many millions of people around the world via giant screen shows, streaming video services, Youtube, and other means. To advance evidence-based practice in this still-emerging frontier of public science communication, applied research is needed that will shed light on how specific choices and techniques affect audience responses and outcomes.

AUTHOR CONTRIBUTIONS

EJ prepared the main body of the initial draft. KB and JN reviewed, edited, and supplemented with additional content, particularly in the introduction. All authors contributed to the article and approved the submitted version.

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Trajectories of Experience Through the Pandemic: A Qualitative Longitudinal Dataset

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INTRODUCTION

The COVID-19 pandemic has introduced a radical rupture into the lives of people around the world. Overnight society slowed to a standstill, strict rules were put in place and people had to adapt to a new set of norms and practices to curb the spread of the virus. In this way, the pandemic has been a naturally occurring experiment on the public's responses to rapid societal changes, bringing earlier niche topics such as trust, compliance, vaccine hesitancy and conspiracy theories to the forefront of both public and scientific discussion. How did people experience, understand and react to these rapid changes? In this article, we describe a dataset of longitudinal semi-structured interviews collected in Germany between December 2020 and September 2021 that sheds light on this question. This dataset was created as part of the *Viral Communication project* (viralcomm.info), which has investigated public responses to the COVID-19 pandemic in Germany including people's changing perceptions, attitudes, beliefs and behaviors. It complements and deepens the explosion of research that has emerged on how societies organized themselves in the wake of the pandemic.

Research has shown that when COVID-19 restrictions have been communicated persuasively through a collective "we," most citizens have demonstrated their willingness to make personal sacrifices for the greater good of the community (Moss and Sandbakken, 2021). In constrast, poor, partisan or politicized communication has often led to the opposite, though other factors such as misinformation also play a crucial part (Jetten et al., 2020). Similarly, COVID-19 vaccines have been heralded as a scientific triumph that is key to ending the pandemic, but vaccination has come up against public hesitancy from many and outright resistance from a few. As MacDonald (2015) put it, "vaccination hesitancy is complex and context specific, varying across time, place and vaccines. It is influenced by factors such as complacency, convenience and confidence" (p. 4163). Explaining people's resistance through scientific illiterate or pathological behavior is insufficient to make sense of the complexity and specificities of the issue (Larson, 2020). Instead, a fine-grained analysis of people's COVID-19 vaccination decision-making is needed to fill the gap. With its mixed-methods approach, *Viral Communication* provides a comprehensive and nuanced approached to the above themes and many more concerning people's evolving responses to the pandemic.

Qualitative longitudinal studies can be done in several ways, including (1) continuous research in the same small society, (2) periodic studies at regular or irregular intervals, and (3) return after a lengthy interval of time has elapsed since the original research was done (Epstein, 2002). The *Viral Communication* interview study followed the second approach, carrying out three rounds of interviews at regular intervals (3–4 month between interviews). Participants of the longitudinal

interview study were purposively sampled from a national representative survey instrument that has been described in a previous publication (Jensen et al., 2021). Interview questions were designed to follow-up on some of the survey questions and to obtain a more in-depth understanding of the relevant topics and discussions (e.g., vaccination, information seeking, trust in political and scientific actors, mask-wearing and conspiracy beliefs). By elaborating on some important themes of the survey, the dataset provides a unique window into health decision making processes, perceived challenges and opportunities as well as the process dynamics of changing attitudes toward mitigation measures during a global health crisis. Researchers can analyse it from a variety of perspectives used in qualitative longitudinal studies (e.g. Davidson, 2009; Shirani and Henwood, 2011; Patrick, 2014; Torregrosa et al., 2015), such as analyzing (1) rich individual cases studies that illustrate the complexity of subjective experience in context, (2) relevant themes within the interview (e.g. vaccination, conspiracy theories, trust) and (3) specific socio-demographic groups (e.g. generational differences in attitudes toward protective measures). Qualitative data (especially longitudinal) is labor intensive and thus still relatively rare. This dataset aims to close this gap by providing researchers with qualitative material that enables a deeper and complex understanding of people's experiences, thinking and behavior through the pandemic.

METHODS

Three rounds of semi-structured qualitative interviews were conducted between December 2020 and September 2021. Participants were recruited initially through a much larger nationally representative online survey conducted in November/December 2020 (and repeated two more times). The interview data were collected as part of a wider suite of qualitative and quantitative data collection methods employed by the Viral Communication (viralcomm.info) project. The full set of research protocols and procedures for this project were reviewed and approved by the Ethics Committee of Sigmund Freud University. All participants gave their consent to having their full anonymized interviews made available within a public dataset.

Data Collection

Three rounds of interviews were conducted. The first, second and third rounds of interviews took place in December 2020, April 2021 and September 2021, respectively. Interviews were carried out in the weeks following the online survey so as to be able to triangulate responses between the two data collections methods. All interviews were conducted in German either via telephone or Zoom. Four pilot interviews were initially held to ensure a good flow between questions and that the interviews were around 40 minutes each (balancing the needs of getting sufficient elaboration and not overly taxing participants). The average length per interview was 41 min (Round 1), 42 min (Round 2) and 45 min (Round 3) with the shortest interview being 22 min (Round 1), 27 min (Round 2) and 23 min (Round 3) long and the longest one being 88 min (Round 1), 64 min (Round 2) and 99 min (Round 3).

Selection of Interview Participants

Within the project's main nationally representative online survey all participants had the option to declare their willingness to participate in three follow-up interviews. In total 278 respondents indicated their willingness to participate in the interview study. A purposive sampling approach was applied to select interview participants aiming for a balanced sample concerning socio-demographic variables as well as attitudes and beliefs. We applied two sets of selection criteria to select the interview participants: The primary set of selection criteria included balancing age group, gender and socio-economic status (SES). Regarding their SES participants were either grouped as having a high (above survey median) or low (below survey median) SES based on their self-indicated yearly income.

In addition, a second level of criteria was applied, focusing on the following attitudes and backgrounds: Level of trust, migration background, vaccination willingness, and attitudes toward protective measures (i.e. mask wearing). This grouping of participants was solely used for the purpose of having a sample representing the wide variety of attitudes and beliefs across different socio-demographic groups in the German population. A full SPSS dataset including all socio-demographic questions and all additional survey items for all interviewees is made available alongside the data for further analysis.

Special attention was paid to the first level criteria, trying to balance out all three variables. If there were multiple possible candidates to contact, the second level criteria were taken into consideration, so as to have a full distribution of attitudes and backgrounds represented in the final sample. A detailed overview of our sampling approach, including selection criteria, can be found in the supplementary material (Table A.1) provided alongside the dataset (https://doi.org/10.5281/zenodo.5556052).

Sample

The final sample consisted of 40 participants. An overview of the sample is given in **Table 1**.

In between the first and second round of interviews, two participants dropped out of the study: (1) One woman from the age group 45–59 with a low SES and low trust; and (2) one woman from the age group 16–29 with a high SES and high trust.

Interviewers

Interviewer 1 was a female psychologist with substantial, previous experience in qualitative research. Six interviews in Round 1 were conducted by a second interviewer. Interviewer 2 was a purposely trained male research assistant who, at the time of data collection, was undertaking his undergraduate degree in psychology. Debriefing between the interviewers and an experienced member of the research team took place shortly after each interview.

Recording and Transcription of the Interviews

After explicit consent from participants, all interviews were audio-recorded using the recording function of the computer (telephone interviews) or by using the Zoom recording function. Following the interview, audio files were pre-transcribed using the f4x automatic transcription function. Afterwards, each

TABLE 1 | Sample characteristics.

Variable	Levels	*n*	%
First level selection criteria			
Age group	16–29 years	12	30.0%
	30–44 years	10	25.0%
	45–59 years	9	22.5%
	60+ years	9	22.5%
Gender	Female	22	55.0%
	Male	18	45.0%
SES	High SES	20	50.0%
	Low SES	18	45.0%
Second level selection criteria			
Trust	High trust	13	32.5%
	Medium trust	20	50.0%
	Low trust	6	15.0%
Migration background		6	15.0%
Vaccination willingness	Pro	20	50%
	Undecided	9	22.5%
	Contra	11	27.5%

N = 40. SES = socio-economic status. SES: Two missing values. Trust: One missing value.

interview was accurately transcribed and corrected by student assistants using the transcription function of the MAXQDA software. The short greeting at the beginning and goodbye at the end of the interview were not transcribed unless something relevant to the topic was raised there.

The interviews were transcribed using an intelligent verbatim transcription approach with only minor adjustments to the transcripts: Pauses were removed and some minor corrections were made (filler words were removed). Within the transcripts questions asked by the Interviewer are indicated by "I1:" or "I2:" respectively. Responses by the Interviewees are introduced by the corresponding interview number (e.g., "02: I don't think that…" for interview number 02). All names that are not part of the public life (e.g., Angela Merkel is kept in) as well as all parts that indicate a location or occupation that could lead to identifying one of the participants have been anonymized. Relevant sections and words have been replaced by inserting "XXXXX." Notes about how something was verbalized (e.g., laughing, incomprehensible, ironic) have been bolded and inserted in parentheses. Words pronounced with strong emphasis were underlined.

Semi-structured Interviews

The interviews were developed to further elaborate on some of the responses in the survey instrument. The topics and questions slightly varied from one interview round to the next, to adjust for new developments and make the interviews less repetitive. All interviews followed a semi-structured interview guide with a fixed set of open-ended questions for each participant. If interesting aspects and topics were mentioned by the interviewee, the interviewer followed up on those aspects with additional questions and asked for clarification and examples where needed.

At the start of each interview, participants were asked to give a short summary of what had happened in Germany with regards to the pandemic in the past 6 months, or since the last interview. This question was asked to help participants "arrive" in the interview situation, but also to identify which "key events" or "critical moments" (biographical or historical) are remembered and perceived as significant, and the consequences they have on individual attitudes and beliefs (Holland, 2011). After that, participants were asked for challenges and coping mechanisms during that time period. This "warm-up" phase was followed by different thematic sections that aimed to further probe participants' answers to the survey, asking for more details and information on the specific topics. A short overview of the thematic sections in each round of interviews can be found below, while the detailed interview guides are provided alongside the dataset (https://doi.org/10.5281/zenodo.5556052).

Phase I

Data collection for the Phase I interview study took place from the 1st of December 2020 to the 28th of December 2020.

The interviews took place shortly after the second round of severe restrictions (called 'lockdown light') was introduced in Germany in the beginning of November 2020. Despite those measures, numbers were rising and a second 'hard lockdown' was introduced on December 16th, including strict contact restrictions, school closures and the closure of "non-essential" business. Shortly before the Christmas holidays, due to the new delta variant, travel from the UK and South Africa was restricted. Concerning the vaccines, the first dose of the Pfizer/BioNTech vaccine was already administered in the UK on the 8th of December but was not available to the general public yet. On December 21, the European Commission authorized the BioNTech/Pfizer vaccine. The first vaccine in Germany was administered on the 26th of December. Only one of our interviews was carried out after that date (Interview Nr. 41).

Topics covered in the interview include: Information/misinformation, trust/distrust in different political/scientific actors and institutions, compliance, vaccination, the cause of the outbreak and conspiracy beliefs. An exemplary question for each respective section can be found below.

- *Information/Misinformation:* "What sources of information are most important to you when looking for information about the coronavirus? What makes this source relevant to you?"
- *Trust/Distrust in different political/scientific actors:* "In your survey, you mentioned that you have [high/low trust] in [political/scientific actor; e.g., the WHO, Angela Merkel]. Can you tell me more about why you feel that way?"
- *Compliance:* "What are the most important measures you use to protect yourself from the coronavirus? In your survey response, you mentioned that you're [frequency of mask wearing] wearing a protective mask where it is mandatory. Could you describe how you feel wearing a face mask?"
- *Vaccination:* "In your survey response, you mentioned that you'd [vaccination willingness] get a voluntary coronavirus vaccination. Could you explain why you're feeling that way?"

- *Cause of the outbreak of the COVID-19 pandemic:* "What do you see as the cause of the outbreak?"
- *Conspiracy beliefs:* "In the survey response you indicated that you [agree/strongly agree] with the statement that [Conspiracy belief]. Can you explain your reasons for agreeing with this statement?"

Phase II

Data collection for the Phase II interview study took place from the 6th of April 2021 to the 28th of April 2021.

In April 2021, case numbers remained persistently high. Vaccination was still not available to everyone and the distribution followed a prioritization based on age, health status and occupation. In the previous month, the AstraZeneca vaccine was suspended on March 15 after reports of rare, but serious, blood clots. A few days later, on March 19, vaccination with AstraZeneca in Germany continued until the 30th of March 2021, when it is decided to only vaccinate people over the age of 60 with the AstraZeneca vaccine. On April 6th, the AstraZeneca vaccine was made available to the whole population, regardless of the prioritization group. In the beginning of April, 11.6 % of the population received at least one dose of vaccination. By the end of April, this number rose to more than 25%.

Despite increasing vaccination efforts, the number of new infections stayed high and the German government announced another short, but very strict, nationwide lockdown over the easter holidays ("Osterruhe") from April 1st to April 5th. After massive criticism and great confusion about the practical implementation, Angela Merkel had to publicly apologize and reverse the decision.

There were slight changes to the questions of each theme and an additional theme was added at the end:

- *Information/Misinformation:* "What specific information about the coronavirus are you looking for? Are you satisfied with the information you find?"
- *Trust/Distrust in different political/scientific actors:* "In the second survey, you mentioned that you have [high/low trust] in [political/scientific actor; e.g., the WHO, Angela Merkel], while in the first survey you indicated that you have [high/low trust]. Can you tell me more about why your level of trust in [political/scientific actor] has [increased/decreased]?"
- *Compliance:* "Are there situations where you break your 'mask-wearing routine'?"
- *Vaccination:* "[Do/did] you have any concerns about being vaccinated?"
- *Cause of the outbreak:* "How did this pandemic come about?"
- *Conspiracy beliefs:* "In the first survey response, you indicated that you [level of agreement] with the statement that [Conspiracy belief], while in the second survey you indicated that you [level of agreement]. Can you explain why your opinion has changed?"
- *NEW: Outlook and Lessons Learned:* "How would you determine the end of the pandemic?", "Are there any lessons learned from the pandemic for the future?"

Phase III

Data collection for the Phase III interview study took place from the 2nd of September 2021 to the 23rd of September 2021.

By September, 84% of the German population had received at least one dose of vaccination. The case numbers were relatively low, and the public discussion has shifted to one focusing on the 're-opening' of society and mandatory vaccination. On September 26, federal elections were held in Germany, leading to a change of government after 16 years of Angela Merkel's chancellorship.

Again, slight changes were made to questions within the existing themes:

- *Information/Misinformation:* "What specific information about the coronavirus are you looking for? Are you satisfied with the information you find?"
- *Trust/Distrust in different political/scientific actors:* "Does the COVID pandemic have a decisive influence on your voting behavior in this year's federal election? How far?"
- *Compliance:* "Has your mask-wearing behavior changed for you since we last spoke? In what way? Why?"
- *Vaccination:* "Has anything changed for you since you had the full vaccine coverage? Are there situations in which you feel unprotected against the virus?"
- *Conspiracy beliefs:* "In the second survey response, you indicated that you [level of agreement] with the statement that [Conspiracy belief], while in the third survey you indicated that you [level of agreement]. Can you explain why your opinion has changed?"
- *Outlook and Lessons Learned*: "What lessons do you personally draw from this time?"

USING THE DATASET

All interview transcripts (in German) are accessible on the open science publication platform Zenodo: https://doi.org/10.5281/zenodo.5556052. In addition, the interview guides for phase I, II and III are provided in English and German. An SPSS file including relevant demographic and contextual information (incl. selection criteria) about all interview participants of the Viral Communication project is provided as an anonymised version. All data can be linked through the ID number (ranging between "01" and "41") that identifies each participant. This ID number stays the same throughout all three interviews (e.g. "05_1" for participant "05"s first interview, "05_2" for participant "05"s second interview and "05_3" for participant "05"s third interview).

This dataset will be especially of interest to researchers that want to study topics such as people's changing narratives of the pandemic in Germany, trust in authorities and institutions, the dynamics of compliance and non-compliance with measures (esp., face-masks), vaccination decision-making and belief in conspiracy theories, to name a few key topics. Researchers applying natural language processing techniques (e.g., automated sentiment analysis, topic modeling, framing) might be especially interested in this unique dataset. Furthermore, the dataset is relevant to political scientist for answer questions related to varying levels of trust in political actors and institutions. For example, it can be helpful in answering questions about *why* trust increased/decreased over time. The same applies

to researchers in communication science trying to explain *why* certain information sources are favored over others and how trust in those sources changed over the course of the pandemic.

In general, the longitudinal character of the data for each participant is of particular value in that it provides a rare opportunity to track people's thoughts and feelings through time. For example, one can see how initial COVID-19 vaccine resistance is progressively overcome by most participants, while a minority of participants become progressively more extreme in their attitudes against it. We also asked people to recall the last 6 months of the pandemic in Germany and to imagine the next period of time in the future; thus, researchers can compare future expectations and subsequent narrations of the past. Another feature worth noting is the dialogical character of some questions: participants were asked how they would respond to others who have an opposing belief with regards to some issue (e.g., face-masks). Finally, the combination with the SPSS dataset containing survey responses of all 40 participants that is provided alongside the interview data offers various options for triangulation. In short, the dataset provides researchers with an extremely rich material to better understand how people have experienced and made sense of the pandemic situation through time.

DATA AVAILABILITY STATEMENT

The anonymized datasets generated for this study can be found on the open science publication platform Zenodo https://doi.org/10.5281/zenodo.5556052.

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ETHICS STATEMENT

AUTHOR CONTRIBUTIONS

LH and BW wrote the report. MW, BW, and LH were responsible for the interview study within the viral communication project. The interview guides were designed by MW, BW, EJ, and LH. EJ commented on the draft of the article. AP and LL helped with the interview process and analysis. All authors contributed to the article and approved the submitted version.

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Examining the impact of media use during the COVID-19 pandemic on environmental engagement

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The COVID-19 pandemic led to global public health campaigns enacting strict orders to slow the spread of the disease. The public health initiatives were communicated broadly through diverse news sources and social media channels, spreading both factual information and misinformation about the environmental benefits related to the shelter-in-place orders. This quantitative study of United States residents (N = 1,048), guided by selective exposure theory, examined if demographics, news and/or social media source use, and public knowledge of environmental changes that took place as a result of COVID-19 shelter-in-place orders predicted intent to engage in environmentally-conscious behavior. Results indicated demographics and social media used predicted intent to engage in environmentally-conscious behaviors. Intent to engage in environmental behaviors is critical for environmental sustainability and the media may provide one avenue for engaging the public in environmental behaviors. Discussion points include environmental communication strategies and understanding messaging strategies within the politicization process of communicating about environmental issues during the COVID-19 pandemic.

KEYWORDS

COVID-19, environmental engagement, environmental knowledge, media, selective exposure

Introduction

Coronavirus Disease 2019 (COVID-19) was declared a pandemic by the World Health Organization (WHO) on 11 March 2020 after causing 4,291 deaths in 114 countries within a 3-month timespan (Bavel et al., 2020). Public health campaigns around the globe called for increased hand washing, social distancing, and wearing masks in public places to slow the spread of the virus (Bavel et al., 2020). One of the most controversial policy decisions made by many global leaders was to require their citizens to shelter in place to prevent the spread of COVID-19; thereby ensuring health care systems were able to accommodate sick patients. The shelter-in-place (SIP) orders

had both positive and negative impacts on the natural environment (Zombrano-Monserrate et al., 2020). For example, the COVID-19 SIP orders reduced air pollution in many parts of the world (Muhammad et al., 2020; Ogen, 2020) due to reduced industrial production and a decrease in automobile and air travel (Lohmann and Aref, 2020). Orders also had a positive indirect effect on beach cleanliness due to the presence of fewer tourists (Zombrano-Monserrate et al., 2020).

There were also negative effects of the SIP orders, such as reduced recycling due to concerns about the spread of COVID-19 among employees in recycling centers and increased waste due to companies requesting the public leave reusable bags and containers at home when purchasing food and beverages (Zombrano-Monserrate et al., 2020). Additionally, increased online food ordering (Zombrano-Monserrate et al., 2020) and large amounts of personal protective equipment (PPE), such as gloves and masks (Saadat et al., 2020), added to the volume of waste produced. According to Frenkel et al. (2020), "as the coronavirus has spread across the world, so too has misinformation about it [...]" (p. 3), which likely caused the spread of misinformation about the direct and indirect environmental impact of the COVID-19 SIP orders within the public sphere. Previous research on misinformation was in the context of social media during the 2016 U.S. presidential election (Roozenbeek et al., 2020) when fake news was a far-reaching public concern (Grinberg et al., 2019). Misinformation dominated the media landscape during COVID-19, and ranged from harmful health advice like ingesting bleach to threats to international relations due to conspiracies about the origin of the virus that were politically motivated (Roozenbeek et al., 2020).

Misinformation about the environmental impacts of the COVID-19 pandemic appeared within both mainstream news channels as well as social media (Frenkel et al., 2020). For example, conflicting information was released about dolphin sightings in the Venetian canals due to the absence of humans due to behavior changes related to the SIP orders (Daly, 2020). The dolphin images were released on popular social media sites, including Instagram and Twitter, with text indicating the dolphins were swimming in the Venetian canals. However, the posts were misleading as the dolphins were filmed a few hundred miles away in the Mediterranean Sea, providing false information about positive environmental benefits of human behavioral patterns related to the SIP orders. Similarly, there was substantial media coverage about the clarity of water in the Venetian canals due to the absence of tourism related to the SIP orders (Daly, 2020). The water clarity in the canals did improve as sediment in the water remained at the bottom of the canal due to the lack of boats that typically cause turbidity and the lack of tourism (Braga et al., 2020). However, water clarity was often mistaken with less water pollution or cleaner water, which was not a result of the absence of tourism related

to the SIP orders (Link, 2020). The rapid, large-scale spread of posts providing inaccurate information demonstrated how quickly misinformation can spread during a time of crisis (Daly, 2020) and the increasingly important role of social media in crisis communication (Austin et al., 2012; Spence et al., 2016). Complex emotions surrounding COVID-19 have also negatively impacted the acquisition of factual information as people shared sensationalized and emotionally-driven stories despite their factual inaccuracy (Bavel et al., 2020).

A crisis is defined as an event that consists of "high levels of uncertainty, confusion, disorientation, surprise, shock, and stress" (Seeger et al., 2003, p. 125). Numerous studies suggest it is critical for crisis communication, such as communicating about the facts surrounding COVID-19, to be clear and concise to yield effective message uptake (Dawes et al., 2004; Netten and van Someren, 2011). According to a Pew Research Center (2020) study, 48% of the United States (U.S.) public reported encountering fake or fabricated news about COVID-19. Additionally, in the same study, individuals that identified as Republicans indicated viewing more "made-up news" about the pandemic than individuals that identified as Democrats (Pew Research Center, 2020, p. 14).

While negative emotions about COVID-19 exacerbated the spread of misinformation in social and news media, there was also been an opportunity to promote environmental awareness simultaneously with crisis information related to the pandemic. However, information obtained from news sources must be accurate and factual to encourage members of the public to become engaged, long-term stewards of the environment. Therefore, this research focused on the influence of news and social media sources and level of knowledge of environmental changes resulting from the COVID-19 SIP orders on respondents' likelihood to engage in future environmental behaviors.

Conceptual framework

Four concepts influenced the framework of the study: self-identified characteristics (education level and political affiliation/ideology), selective exposure to media, knowledge of environmental changes related to the SIP orders, and intent to engage in environmentally-conscious behavior. Figure 1 demonstrates the proposed framework, detailing how education level and political affiliation/ideology influences selective exposure to both news and social media, which in turn influences knowledge of environmental changes. Finally, knowledge of environmental changes then influences one's intent to engage in environmentally-conscious behavior (see Figure 1). Each component of the conceptual framework is described below.
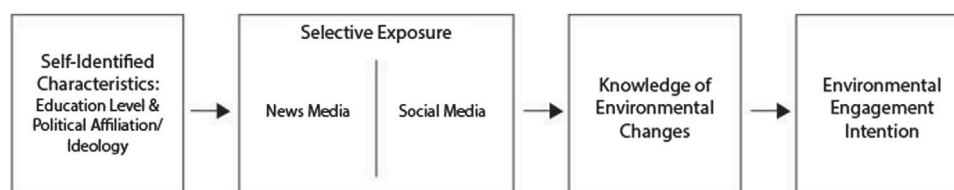
FIGURE 1
Conceptual Framework of Selective Exposure to Media and its Influence on Knowledge of Environmental Changes and Engagement Intention.

Self-identified characteristics: Education level and political affiliation/ideology

Those with higher levels of education generally display higher levels of knowledge, contributing to a disparity within the knowledge gap of a population. According to Tichenor et al. (1970), "as the infusion of mass media information into a social system increases, higher socioeconomic status segments tend to acquire this information faster than lower socioeconomic status population segments" (p. 159). Within the new media landscape, which includes both traditional news media as well as social media, there is not as strong of a direct linear relationship between education level and media literacy. Gerosa et al. (2021) found that education level did not play a role in believing false news information related to COVID-19. They did find, however, that social media, in contrast with news media, was associated with lower levels of knowledge and fake news beliefs.

In addition to the findings of Gerosa et al. (2021), political affiliation and ideology is often associated with belief in fake news information. Pedro Baptista et al. (2021) found the belief and dissemination of fake news was related to a more conservative political ideology as well as lower education levels. Additionally, media consumers with a conservative ideology are more likely to associate mainstream news sources with the term "fake news," specifically when discussing more liberal media outlets such as The Cable News Network (CNN; van der Linden et al., 2020). Thus, there may be a relationship between education level, political affiliation, and political ideology related to knowledge of fake news within the media landscape, but more exploration is needed to operationalize the relationship between these constructs.

Selective exposure to media

The media plays a crucial role in informing the public about global sustainability as well as engaging ordinary citizens in environmental issues (Zhao, 2009; Arlt et al., 2011; Olausson, 2011; Östman, 2014). However, because the public has the ability to selectively engage with certain media platforms (Rubin, 2002),

individuals are not passive in the media sources they consume (Katz et al., 1973; Katz et al., 1974; Hennessy et al., 2016); rather, individuals are selective in that they purposefully and strategically engage in media that satisfies their interests and needs (Konijn and Hoorn, 2005; Konijn et al., 2007). Selective exposure refers to a psychological preference for experiencing like-minded content in media (Festinger, 1964; Gvirsman, 2014). The preference for information consistent with one's attitudes, values, and beliefs reduces cognitive dissonance, or the undesirable feelings that arise from experiencing contradictory cognitions (Stroud, 2014). With the growing number of news sources available for science information, both accurate and inaccurate, it is difficult for individuals to avoid selective media exposure (Feldman et al., 2014; Jamieson and Hardy, 2014).

While selective exposure to media may be benign related to some information (e.g., hobbies), it is a critical issue when impacting policies influenced by political affiliation and ideology, such as climate change (Hennessy et al., 2016). Scholars have found that selective exposure to media exacerbates the extremities of people's attitudes, resulting in polarization (Bennett and Iyengar, 2008; Iyengar and Hahn, 2009; Stroud, 2010; Gvirsman, 2014). McCright and Dunlap (2011) evaluated Gallup polling data between 2001 and 2010 regarding public belief that global warming effects have already begun and found there was a growing gap between Democrats and Republicans/liberals and conservatives. Similarly, Dunlap and McCright (2008) evaluated public opinion on global warming and found Democrats were more likely to think the media does not greatly exaggerate global warming and that there was consensus among the scientific community about global warming whereas Republicans held a contrary perspective. For example, politically selective exposure to news sources affected public awareness of the 2014 walrus haul out that involved unprecedented numbers of walruses gathered on a beach due to a decrease in Artic Sea ice caused by climate change (Hennessy et al., 2016). Hennessy et al. (2016) found news channels, levels of news exposure and viewing, and political ideology were strong predictors of respondents' exposure to information about the haul out. In another example, Anderson et al. (2018) evaluated media coverage of the

bushfires in Australia in 2009, also known as Black Saturday, and found the crisis response by the media was influenced by an ideological conflict in Australia. These examples demonstrate how political environments in a nation can strongly influence public perceptions of environmental issues, depending on an individual's position on the political continuum and engagement in selective exposure behavior.

Many popular news media sources align with a political leaning in the U.S., such as Democrat or Republican and liberal or conservative (Pew Research Center, 2014). According to a 2014 Pew Research study, Fox News tended to have a conservative audience, whereas the Columbia Broadcasting System (CBS) News and the American Broadcasting Company (ABC) News audience were more consistently moderate. The National Broadcasting Company (NBC) News audience was more consistently liberal (Pew Research Center, 2014). Fox News was identified as the main source of news coverage for conservatives; and while the NBC audience was more consistently liberal, there was not one main source of news coverage among liberals (Pew Research Center, 2014). High levels of politicization and polarization within media contribute to a complex science communication environment (Kahan, 2012). In times of crisis, these communication challenges are exacerbated, particularly when combined with individuals' value differences surrounding environmental issues (Hart et al., 2020). Polarization of news outlets during the COVID-19 pandemic significantly impacted engagement in social distancing, masking, and vaccination behaviors to mitigate the spread of the disease (Ash et al., 2020; Hornsey et al., 2020; Simonov et al., 2020; Hao et al., 2021; Kahane, 2021). Consumption of right-leaning news media sources in the U.S., such as Fox News, correlated with non-compliance with preventative health behaviors related to COVID-19 due to the spread of misinformation about the virus (Motta et al., 2020; Simonov et al., 2020; Kahane, 2021).

Selective exposure also influences interactions on social networking sites. Social media users tend to follow or befriend other users with similar viewpoints. For example, the Pew Research Center (2014a) found conservatives were more likely to have friends who are like-minded on Facebook. Pearce et al. (2014) analyzed individuals using Twitter and how they interacted with a report by the Intergovernmental Panel on Climate Change and found individuals who shared a similar stance on climate change often interacted with one another. Social networking sites may increasingly foster selective exposure behavior due to the constant barrage of information presented to users, triggering further polarization attitudes (Spohr, 2017). The customizability of social networking sites, mediated through technology, allows for echo chambers that reduce users' cognitive dissonance associated with encountering information that challenges their values, attitudes, and beliefs (Dylko et al., 2017).

Knowledge of environmental changes and engagement intention in the media landscape

Recent studies have demonstrated that the media affects public knowledge of environmental issues (e.g., Zhao, 2009; Arlt et al., 2011; Olausson, 2011; Östman, 2014; Wallace, 2018). Guo et al. (2019) evaluated the risk perception of nuclear radiation post-Fukushima in the Japanese public and found individuals who trusted the media were more likely to consider themselves knowledgeable about nuclear radiation. According to Ho et al. (2014), "perceived threats of environmental risks may heighten people's reliance on media for information about the environment" (p. 93). However, the public is often unable to determine if the news presented to them about the environment is factual or fake. Wallace (2018) found "[...] until audiences are provided with the tools to critically engage with fake fact media there is the tangible threat of fake facts [...] permeating and ultimately degrading integral sites for promoting environmental ethics and sensitivity" (p. 803). Similarly, Littlefield and Quenette (2007) found media outlets "implicitly have the ability to create a view of reality reflecting their perspective" (p. 43) during times of crisis. Wallace (2018) defined fake facts as those that "eschew the established ethos and reliability of [credible] networks [...] in order to gain viewers and increase spreadability *via* entertainment value instead of educational value" (p. 791). Fake facts often are used in the promotion of fake news, or "news content published on the internet that aesthetically resembles actual legitimate mainstream news content, but that is fabricated or extremely inaccurate" (Pennycook and Rand, 2021, p. 389). Misinformation caused by fake facts may negatively influence public knowledge of environmental changes that occur during times of crisis.

The media also plays an important role in public engagement with environmental issues (e.g., Zhao, 2009; Arlt et al., 2011; Olausson, 2011; Östman, 2014; Wallace, 2018). Östman (2014) examined the relationship between news media use and environmental engagement in Swedish adolescents and found the news media raised awareness of environmental issues, thereby promoting pro-environmental behavior. Zhang and Skoric (2018) evaluated the links between news and social media on environmental engagement in Hong Kong, China and found news media use had a positive relationship with environmental activism and consumerism. Additionally, recreational social media use had a positive relationship with environmental consumerism but a negative relationship with environmental activism. Furthermore, respondents who indicated using social media for political reasons had a positive relationship with environmental activism and consumerism. Skoric and Zhang (2019) examined environmental engagement predictors in China and found news media consumption, opinion leadership, and Weibo use (a social networking site) significantly predicted environmental

engagement among Chinese citizens. Environmental knowledge among the Chinese public was partly mediated by this effect.

Studies have demonstrated that environmental knowledge can have a positive influence on engagement in pro-environmental behaviors (Liobikienė and Poškus, 2019). Due to knowledge being perceived as a precondition for behavior change, many environmental interventions focus on education through knowledge transfer (Frick et al., 2004). The relationship between knowledge and pro-environmental behavior may be more complex, however, than the initial linear and transfer-oriented knowledge models suggest (Frick et al., 2004). In addition, knowledge of environmental changes that occur in times of crisis may aid in explaining environmental engagement post-SIP orders. Thus, more research is needed to investigate the relationship between environmental knowledge and engagement in pro-environmental behavior.

While under normal circumstances media plays a large role in affecting public environmental knowledge and engagement (e.g., Zhao, 2009; Arlt et al., 2011; Olausson, 2011; Östman, 2014), this effect may be exacerbated due to the risk of the COVID-19 pandemic. With literature indicating potential causal factors influencing health behaviors during COVID-19, further research is needed to investigate relationships between news sources, social media use, and intent to engage in environmental protection behavior due to the influence of the politically polarized media environment during the pandemic. Therefore, communicators must first determine what media sources the public uses to receive information about environmental issues during the pandemic in order to determine how to effectively disseminate information to influence intent to engage in natural resource protection behaviors accounting for barriers presented by selective exposure.

Purpose and methods

The purpose of this study was to determine if media sources and knowledge levels related to the environmental changes resulting from the COVID-19 SIP orders impacted intent to engage in environmental behaviors in the future during the COVID-19 shelter-in-place orders. The following research objectives were used to guide the study:

1) Identify news sources and social media sources the U.S. public used to obtain COVID-19 information while most states were under shelter-in-place orders;
2) Identify public knowledge levels and environmental engagement intention levels related to the environmental changes resulting from the COVID-19 shelter-in-place orders;
3) Determine if demographics, news sources, social media sources, and knowledge of environmental changes

predicted future environmental engagement intention levels related to the environmental changes resulting from COVID-19 shelter-in-place orders.

Survey measures

The survey instrument included demographic, Likert-type, select-all-that-apply, multiple choice, and true/false questions. One select-all-that-apply question was used to determine the social media platforms respondents used when most states were under the COVID-19 SIP orders. Options included Facebook, Instagram, and Twitter. The variables in the scale were subsequently coded into three dichotomous variables for data analysis. Respondents who indicated they used the social media platform were coded as one and respondents that indicated they did not use the platform were coded as 0.

Five questions were used to determine the news sources (on television or online) respondents used when most states were under COVID-19 SIP orders with a five-point Likert-type scale (1 = Almost constantly; 2 = About once a day to several times a day; 3 = Once to several times a week; 4 = Less than once a week; 5 = Never). The questions asked respondents to indicate how often they used the following news sources: Fox News, CBS News, NBC News, and ABC News. The scale responses were subsequently re-coded into dichotomous variables for data analysis. Specifically, respondents who indicated they used a news source less than once a week or more were coded as one and respondents who indicated they never used a news source were coded as 0.

Nine knowledge questions were used to determine public knowledge levels related to the environmental changes resulting from the COVID-19 SIP orders. These items were sourced from Link (2020). Seven questions were true/false and asked respondents if the global SIP orders related to reducing the spread of COVID-19 have led to: 1) short-term reductions in air pollution around the world (true), 2) the hole in the ozone above the Arctic closing (false), 3) increased recycling (false), 4) increased medical waste filling landfills (true), 5) less overall trash accumulation (true), 6) cleaner canals in Venice (false), and 7) a reduction in atmospheric CO_2 levels (false). Two questions were multiple choice. The first multiple-choice question asked respondents to indicate what percentage of the normal pollution in New York City has been reduced as a result of measures used to contain the COVID-19 virus. The answer choices were 100%, 75%, 50%, 25%, and 0% (correct answer, 50%). The second multiple-choice question asked respondents to indicate the results associated with the reduction in air pollution resulting from COVID-19 virus health and safety containment measures. The answer choices were improved cardio-pulmonary health, atmospheric CO_2 levels dropping, and average temperatures dropping across the world (correct answer, cardio-pulmonary health). Public knowledge levels related to

the environmental changes resulting from the COVID-19 SIP orders were measured rather than traditional environmental knowledge because of their sensationalized media presence during the SIP orders. A limitation to using multiple choice and true/false knowledge questions for measurement is the research assumes the respondent is not guessing the answer they selected (Ruth et al., 2017).

Seven questions were used to determine how likely the public is to intend to engage in environmentally-conscious behavior in the future as a result of the COVID-19 outbreak with a five-point Likert-type scale (1 = Very unlikely; 2 = Unlikely; 3 = Undecided; 4 = Likely; 5 = Very likely). The scale was adapted from Owens and Lamm (2017). Respondents were allowed to select Not applicable if the item did not apply to them. Respondents who selected Not Applicable received a mean score for that item. The questions prompted respondents to indicate how likely they were to engage in the following activities: 1) join an environmental conservation organization, 2) buy a specialty license plate that supports environmental protection efforts, 3) volunteer for a stream cleanup or wetland restoration event, 4) volunteer to keep public greenspaces/parks available and healthy, 5) vote for a candidates who support environmental conservation, 6) vote to support environmental conservation programs, and 7) support restrictions issues by their local government that protect the environment. Respondents' intent to engage in environmentally-conscious behavior score was calculated based on the average response to the seven items used to determine how likely a respondent was to engage in environmental behavior in the future as a result of the COVID-19 outbreak. Reliability was calculated post hoc (α = 0.91). The real limits of the scale were: 1.00—1.50 = Very unlikely; 1.51—2.50 = Unlikely; 2.51—3.49 = Undecided; 3.50—4.49 = Likely; 4.50—5.00 = Very likely.

Data collection

The survey instrument was researcher-developed and then reviewed for face and construct validity by a panel of external experts in survey design, communications research, and environmental conservation (Lamm et al., 2020). The University of Georgia Institutional Review Board approved the study and then the survey instrument was pilot tested for content validity with 50 individuals who were representative of the sample. All scales were deemed reliable based on Cronbach alpha coefficients 0.70 or higher and full data collection commenced.

Data were collected from U.S. residents in May 2020 *via* Qualtrics, an online survey platform. The targeted population was U.S. residents age 18 or older who were representative of the population based on age, gender, race, ethnicity, and geographic location. One limitation of online surveys is only residents with access to a computer and internet access have the ability to

TABLE 1 Demographics of respondents (N = 1,048).

	F	*%*
Sex		
Male	502	47.9
Female	546	52.1
Age		
18–34 years	227	21.7
35–54 years	438	41.8
55 + years	383	36.5
Race*		
White	896	85.5
Black	83	7.9
Asian	41	3.9
American Indian or Alaska Native	34	3.2
Other	20	1.9
Ethnicity		
Hispanic	73	7.0
Non-Hispanic	975	93.0
Education		
Less than 12th grade	18	1.7
High school diploma	140	13.4
Some college	190	18.1
2-year college degree	104	9.9
4-year college degree	268	25.6
Graduate or Professional degree	328	31.3
Family Income		
Less than $24,999	156	14.9
$25,000 - $49,999	195	18.6
$50,000 - $74,999	148	14.1
$75,000 - $149,999	295	28.1
$150,000 - $249,999	181	17.3
$250,000 or more	73	7.0
Political Affiliation		
Republican	383	36.5
Democrat	405	38.6
Independent	186	17.7
Non-affiliated	65	6.2
Other	9	0.90
Political Ideology		
Very liberal	112	10.7
Liberal	200	19.1
Moderate	393	37.5
Conservative	218	20.8
Very conservative	125	11.9

Note: *Respondents were allowed to select more than one race.

participate in the study, which may be exacerbated by COVID-19, impacting the generalizability of the results (Ary et al., 2010). Non-probability opt-in sampling methods were used to locate respondents for this research (Baker et al., 2013; Wiśniowski et

TABLE 2 News sources used (N = 1,048).

	Never %(F)	Less than once a week %(F)	Once to several times a week %(F)	About once a day to several times a day %(F)	Almost constantly %(F)
Fox News	29.5 (309)	7.7 (81)	17.3 (181)	30.6 (321)	14.9 (156)
CBS News	25.0 (262)	10.9 (114)	22.8 (239)	32.2 (337)	9.2 (96)
NBC News	24.9 (261)	7.1 (74)	26.9 (282)	31.9 (334)	9.3 (97)
ABC News	24.0 (252)	10.1 (106)	22.1 (232)	33.6 (353)	10.0 (105)

at., 2020). Public opinion research often uses non-probability sampling techniques (Baker et al., 2013). For example, Gorham et al. (2017) used non-probability opt-in sampling to determine Florida residents' critical thinking styles and levels of engagement in water conservation behaviors.

Sample population demographics

A total of 1,048 individuals completed the survey. The 2010 Census data was used to weight the data on geographic location, age, gender, and race to ensure the respondents were representative of the population of interest (U.S. Census Bureau, 2010). The respondents were 52.1% female and 47.9% male (Table 1). The average respondent was White (85.5%), 35 years and older (78.3%), and had at least some college education (84.9%). The majority of respondents were Democrat (38.6%) or Republican (36.5%), with few individuals indicating Independent (17.7%), non-affiliated (6.2%), or other (0.90%). One limitation of the study was that respondents were disproportionately White compared to the general U.S. population, which may have influenced the results of the present study. Table 1 includes the demographic profile of respondents.

Statistical analysis plan

Descriptive statistics were used to identify news sources and social media sources the U.S. public used to obtain COVID-19 information and to identify public knowledge levels and intent to engage in environmentally-conscious behavior levels related to the environmental changes resulting from the COVID-19 SIP orders. Variance of Inflation Factor (VIF) and multicollinearity tolerance coefficient (MTC) were used to determine any issues of high multicollinearity that may impact the regression analysis (Cohen, 1988). Multiple linear regression models, which are commonly used in the social sciences when several independent variables are used to predict one dependent variable, were used to predict intent to engage in

TABLE 3 Social media sources used (N = 1,048).

	Did not use %(F)	Platform used %(F)
Facebook	20.0 (210)	80.0 (838)
Instagram	46.3 (485)	53.7 (563)
Twitter	51.6 (541)	48.4 (507)

TABLE 4 Knowledge of environmental changes test score (N = 1,048).

Questions Answered Correctly	F	%
0 - None Correct	0	0.0
1	15	1.4
2	96	9.2
3	252	24.0
4	343	32.7
5	210	20.0
6	99	9.4
7	26	2.5
8	6	0.6
9—All Correct	1	0.1

environmentally-conscious behavior levels related to the environmental changes resulting from the COVID-19 SIP orders. Data were analyzed using SPSS 26 (Chicago, IL).

Results

Descriptive statistics

Survey respondents were asked to indicate how often they used news sources to obtain COVID-19 information while most states were under the SIP orders (Table 2). Respondents were likely to use Fox News (45.5%), ABC News (43.6%), CBS News (41.4%), and NBC News (41.2%) at least once a day. The majority

TABLE 5 Results of Variance of Inflation Factor (VIF) and Multicollinearity Tolerance Coefficient (MTC) used to determine multicollinearity for environmental engagement intention regression analysis (N = 1,048).

-	Model 1		Model 2		Model 3		Model 4	
	VIF	MTC	VIF	MTC	VIF	MTC	VIF	MTC
Demographics								
Less than high school education	1.056	0.947	1.065	0.939	1.07	0.935	1.07	0.935
High school education	1.328	0.753	1.408	0.71	1.412	0.708	1.416	0.706
Some college education	1.412	0.708	1.51	0.662	1.511	0.662	1.512	0.661
2-year college education	1.26	0.794	1.314	0.761	1.328	0.753	1.331	0.751
Graduate school education	1.558	0.642	1.612	0.62	1.625	0.615	1.625	0.615
Democrat political affiliation	1.576	0.635	1.58	0.633	1.636	0.611	1.637	0.611
Independent political affiliation	1.349	0.741	1.368	0.731	1.371	0.729	1.371	0.729
No political affiliation	1.19	0.84	1.198	0.835	1.208	0.827	1.209	0.827
Other political affiliation	1.028	0.973	1.033	0.968	1.035	0.966	1.036	0.966
Very liberal political belief	1.221	0.819	1.242	0.805	1.256	0.796	1.256	0.796
Liberal political belief	1.336	0.749	1.336	0.748	1.354	0.738	1.357	0.737
Conservative political belief	1.363	0.734	1.38	0.724	1.398	0.716	1.398	0.715
Very conservative political belief	1.288	0.776	1.296	0.772	1.313	0.762	1.314	0.761
Social Media Sources								
Facebook			1.099	0.91	1.107	0.903	1.11	0.901
Instagram			1.433	0.698	1.443	0.693	1.444	0.692
Twitter			1.572	0.636	1.689	0.592	1.69	0.592
News Sources								
Fox News					1.484	0.674	1.491	0.67
CBS News					3.032	0.33	3.038	0.329
NBC News					2.642	0.379	2.656	0.377
ABC News					2.497	0.4	2.498	0.4
Knowledge of Environmental Changes							1.038	0.964

of respondents used ABC News (75.8%), Fox News (70.5%), CBS News (75.0%), and NBC News (75.1%) at some point during the week while most states were under the SIP orders.

Survey respondents were asked to indicate which social media platforms they used when most states were under the COVID-19 SIP orders (Table 3). Over half of respondents used Facebook (80.0%) and Instagram (53.7%) when most states were under the COVID-19 SIP orders. Less than half of respondents used Twitter (48.4%) when most states were under the COVID-19 SIP orders.

Respondents' knowledge of environmental changes test scores could range from zero (no items were answered correctly) to nine (all items were answered correctly). Overall, respondents' knowledge of environmental changes levels were moderate (M = 4.02, SD = 1.29). The majority of respondents (76.7%) answered three to five knowledge questions correctly (Table 4). Only one respondent answered all nine questions correctly and zero respondents answered none of the questions correctly. Respondents' intent to engage in environmentally-conscious behavior score could range from one (very unlikely)

to five (very likely). Overall, respondents' intent to engage in environmentally-conscious behavior scores indicated respondents were undecided (M = 3.25, SD = 1.12).

Multicollinearity diagnostics and multiple linear regression analyses

VIF and MTC were conducted prior to the regression analysis to assess multicollinearity diagnostics (Table 5). VIF should be less than 10 and tolerance should be greater than 0.10 to ensure no issues of multicollinearity. Based on the findings, the rate of multicollinearity among the independent variables should not affect the results of this study (Cohen, 1988).

A series of regression models were used to determine if demographics, social media sources used, news sources used, and knowledge of environmental changes predicted intent to engage in environmentally-conscious behavior in the future related to the environmental changes resulting from COVID-19 SIP orders. Initially, a multiple linear regression model was

TABLE 6 Predicting the likelihood of intent to engage in future environmentally-conscious behavior using Demographics, Social Media Use, News Media, and Knowledge of Environmental Changes (N = 1,048).

	Model 1	*Model 2*	*Model 3*	*Model 4*
R^2	0.238***	0.336***	0.356***	0.357***
ΔR^2		0.098***	0.020***	0.001
Demographics				
Less than high school education	-0.404	-0.225	-0.239	-0.236
High school education	-0.524***	-0.241*	-0.23*	-0.225*
Some college education	-0.508***	-0.228*	-0.234**	-0.231**
2-year college education	-0.477***	-0.211	-0.164	-0.17
Graduate school education	0.521***	0.346***	0.323***	0.323***
Democrat political affiliation	0.046	0.076	0.053	0.051
Independent political affiliation	-0.048	0.072	0.081	0.08
No political affiliation	-0.136	-0.079	-0.033	-0.035
Other political affiliation	-0.572	-0.42	-0.38	-0.374
Very liberal political belief	0.392***	0.235***	0.257**	0.258*
Liberal political belief	0.177*	0.17*	0.168*	0.163*
Conservative political belief	-0.369***	-0.287***	-0.279***	-0.277***
Very conservative political belief	-0.391***	-0.344***	-0.288**	-0.287**
Social Media Sources				
Facebook		0.185*	0.176*	0.172*
Instagram		0.261***	0.245***	0.243***
Twitter		0.614***	0.522***	0.52***
News Sources				
Fox News			0.075	0.08
CBS News			0.128	0.133
NBC News			0.133	0.125
ABC News			0.134	0.133
Knowledge of Environmental Changes				-0.023

Note. *$p < .05$, **$p < .01$, ***$p < .001$.

used to determine if demographic characteristics predicted level of intent to engage in environmentally-conscious behavior in the future (see Table 6, Model 1). The model was found to be statistically significant ($F = 24.864$, $p = 0.000$) and predicted 23.8% of the variance. A high school education, some college education, and a 2-year college education predicted a negative intent to engage in environmentally-conscious behavior in the future as compared to respondents with a 4-year college degree. A graduate school education predicted a positive intent to engage in environmentally-conscious behavior in the future as compared to respondents with a 4-year college degree. In addition, very liberal and liberal political beliefs predicted a positive intent to engage in environmentally-conscious behavior in the future as compared to moderate political beliefs. Conservative and very conservative political beliefs predicted a negative intent to engage in environmentally-conscious behavior behaviors in the future as compared to moderate political beliefs.

A second model included social media sources used (Facebook, Instagram, and Twitter) as a predictor (see Table 6, Model 2). The second model was statistically significant ($F = 32.627$, $p = 0.000$) and predicted 33.6% of the

variance. The change in R^2 was statistically significant indicating the second model was more effective at predicting intent to engage in environmentally-conscious behavior in the future than the first model. Within the second model, high school education and some college education predicted a negative intent to engage in environmentally-conscious behaviors in the future as compared to a 4-year college degree. A graduate school education predicted a positive intent to engage in environmentally-conscious behaviors in the future as compared to a 4-year college degree. A 2-year college education was no longer significant. In addition, very liberal and liberal continued to predict a positive intent to engage in environmentally-conscious behavior in the future as compared to moderate political beliefs. Conservative and very conservative political beliefs continued to predict a negative intent to engage in environmentally-conscious behaviors in the future as compared to moderate political beliefs. The social media platforms Facebook, Instagram, and Twitter were positive significant predictors of intent to engage in environmentally-conscious behavior in the future.

A third model included news sources used (see Table 6, Model 3). The third model was statistically significant ($F = 28.409$, $p = 0.000$) and predicted 35.6% of the variance. The change in R^2 was statistically significant, indicating the third model was more effective at predicting the intent the respondent would engage in an environmental behavior in the future than the second model. Consistent with observations in Models 1 and 2, a high school education, some college education, and graduate school education predicted intent to engage in environmentally-conscious behaviors in the future as compared to a 4-year college degree. Very liberal political beliefs and liberal political beliefs continued to predict a positive intent to engage in environmentally-conscious behavior in the future as compared to moderate political beliefs. Conservative political beliefs and very conservative beliefs continued to predict a negative intent to engage in environmentally-conscious behaviors in the future as compared to moderate political beliefs. Facebook, Instagram, and Twitter continued to predict a positive intent the respondent would engage in environmentally-conscious behavior in the future. News source use did not predict respondents' intent to engage in environmentally-conscious behavior in the future.

Finally, a fourth model included knowledge of environmental changes as a predictor (see Table 6, Model 4). The fourth model was also statistically significant ($F = 27.11$, $p = 0.001$); however, the change in R^2 was not significantly different from Model 3. Therefore, the model was deemed to be less parsimonious and less effective at predicting intent to engage in environmentally-conscious behavior than model 3, no further analysis or interpretation of results was conducted.

Discussion

This study added to the literature by determining if intent to engage in environmentally-conscious behavior during the COVID-19 pandemic was predicted by demographics, social media sources used, news sources used, and knowledge of environmental changes, which may provide a basepoint for disseminating environmental information in future crisis events. There were several limitations to this study that should be noted prior to interpretation of the results, including the use of non-probability opt-in sampling techniques. According to Wiśniowski et at. (2020), "the lack of an underlying mathematical theory akin to probability sampling is problematic with respect to achieving accuracy and measuring uncertainty (sampling error) for estimates derived from nonprobability samples" (p. 121). However, multivariate estimates, such as regression coefficients, are not as prone to the inconsistencies between probability and non-probability samples (Wiśniowski et at., 2020). Another limitation of the study was that it is specific to U.S. residents and may not be generalizable in other countries due to the specific political context of the U.S. Future studies should determine if the

political polarization of news sources impacted environmental knowledge and intent to engage across various international settings.

Despite these limitations, the results of the study provide important implications for environmental communicators interested in increasing environmental knowledge and engagement. Results of the analysis indicated select demographic variables and social media use predicted differences among respondents' intent to engage in environmentally-conscious behavior in the future. It is possible that crises like the COVID-19 pandemic may cause the public to largely rely on social media for environmental information due to uncertainty that emerges around crises and complex information environments across media platforms (Ho et al., 2014). Environmental communicators should be prepared to use social media platforms when sharing information during times of crisis. This can be accomplished by understanding how the public engages with and processes information during times of crisis, which differs from information processing that occurs outside of crisis environments. The average respondent had a moderate environmental knowledge score ($M = 4.02$, $SD = 1.29$) and an undecided intent to engage level ($M = 3.24$, $SD = 1.12$), indicating facts about how COVID-19 SIP orders impacted the environment needs to be improved within crisis communication initiatives (Dawes et al., 2004; Netten and van Someren, 2011).

The third regression model examining how demographics, social media sources, and news sources impacted intent to engage in environmentally-conscious behavior accounted for the greatest amount of observed variance (see Table 6, Model 3). Respondents who had very liberal political beliefs or liberal political beliefs predicted a positive relationship with intent to engage in environmentally-conscious behavior. Respondents who were conservative or very conservative predicted a negative relationship with intent to engage in environmentally-conscious behavior. News media was not a predictor of intent to engage in environmentally-conscious behavior. This finding contradicts Skoric and Zhang (2018) who found news media use had a positive relationship with environmental activism and consumerism. It is possible that news media was not a significant predictor because news sources are often aligned with a political affiliation and ideology, which were variables already accounted for in the model. For example, Fox News is primarily aligned with a conservative audience and NBC News is more consistently liberal (Pew Research Center, 2014). Moreover, Facebook, Instagram, and Twitter predicted intent to engage in environmentally-conscious behaviors in the future, suggesting social media may be an appropriate channel to elicit emotional responses that lead to environmentally-conscious behavior engagement.

The fourth regression model that added knowledge of environmental changes as a predictor was less effective at predicting intent to engage in environmentally-conscious behavior than the third model that did not include

environmental knowledge as a predictor. This finding contradicts Skoric and Zhang (2019) who found environmental knowledge mediated environmental engagement among Chinese citizens. It is possible cultural factors play a role in the predictors of environmental engagement as the research of Skoric and Zhang (2019) was conducted in China whereas the present study was conducted in the U.S. It is also possible that general environmental knowledge plays a stronger role in predicting environmental engagement as compared to knowledge of environmental changes that occur during a crisis. Moreover, Frick et al. (2004) explained that the relationship between knowledge and environmental behavior may be more complex and less linear than most models assume. It is possible that during times of crisis a more complex model is needed to explain intent to engage in activities than knowledge of environmental changes. Future research is needed to warrant this claim, however, as the findings of this study are preliminary and knowledge has been a significant predictor of environmental engagement previously. The positive intent to engage in environmentally-conscious behavior associated with liberals and social media users lends the question: is exposure to sensationalized environmental benefits from overzealous media sources more beneficial in encouraging environmental engagement than factual environmental impact information?

Literature provides insight as to why some respondents may have engaged in selective exposure behaviors to certain media landscapes as compared to others. Similar to the findings of Hennessy et al. (2016), selective exposure to media sources about important environmental matters may cause negative consequences because politically polarized media does not expose the public to all information about a specific issue. This was especially relevant during the COVID-19 pandemic as there was a high degree of politicization of news coverage for COVID-19 related information (Hart et al., 2020). Future studies would benefit from determining the best way to expose the public to environmental information through different platforms. Testing environmental messages (with both factual and emotional frames) on both news and social media platforms could provide insight into how to proactively communicate about the environment during times of crisis. Doing so would proactively ensure communicators are prepared when issues arise. Given the public will continue to engage in selective exposure to media, compounded by a politicized media environment, building consensus about environmental issues while dealing with a growing media platform will only become more difficult (Feldman et al., 2014; Jamieson and Hardy, 2014).

The results of this study should be treated as preliminary as the novelty and context of COVID-19 in the era of online news and social media make it difficult to compare respondents' knowledge of environmental changes and intent to engage in environmentally-conscious behavior to previous risk events. However, it is important environmental communicators determine the type of information the public receives and how they process information during the pandemic to effectively share environmental impact and encourage future engagement in environmentally-conscious behaviors. Given the pandemic was global in nature, and this study focused on U.S. citizens, similar studies should be conducted around internationally to determine if worldwide messaging strategies could have a greater impact on the environment. Working collectively, communicators prepared for times of crisis can capitalize on the focused attention among information consumers that is generated by crises, thereby encouraging increased environmentally-conscious behavior.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by the University of Georgia Institutional Review Board. The participants agreed to participate in this study by selecting yes at the start of the survey.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Science journalism in pandemic times: perspectives on the science-media relationship from COVID-19 researchers in Southern Europe

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Several studies have investigated the relationship between scientists and journalists. However, Southern Europe has been less studied when it comes to understanding the nature and effectiveness of collaborations between these two groups of professionals. To address this gap, this study focused on researchers (i.e., academics and scientists from different fields, including clinical researchers and medical doctors) who conducted research activities on COVID-19-related topics in three Southern European countries (Italy, Portugal, and Spain). Using an approach that combined survey data ($n = 317$) with semi-structured interviews ($n = 40$), we explored researchers' personal beliefs, opinions, and experiences regarding their encounters with the media during the pandemic. Our results show that researchers' motivations, concerns, and benefits in their interactions with the media remained largely unchanged during the pandemic. Despite the additional challenges posed by the health emergency, most researchers in Italy, Portugal, and Spain rated their interactions with journalists positively. Several practices to promote and maintain trustful and fruitful cooperation with journalists were also identified. Additionally, lessons learned were extracted from the interactions between researchers and journalists during the pandemic. They hold particular relevance in a context of uncertainty, fake news, high demand for information and high expectations in science and technology. These findings aim to support both the scientific community and media professionals to deal with current and future communicative challenges such as health, environmental and social crises that require joint efforts from multiple societal actors.

1. Introduction

The COVID-19 pandemic posed multiple social and political challenges worldwide. In a moment of high uncertainty where information was scarce, the scientific community and media professionals were confronted with the common goal of communicating accurate and trustworthy scientific information and recommendations to guide society in facing

the pandemic. As a result of growing demands for information, public communication of COVID-19 issues thrived in both traditional and social media. The information overload increased the risk of misinformation (i.e., false or inaccurate claims not intended to deceive) and disinformation (i.e., deliberate dissemination of false information intended to deceive; Wardle and Singerman, 2021) that threatened the ability of media professionals to ensure accountability on behalf of the public. Soon it became evident that disseminating accurate and truthful information was crucial in tackling the spreading of false information (Zarocostas, 2020). Even before the World Health Organization (WHO) declared SARS-CoV-2 a pandemic, the organization alerted to the risks of "a massive *infodemic*" (World Health Organization, 2020, p. 2). The race to combat the spread of the virus triggered scientific production related to this novel disease (Oliveira et al., 2021), which was also reflected in the global mass media coverage of COVID-19-related research (Hart et al., 2020; Sousa-Pinto et al., 2020). As such, frequent interactions between scientists and journalists reporting on COVID-19 were necessary and inevitable.

Facing the spreading of misinformation and disinformation (or fake news) associated with the pandemic represented a challenge for media professionals, health professionals and scientists (Mesquita et al., 2020; Naeem et al., 2021), but it was not the only one. Recent works have investigated how some practices of these professionals have been shaped in the context of the pandemic. These include dealing with the growing use of pre-print data in media outlets (Fleerackers et al., 2021, 2022; Fraser et al., 2021), the increasing coverage of science topics in the media and their impact on the cultural authority of science and scientists (Metcalfe et al., 2020), the intense workload and associated anxiety and stress problems reported by journalists (Massarani et al., 2021), the stress and pessimism associated to the pressure to publish reported by academic researchers (Suart et al., 2022), or a shift in the selection of sources in the news coverage of COVID-19 (Catalan-Matamoros and Elías, 2020; Leidecker-Sandmann et al., 2022). However, how the relationship between scientists and journalists was impacted by the pandemic has received less attention. To our knowledge, no study has yet investigated this aspect. Therefore, we aim to fill this gap in knowledge about the prevailing relationships between scientists and journalists by providing novel insights into how these interactions developed during the pandemic, with a focus on Southern Europe.

A large body of literature has explored the nature and quality of the interactions between journalists and scientists working in different research fields and countries (for an overview of the topic see, e.g., Dudo, 2015; Yeo and Brossard, 2017). With a few exceptions (Kaye et al., 2011; Lo and Peters, 2015; Appiah et al., 2020; Koso, 2021), research on the science-media relationship has largely focused on the USA and other English-speaking countries, as well as on Northern and Western Europe (e.g., Peters, 2007, 2013; Peters et al., 2008a; Dijkstra et al., 2015). In consequence, regions such as Southern European countries have been less studied when it comes to understanding the science-media relationship. In a recent study on the European science communication landscape (Davies et al., 2021), authors acknowledged the need to go beyond the anglophone context when thinking and discussing science communication practices.

Our focus on three Southern European countries (Italy, Portugal, and Spain) responds to this demand and explores three countries that share many historical and structural characteristics of their media ecosystems (Hallin and Mancini, 2004; Brüggemann et al., 2014). A recent report identified commonalities between Greece, Italy, Portugal, and Spain, such as a certain degree of state interference compared to the EU average, lower media plurality and social inclusiveness, lower freedom of expression, and financial sustainability of the media sector at risk (PromethEUs, 2022). In addition, declining resources to invest in using innovative formats and supporting in-depth investigations, as well as scarce capacity to deal with crucial issues such as content verification, which can lead to a potential acceleration of misinformation, pose multiple challenges to media professionals in the region.

The research questions guiding our study are the following: (i) How (and why) did interactions between researchers and journalists develop during the COVID-19 pandemic? (ii) What practices helped researchers to overcome their hesitance to interact with the media during the COVID-19 pandemic, which could also facilitate future collaboration between researchers and journalists? and (iii) What lessons can be learned from the COVID-19 pandemic that may help address current and future communication challenges?

The combination of survey data with semi-structured interviews allowed us to understand how researchers in three Southern European countries experienced their interactions with journalists and to address practical insights on opportunities to advance the building and strengthening of fruitful collaborations between researchers and journalists. We argue that these findings can help both the scientific community and media professionals in other EU countries.

2. Literature review

In the last decade, a growing body of literature has discussed scientists' motivations to participate in public engagement and communication activities. See Weingart et al. (2021) for a systematic analysis of academic literature on the topic. Additionally, barriers and facilitators for co-production activities involving the interaction between researchers and journalists have been identified (MacGregor et al., 2020). Focusing on science-media interactions, scholars have identified multiple predictors of scientists' willingness to engage with media professionals, namely professional status or seniority (Dunwoody et al., 2009; Bauer and Jensen, 2011; Besley and Nisbet, 2013; Dudo, 2013; Leidecker-Sandmann et al., 2022), learning opportunities (Dunwoody et al., 2009), personal rewards such as research funding, public accountability, increased legitimacy of their research (Gascoigne and Metcalfe, 1997; Allgaier et al., 2013; Dijkstra et al., 2015), perception of moral or professional duty (Allgaier et al., 2013; Peters, 2013), positive intrinsic rewards that include raising positive attitudes toward science, promotion of science literacy, influencing public understanding of science, self-growth, personal enjoyment, or the feeling of being valued or having made a difference (Gascoigne and Metcalfe, 1997; Peters et al., 2008a,b; Dunwoody et al., 2009; Besley and Nisbet, 2013; Dudo, 2013; Besley et al.,

2018; Larsson et al., 2019), and normative expectations of scientific organizations and research institutions (Peters, 2013).

Disincentives, concerns, challenges and conflicts associated with these interactions have also been identified in the literature (Peters, 1995; Gascoigne and Metcalfe, 1997; Peters et al., 2008a; Larsson et al., 2019). For example, the different expectations of researchers' and journalists' goals and their control over the communication process (Peters, 1995), or the risk of misquotes, the unpredictability of journalists, and the possibility of negative publicity (Peters et al., 2008a). Medical experts reported short and exaggerated headlines, the media's choice of topics, and lack of medical knowledge as some of the difficulties encountered in their relationships with journalists (Larsson et al., 2019). Considering their shortcomings, scientists and health professionals have also reported the lack of communication skills and media training as critical factors in their encounters with the media and, in general, with the public (Gascoigne and Metcalfe, 1997; Kaye et al., 2011; Allgaier et al., 2013; Dudo, 2013; Larsson et al., 2019; Weingart et al., 2021).

Even though some reluctance exists, scientists are increasingly oriented toward the mass media and the media logic, that is, understanding processes, routines, and formats that frame the production of media content and its effects. This phenomenon, named "medialization of science," and discussed by several authors (Peters, 2012; Allgaier et al., 2013; Lo and Peters, 2015; Koso, 2021; Olesk, 2021) stresses the increasing need for public visibility that scientists and scientific organizations perceive as a way to legitimize their research toward society. In addition, the medialization of science provides an opportunity to bridge existing knowledge gaps between scientists and journalists (Allgaier et al., 2013).

When considering the number and quality of interactions between scientists and journalists, the works by Peters et al. (2008a,b) have challenged the perception of conflicting and difficult encounters between them. Based on the scientists' views, the authors concluded that interactions between these two actors were more frequent, pleasant and beneficial for researchers than previously expected. Interestingly, modest differences were observed across the five countries examined (France, Germany, the UK, the USA, and Japan), reporting similar global trends. Other studies have proven similar findings in other countries and research fields (Allgaier et al., 2013; Peters, 2013; Dudo et al., 2014; Lo and Peters, 2015) indicating that the interactions between scientists and journalists are, overall, considered positive and fruitful in terms of their impact. Despite this trend, research has also shown more cautious approaches and negative outcomes of these interactions have been observed, such as poor-quality coverage, sensationalized research findings, disruption of scientists' work routines, or increased distrust in science due to media coverage (Gascoigne and Metcalfe, 1997; Allgaier et al., 2013; Koh et al., 2016; Metcalfe et al., 2020). Notwithstanding, the effect that the intensive and exhaustive contact may have had on the interactions between journalists and scientists during the pandemic is still unclear.

Previous studies have explored cooperative practices between journalists and scientists such as co-authored science journalism articles (Canan and Hartman, 2007). In the context of the pandemic and the current post-pandemic, closer collaborations between scientists, physicians, journalists, and the public to fight online misinformation on public health issues (Swire-Thompson and Lazer, 2020) seem nowadays more relevant than before.

Several authors pledged the cooperation of the scientific community and journalists to halt the spreading of misinformation (e.g., vaccination rumors; Harper and Attwell, 2022) and help society to identify COVID-19 fake news stories (Naeem et al., 2021). Similarly, the collaboration between science communication professionals and scholars to develop evidence-based approaches can support responsible science communication by reflecting on the value, quality and effectiveness of its practice and research (Jensen and Gerber, 2020).

3. Data and methods

3.1. Study design

To investigate the interactions between researchers and journalists in the context of the COVID-19 pandemic in Southern Europe (Italy, Portugal, and Spain), we used a mixed-methods approach (Teddlie and Tashakkori, 2009) that combined survey research with semi-structured interviews. Our study specifically addresses researchers (academics and scientists from different fields, including clinical researchers and medical doctors) who were involved in COVID-19 research activities during the pandemic. Survey data portrayed general trends about the interactions between researchers and journalists in Italy, Portugal, and Spain. Specifically, it explored some motivations that could influence researchers' willingness to interact with the media (Gascoigne and Metcalfe, 1997; Allgaier et al., 2013; Peters, 2013), perceived benefits and concerns regarding their media contacts (Peters et al., 2008a), the medialization effect of the pandemic (Massarani et al., 2021) or the nature and assessment of the encounters between these actors (Peters et al., 2008a). This information was complemented with more in-depth insights collected through semi-structured interviews with researchers in the three countries. The design of the interview questionnaire was mainly informed by the results of the survey, previous works that explored scientists-journalists relations (e.g., Gascoigne and Metcalfe, 1997; Peters et al., 2008a; Kolandai-Matchett et al., 2021) and recent works on the impacts of the pandemic (e.g., Mesquita et al., 2020; López-García et al., 2021; Massarani et al., 2021). Interview questions aimed at gathering more in-depth insights into researchers' experience with journalists during the pandemic, which helped us to reply to our first research question, as well as their views on how to advance in the construction and strengthening of fruitful science-media relationships by identifying some of the practices that can support collaborations between these actors (second research question) and address future communication challenges beyond the COVID-19 pandemic (third research question).

3.2. Participants

Survey participants were recruited following two approaches. First, we conducted an online search on Scopus and Web of Science to identify published research work on COVID-19 in the three

studied countries (March 2022). Corresponding authors and co-authors (when contact information was available) were invited to participate in the study. Next, we contacted scientific and medical societies, professional associations, research institutions and universities in Italy, Portugal, and Spain to request the distribution of the survey among their employees and/or associates. A total of 465 people accessed the survey link. Of these, 148 questionnaires were excluded because respondents did not meet the study criteria, i.e., did not participate in COVID-19 research or had not worked in the studied countries; 44 responses), or questionnaires were incomplete (104 responses). The remaining 317 respondents completed the questionnaire and represent the final sample (with 140 valid responses from Italy, 70 from Portugal, and 107 from Spain). Overall, the sample was mainly composed of respondents with Ph.D. degrees, with primary responsibilities in research, clinical services, or teaching, who mainly worked in universities (59.6%) or hospitals (21.1%). Almost two-thirds of the respondents had an indefinite-term contract. Divided by research field, most respondents worked in medical and health sciences or social sciences. Gender distribution shows that 46.4% of the sample identified as female, 51.1% as male, and 0.6% as non-binary. Most respondents were between 35 and 44 years old (31%). Out of the 317 researchers, 147 individuals interacted with the media during the COVID-19 pandemic (46.4%). Specifically, 53 respondents from Italy, 31 from Portugal, and 63 from Spain had media contacts (Supplementary Table 1 shows a description of demographic and background variables).

Interview participants were identified through purposive sampling. Inclusion criteria for participation were (i) to have been involved in research on the COVID-19 pandemic (any topic or perspective), and (ii) to have interacted with journalists covering COVID-19 issues. Gender and research fields were also considered to ensure the diversity of profiles. Additionally, survey respondents who interacted with journalists and expressed their willingness to give more in-depth replies were also contacted to participate in the interviews. In total, 40 participants (13 in Italy, 15 in Portugal, and 12 in Spain) were interviewed. Supplementary Table 2 shows the interviewees' country, areas of expertise, and codes used for data anonymization.

3.3. Data collection and analysis

To collect the quantitative data, an online survey was created on the platform Qualtrics XM (a web-based software) in four languages (Italian, Portuguese, Spanish, and English) and was distributed through an anonymous link from May to July 2022. It addressed researchers who conducted research on COVID-19 in Italy, Portugal, and Spain. The questionnaire was constructed mainly based on the studies of Peters et al. (2008a) and Massarani et al. (2021) to allow comparability with previous studies exploring interactions between scientists and journalists (Peters et al., 2008a), and the impact of COVID-19 on journalists practices (Massarani et al., 2021). It consisted of four questions addressing respondents who indicated contacts with the media during the pandemic. These questions aimed at understanding the nature and quality of

these interactions (i.e., their origin and number, and researchers' assessment of these encounters). One of these questions (personal assessment of the interactions) was constructed on a Likert scale in which respondents indicated their level of agreement with several statements on a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). Cronbach's alpha showed high reliability (0.87). Moreover, three questions explored the motivations, benefits, and concerns of the overall sample of researchers to interact with the media. Lastly, one question aimed at collecting the perception of researchers regarding the impact of the pandemic on science and media relations. This last question was also constructed on a 5-point Likert scale. Cronbach's alpha (0.68) showed moderate but sufficient reliability and internal consistency (Pallant, 2020). At the end of the survey, seven questions collected information about respondents' demographics. The entire questionnaire is provided in Supplementary File 1. Statistical analysis of survey data was performed using IBM SPSS statistical software (v.28.0). Descriptive statistics are presented for categorical variables as percentages. Data is presented in percentages per country.

Semi-structured interviews were conducted between September and November 2022 via an online video conferencing platform (Zoom). A guideline with seven questions was developed and used. The questions explored the personal experiences of researchers in interacting with journalists during the pandemic, their motivations and concerns, and ways to improve these collaborations and deal with infodemic and other communication challenges (Supplementary File 2). The interviews were conducted in the participant's native language (Italian, Portuguese, or Spanish). Interviews were audio-recorded and transcribed and had an average duration of 25.5 min (SD = 5.9) in Italy; 44.7 min (SD = 13.6) in Portugal, and 46.6 min (SD = 12.6) in Spain. Interview data from Portugal and Spain were analyzed in their original language while the interviews in Italian were translated into English before analysis.

To analyze the interview data, we employed a reflexive approach to thematic analysis supported by Atlas.ti v22. Thematic analysis is a flexible method that enables the identification of patterns of meaning (themes) across data sets by interrogating both semantic and latent meanings (i.e., content, ideas, assumptions) below the surface (Braun and Clarke, 2006, 2012). Initially, the transcripts were coded using a combination of inductive and deductive approaches. Next, themes were developed for each country by reviewing the coded data and identifying patterns (i.e., similarities and overlaps among the codes), which were then grouped into potential themes. Themes and subthemes were carefully reviewed against the coded data extracts, the entire data set, and the themes themselves to ensure meaningful capture of the most essential elements of the data. Whenever necessary, themes and subthemes were refined. Lastly, a cross-national comparison was conducted to identify commonalities. Relevant quotes were selected to provide vivid and compelling examples that support and illustrate the meaning of each theme. To ensure the validity of this analysis, codes, and themes underwent iterative review and discussion among the three coders involved in all steps of data analysis until a consensus was reached. Although inter-coder reliability was not calculated, there was a high level of agreement between the coders, and regular peer debriefing were

held throughout the analysis to uphold reliability. Moreover, we adopted a reflexive approach to data analysis, recognizing that the backgrounds and positions of researchers can influence the perceptions and interpretations of the data.

3.4. Ethical approval

The Ethics Committee of the Faculdade de Ciências da Universidade de Lisboa (CEC/1/2022) gave ethical approval to conduct this research. All study participants were informed about the voluntary, confidential, and anonymous nature of their participation and consent was given freely.

4. Results

4.1. Survey data

Survey data helped to outline general trends in the reasons that move researchers to interact or had some hesitance to interact with journalists, the perceived benefits of these encounters, the nature of these interactions, and the impacts of the pandemic on the medialization of science and scientists. The following sub-sections present the results emerging from the three studied countries are present.

4.1.1. Motivations, benefits, and concerns to interact with the media

Most respondents deemed three main reasons to be in contact with the media, namely, improve the scientific culture of society (79.2%), contribute to fighting misinformation related to the COVID-19 pandemic (74.4%), and promote science in the media (70.3%). Relative importance was also given to the fact that researchers considered it a professional duty, particularly in Portugal and Spain (Figure 1). This trend is observed in the three analyzed countries. Supplementary Table 3 provides the distribution of responses per country.

Interactions with the media were also seen as potentially beneficial at different levels. Survey respondents were asked to identify possible benefits that may increase their confidence in interacting with journalists. Results indicate that promoting a more positive public attitude toward research is one of their main incentives (75.7%), together with a better-educated public (66.9%), and the possibility of influencing public debate (57.1%; Figure 2). Although all three countries showed very similar trends (Supplementary Table 4), it is noteworthy that 8 in 10 respondents from Portugal considered educating the public as the main perceived benefit of interacting with journalists.

Yet, some concerns increase researchers' reluctance to interact with the media. Researchers in the three countries shared common concerns regarding the risk of incorrect quotation (69.7%) and the unpredictability of journalists (66.6%; Figure 3). Respondents from Portugal and Spain pointed to the possibility of negative publicity as the third reason for refusing to interact with the media (44.3 and 39.3%, respectively) while for their Italian colleagues, critical reactions coming from their heads of departments or

organizations were also a concern. Supplementary Table 5 provides the distribution of responses per country.

4.1.2. Changes in medialization due to the COVID-19 pandemic

Survey respondents were asked to agree or disagree with six positive statements about the medialization (i.e., media presence) of science and scientists during the COVID-19 pandemic compared to the media attention received before. Overall, researchers of the three countries shared similar thoughts, agreeing with all the statements (Figure 4), and indicating greater agreement with the following two: "researchers are more frequently accessed and cited as sources of information in the media than before the pandemic" (57.4 and 15.1% reported their agreement and strong agreement, respectively) and "there is a higher presence of scientific topics in the general media than before the pandemic" (51.7 and 13.2% reported their agreement and strong agreement, respectively). Across countries, similar trends were observed in four of the six statements with the highest consent (Supplementary Table 6).

4.1.3. Nature and assessment of personal interactions with the media

To gain further insights into the researchers' experiences with the media on issues related to COVID-19, we directed specific questions exclusively to respondents who reported such interactions (147 respondents; Figure 5A shows their distribution per country).

First, when asked how many interactions they had with the media on issues related to COVID-19, over 60% of respondents indicated that they interacted between one and five times, while almost 20% stated that the number of interactions with journalists exceeded 10 times (Figure 5B). The latter is particularly prominent for respondents from Spain, where almost three out of 10 researchers interacted with journalists more than 10 times during the pandemic (28.6%). Despite some variation, the number of interactions reported is similar across countries, indicating that researchers in the three countries were comparably contacted, in most cases up to five times.

Regarding the origin of the interactions, 72.8% of respondents were contacted due to their area of expertise, whereas 21.1% were contacted after a press release. In a small number of cases (2.7%), both reasons were given for the origin of the interaction. Other reasons mentioned (3.4%) included, among others, previous interactions with journalists or contacts initiated by researchers (Figure 5C). This distribution is similar across countries.

Considering how researchers assessed these interactions, results show that almost 70% of the respondents rated their media contacts positively (53.1% were considered "good" and 16.3% "excellent"). By contrast, 10.2% were negatively assessed (1.4% "terrible" and 8.8% "poor") and about 20% were considered neutral ("neither good nor bad"; Figure 5D). This trend is observed across countries. Results indicate that a large proportion of researchers in Italy, Portugal, and Spain coincide in rating positively their interactions

FIGURE 1
Reasons that motivate researchers to interact with the media. Distribution of responses to the question "Regardless of whether you have interacted with the media or not, your reasons to interact with journalists would be/are…" in percentages per country.

FIGURE 2
Benefits that increase researchers' confidence to interact with the media. Distribution of responses to the question "Regardless of whether you have interacted with the media or not, how important to you are the following possible benefits that increase researchers' confidence to interact with the media?" in percentages per country.
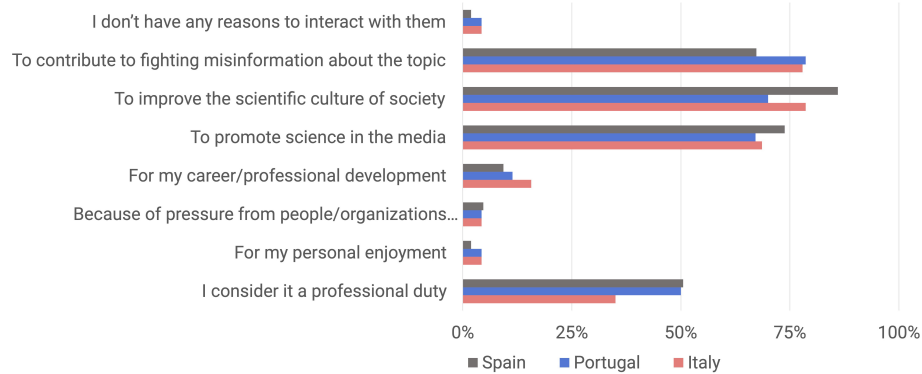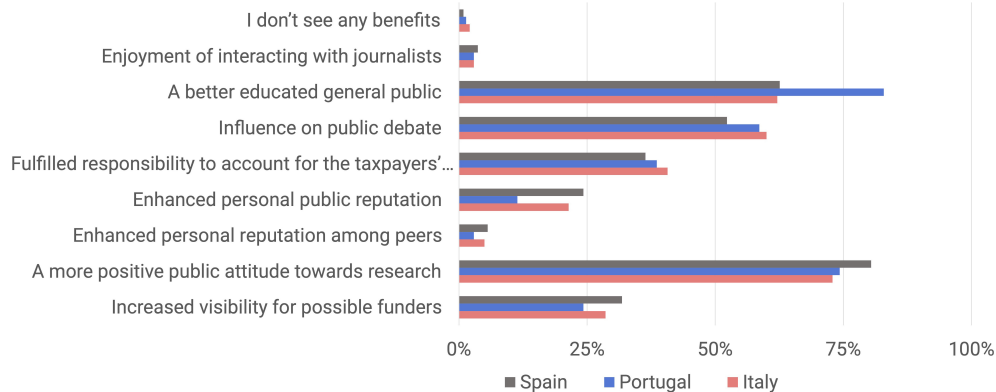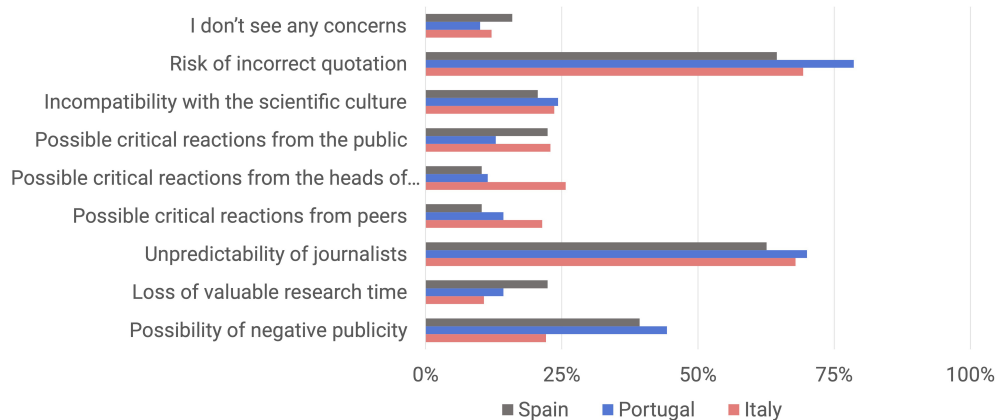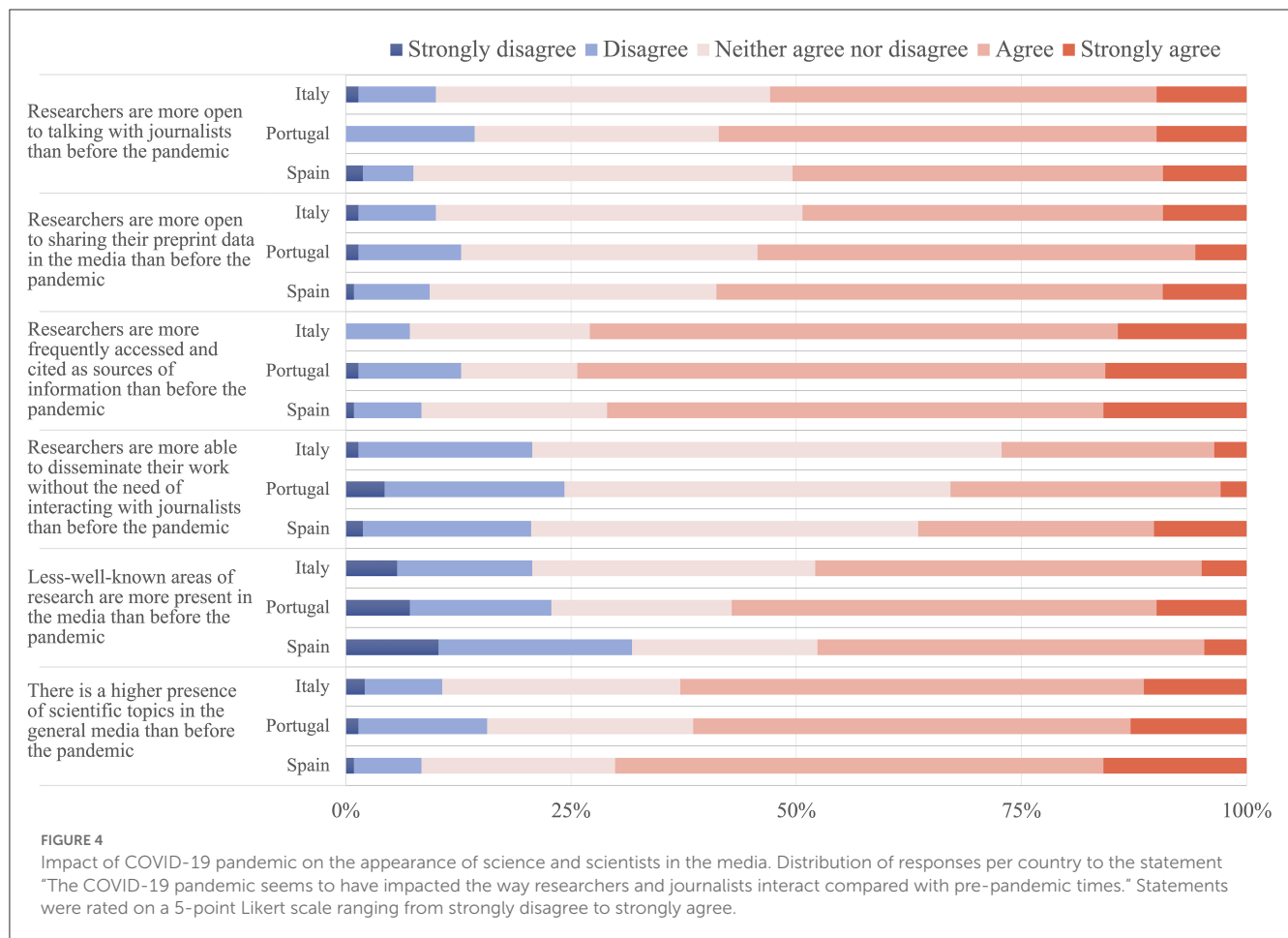

FIGURE 3
Concerns that increase researchers' reluctance to interact with the media. Distribution of responses to the question "Regardless of whether you have interacted with the media or not, how important to you are the following possible concerns that increase researchers' reluctance to interact with the media?" in percentages per country.

FIGURE 4
Impact of COVID-19 pandemic on the appearance of science and scientists in the media. Distribution of responses per country to the statement "The COVID-19 pandemic seems to have impacted the way researchers and journalists interact compared with pre-pandemic times." Statements were rated on a 5-point Likert scale ranging from strongly disagree to strongly agree.

with the media. Supplementary Table 7 provides the distribution of responses per country.

Next, researchers' interactions with journalists were explored in more detail through a series of positive and negative statements. Respondents who reported contacts with the media were asked to show their level of disagreement or agreement with 11 plausible situations they could have experienced during their encounters with journalists covering COVID-19 topics. Echoing previous studies (Peters et al., 2008a), respondents in all three countries agreed with the positive statements and disagreed with the negative ones (Figure 6). In general, respondents from Portugal were overall more positive in their assessment of media contacts. On average, the three positive statements that obtained higher levels of agreement were "I was able to get my message out to the public" (59.7 and 17.9% reported their agreement and strong agreement, respectively), "Talking to the journalists was pleasant" (49.8 and 20.5% reported their agreement and strong agreement, respectively) and "The journalists really listened to what I had to say" (48.2 and 21.1% reported their agreement and strong agreement, respectively). Conversely, the negative statements that reach higher levels of disagreement were "The journalists treated me with little respect" (47.6 and 39.5% reported their strong disagreement and disagreement, respectively), "My statements were distorted" (32.7 and 42.9% reported their strong disagreement

and disagreement, respectively), "I felt unsure when talking to journalists" (35.4 and 38.8% reported their strong disagreement and disagreement, respectively), and "The most important information I gave was omitted" (25.9 and 45.6% reported their strong disagreement and disagreement, respectively). These results show that researchers were pleased with the interactions they had with the media and with the outcomes derived from these encounters. Supplementary Table 8 provides the distribution of responses per country.

In summary, these findings show that, as a whole, researchers' interactions with the media were motivated by their desire to improve society's scientific culture, promote more favorable public attitudes toward research, and contribute to a better-educated public. Conversely, concerns arise due to the risk of being misquoted and the unpredictability of journalists. Despite these reservations, researchers agreed that they were approached and cited more frequently as sources of information, with a higher presence of scientific topics in the media than in pre-pandemic times. Overall, researchers who encountered journalists to cover COVID-19-related topics expressed favorable views of their interactions across all three countries. Researchers acknowledged that, in general, they conveyed their message to the public and found their conversations with journalists pleasant and attentive.
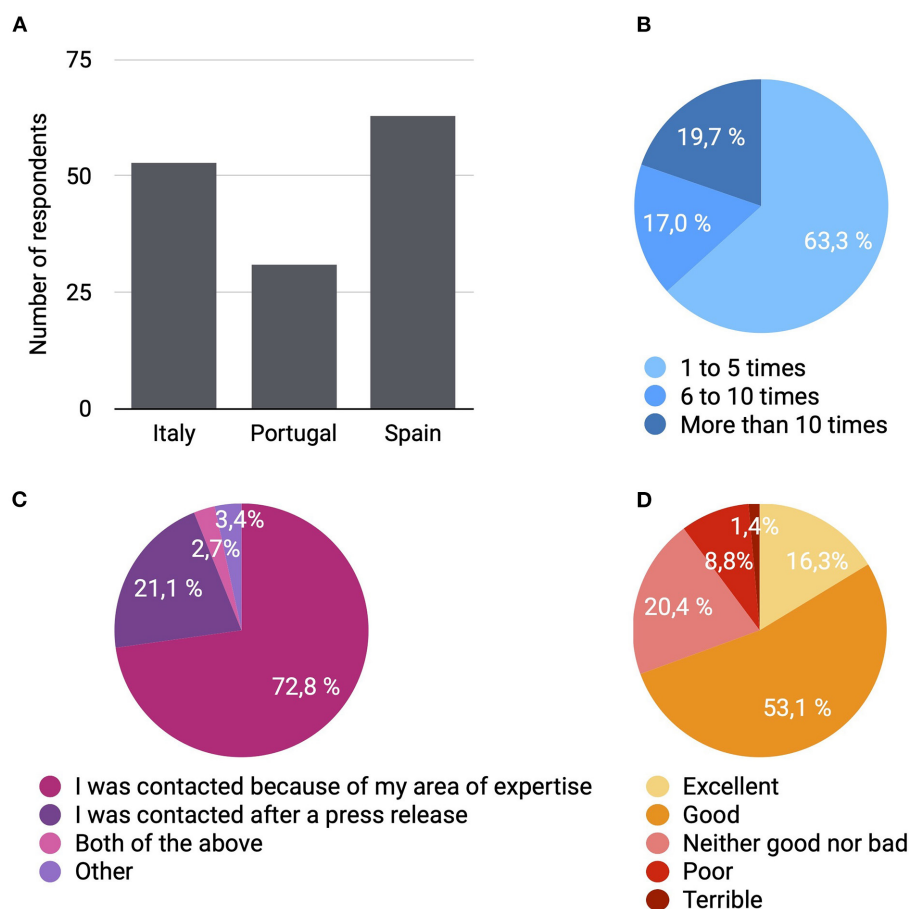
FIGURE 5
Characterization of the sub-group of researchers who interacted with journalists during the COVID-19 pandemic in the three studied countries. **(A)** Distribution of respondents that reported contacts with the media per country. **(B)** Number of contacts with the media. **(C)** Origin of the contacts. **(D)** Researchers' assessment of their interactions with journalists. Data is shown in percentages except for the number of respondents.

4.2. Semi-structured interviews

Through thematic analysis of the interview transcripts, a series of themes and subthemes were identified per country and compared cross-nationally to distill commonalities among them. In this section, common themes and subthemes are presented, organized into four main topics (Figure 7). Supplementary Table 9 shows themes, subthemes, codes used and some extracts that illustrate these findings.
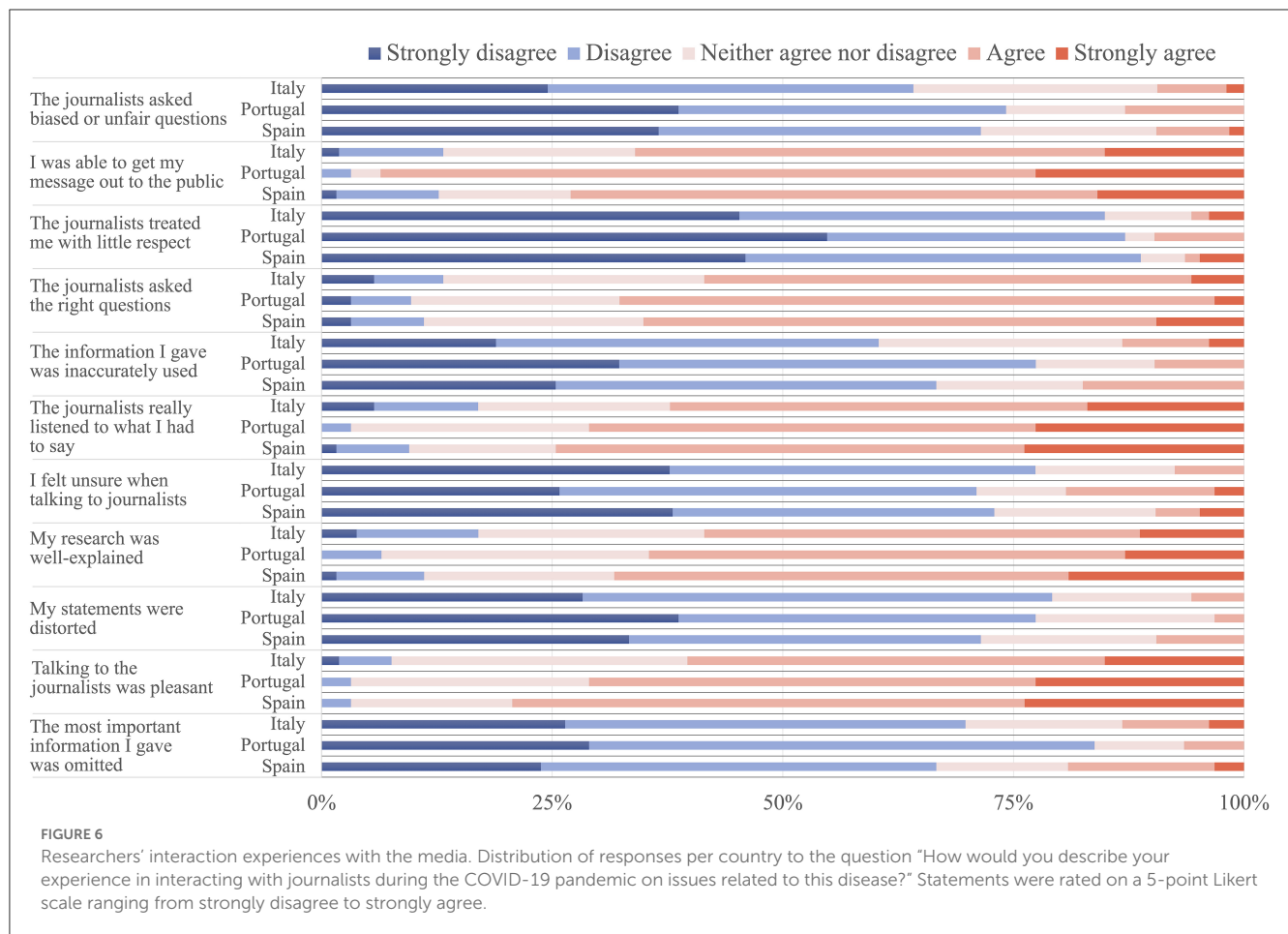
4.2.1. Reasons to interact with the media

It was possible to distill one common driver (theme) across countries that moved researchers to interact with the media in the context of the COVID-19 pandemic: a sense of commitment to meet the need for information related to the appearance and spreading of the virus during early stages of the pandemic, and later, the development of the vaccines. Intrinsic motivations to interact with the media also emerged (e.g., rewarding at the personal level, having had previous positive interactions with journalists, or their

willingness to promote scientific culture and interest in science), although these were less prevalent and not common in all countries.

The commitment to understand and respond to societal information needs can be divided into two normative motivations (subthemes), i.e., the consideration of communication practices as part of researchers' work and the willingness to ensure citizens' right to be informed. These common motivations were guided by the rationale of keeping society updated about evidence-based recommendations and novel scientific findings on COVID-19 research (as stated by one-third of the participants interviewed), the responsibility of giving back their knowledge to society as part of their duties (one-third) and understanding and meeting societal needs and interests related to COVID-19 related-information (one-fourth, approx.). One participant expressed their motivations as follows:

> *"We understood that we had to be available to help clarify things and try to somehow alert people to the need for means, policies, and solutions to a problem that was obviously very serious, and we had this availability"* (PT3)

FIGURE 6
Researchers' interaction experiences with the media. Distribution of responses per country to the question "How would you describe your experience in interacting with journalists during the COVID-19 pandemic on issues related to this disease?" Statements were rated on a 5-point Likert scale ranging from strongly disagree to strongly agree.

4.2.2. Assessment of personal interactions with the media

During the first 2 years of the COVID-19 pandemic, researchers had positive and negative experiences in their contact with the media. Although most participants described pleasant interactions with the media, negative contacts were also identified. Thus, two common themes ("positive assessment of interactions" and "negative assessment of interactions") emerged across countries.

Overall, more than half of the researchers described satisfactory interactions related to the specialization of some journalists in covering science topics. Some participants also acknowledged positive interactions associated with the good preparation or previous knowledge of journalists on the topic covered (almost one in four), and respectful attitudes (approximately, 1 in 10). Positive interactions associated with the good preparation of the topic and the interview process are illustrated in the following quote:

> "I was contacted by journalists that I knew were already more or less into the subject because the questions were specific (...) there was always a preparation, I was always informed about the topic and the questions that they were going to ask me" (PT7)

Conversely, poor interactions with the media were divided into two subthemes based on researchers' critical assessment of their practices, attitudes, or skills ("researchers' role") and the practices,

attitudes and skills displayed by journalists ("journalists' role"). Thus, when reflecting on their capacities, half of the researchers identified the lack of training to deal with the media as an element that hindered their interpersonal relations with journalists. Also, some researchers felt out of their comfort zone when interacting with the media (one out of 10 participants). One participant described the pandemic as a learning-by-doing-period due to a lack of previous media training:

> "It has been a (learning) process throughout these two and a half years. The first half year was especially difficult because the novelty was combined with the seriousness of the situation (...) little by little we began to understand how we had to do it (interact with journalists)" (ES8)

On the other side, participants identified journalists' practices or attitudes that reduced the quality of their interactions, such as the use of sensationalist headlines (and clickbait tactics), alarmism or false expectations when covering the topic (stated by almost half of the participants), the risk of being incorrectly cited (which in some cases was associated with a negative impact on researchers' reputation, but in most cases, with a negative effect on the accuracy of news coverage; one third), the lack of preparation or knowledge of journalists on the topic (one in four), and less frequently, a politicization of the scientific knowledge (one out

FIGURE 7
Common themes and sub-themes identified across the three studied countries organized by topic. Topics cover reasons that moved researchers to interact with the media during the COVID-19 pandemic, assessment of their interactions, practices that researchers considered helpful to overcome concerns and facilitated (or could facilitate) collaborations with the media, and lessons learned from the COVID-19 pandemic that can contribute to deal with current and future communication challenges.

of five). Regarding sensationalism and raising false expectations, researchers highlighted the existence of practices that seek to attract audiences by providing immediate, superficial or inaccurate information. In some case, researchers justified these practices on the basis that generalist journalists have limited knowledge, time, and resources to cover highly specialized areas, whereas others, associated these practices to commercial interests (e.g., click bait tactics or the creation of conflicts and controversies to increase audience impact). As illustrated by one participant:

> *"I had the feeling that the journalist was constantly waiting for me to say something controversial and tried to force me to say a sentence that went against what was being done by other colleagues or by the General Directorate of Health. The intervention was relatively short, but the feeling I had was that I was always trying not to say anything that would be used as a headline (…) our objective was to contribute to the control of the pandemic and not to enter unnecessary controversies"* (PT6)

In general, these negative features increased researchers' worries about the interview process (feeling unprepared, out

of their comfort zone, and misused) and the communication outcomes (misinterpretation of their statements) and might increase researchers' reluctance to interact with the media in the future.

4.2.3. Practices to overcome concerns and facilitate collaborations with the media

When asked about possible ways to overcome some of their concerns to interact with the media and to enhance further collaborations with journalists, researchers across the analyzed countries suggested three common ways of action. Participants referred to journalists' practices that helped (or could help) them to smooth the way for the establishment of fruitful interactions with the media. This theme, named "improving science coverage in the media," relates to the researchers' expectations of journalists' work in the process of news production. Moreover, participants also critically reflected on their practices and competencies (and their limitations) as well as journalists' limitations to develop their work and identified some factors that could pave the way for fostering

mutual learning and understanding (theme "acknowledgment of limitations"). The third emerging theme was directed at the ways researchers can support and facilitate journalists' work. Additionally, in Portugal and Spain, some participants identified a fourth way of action that involved building science-media relationships based on mutual trust and respectful attitudes and avoiding personal interests to serve society's needs. This set of practices was aimed at both groups of actors, in a joint effort, to facilitate collaborations.

Within the theme that addresses how journalists cover scientific topics in the news, four subthemes associated with the process of news production emerged, i.e., topic approach, interview preparation, piece production, and their review before publication. From the point of view of most researchers interviewed (around two-thirds), the way journalists approach science topics, also COVID-19 research, should be based on a good understanding of scientific practices. This involves knowledge of the scientific method, the timings of science and, more importantly, the fact that science is open to change thus not providing immutable facts. These features are exemplified in the following quote:

> *"Sometimes it is difficult to convey which things are proven and which are not (...) that must be transmitted better, what is the scientific method (...) and that science always doubts, that science is not the truth. Science is continually trying to get closer to the truth (...) nuances must also be explained to journalists (...) more than explaining the details, it is important to transmit concepts"* (ES5)

Moreover, within this subtheme more than half of the participants also recognized that there is a need for journalists specialized in science issues, or at least, to have the basis to be able to understand and prepare news about scientific topics. This would help, according to many of the interviewed participants, to overcome some reluctance to interact with the media, improve science coverage, and ultimately, foster mutual trust relationships.

To facilitate the interview process, almost one out of five researchers considered that having the questions in advance (or, at least, some information) would make their interactions with the media easier. This request was commonly associated with the responsibility participants felt toward the message sent in the context of the COVID-19 pandemic when data was limited, and new findings appeared regularly.

Regarding the coverage of the topic (i.e., COVID-19-related issues), almost half of the participants highlighted the importance of avoiding sensationalist headlines, alarmism or the creation of false expectations associated with novel scientific findings, such as the effectiveness and/or risk of the vaccines. Some participants (more than one-third) also appealed to journalists' responsibility toward the information published or broadcasted or remarked on the need to make nuances and uncertainty apparent in the news produced, particularly in a context of high uncertainty such as the early stages of the pandemic (one out of five). For some participants, contextualizing research findings, especially when pre-print data was used, as was often the case in pandemic coverage, was also considered an important practice to overcome concerns and foster collaborations with the media.

The openness to review and the possibility of making corrections before publication was a common requirement that almost half of the researchers interviewed pointed out to avoid or reduce the risk of incorrect quotations and to allow content checking for the accuracy of reports and news.

Within the theme that identified the limitations, two subthemes about researchers' and journalists' limitations emerged. Here, almost half of the participants were aware of their shortcomings in communicating effectively with the media due to a lack of training in dealing with journalists and, in general, with the public.

At the same time, participants recognized the limitations of journalists in doing their job, such as structural problems of journalism (e.g., limited time and resources to cover their stories, and for some, the existence of agendas and private interests behind them that reduce their independence) and the lack of knowledge to cover science topics when they are generalist journalists that cover several topics.

> *"... journalists are often forced to write a piece in a microsecond because they must beat the news immediately and they don't have a lot of time to look at it, report it and maybe send it back to the interlocutor for him/her to correct it before it goes to print. I am not sure that in a period of emergency like the one we have experienced, there was time to make these steps..."* (IT9)

Finally, more than half of the participants identified the need of sending clear messages (using accessible language) to facilitate journalists' work, as well as showing their availability and willingness to respond to journalists' demands for clarifications to solve any doubts they could have for the benefit of accuracy (one-third). These two practices aimed at supporting journalists' work could also facilitate more fruitful collaborations between researchers and journalists.

Altogether, these practices were identified as facilitators that helped participants (or could help them in the future) to overcome concerns to collaborate with the media and/or to enhance further collaborations with the media.

4.2.4. Dealing with current and future communication challenges

Researchers in all three countries discussed how the infodemic, misinformation and fake news arose during the pandemic and how uncertainty and scarcity of accurate information, especially in the first weeks, was also a struggle for both producers and consumers of information. Additionally, participants proposed practices to improve the effectiveness of science communication activities and foster scientific culture. These three themes summarized several ways of action that researchers, journalists, and other publics can undertake to face current and future socio-technical scenarios (e.g., new pandemics, climate emergency, or the energy transition) and their associated communication challenges.

One of the main problems that information producers and consumers suffered during the COVID-19 pandemic was the need to deal with the excess of information, particularly, regarding mis/disinformation and fake news. In this regard, participants identified some practices associated with their own role that could help to tackle these problems. Specifically, half of the

participants recognized that it is necessary to be aware of the lack of knowledge or capacities when talking about topics that are not directly related to their scientific areas or research topics, thus, claiming responsibility toward the message sent. For one-third of the researchers, making clear distinctions between opinions and facts when talking to the media was crucial to avoid sending wrong messages to the audience, especially in moments of high uncertainty. To avoid some of these issues, more than one-third of the participants proposed increasing researchers' availability and willingness to respond to journalists' needs (e.g., clarify any unclear aspects after an interview).

On the journalists' side, participants identified practices that can help communication professionals to tackle infodemic and far-reaching spreading of inaccurate or false information, such as looking for relevant and reliable sources (almost half of the participants). Other practices mentioned were the need to make reliable and verified information accessible (two in five), to assume responsibility toward the information published or broadcasted (one-third), to make use of fact-checking to ensure that information is accurate, reliable, and truthful (almost one-third), and clearly identify opinions and facts in a report or news (more than one-quarter of participants).

> *"Journalists must contrast the information, look for more than two sources. And if there is a mistake or misreporting, they have a moral duty and a professional duty to restore the information"* (ES7)

Several groups of stakeholders can play a role in tackling misinformation and fake news. Communication departments of research institutions, governmental agencies, professional associations, and policymakers were pointed out as key players in centralizing information and identifying good spokespeople to avoid sending contradictory information to the media and, more generally, to the public (one-third). Moreover, according to one-quarter of researchers, the public is expected to play a key role in fighting fake news spreading through the development of media literacy and critical thinking skills.

The second major issue identified by the participants was dealing with uncertainty and some problems associated with limited knowledge available, especially during the first months of the COVID-19 pandemic. For many participants, some ways of facing this problem included understanding and presenting how science works (e.g., the scientific method, the timings of science, and science as a process open to change), acknowledging the lack of existing knowledge, and making nuances and uncertainty apparent.

> *"Journalists need to be aware of the complexity and uncertainty associated with the communication of science, in particular with the communication of a pandemic and do not expect definitive answers from scientists"* (IT2)

Finally, a set of practices emerged to improve the effectiveness of science communication and to foster scientific culture, preparing society to deal with future health crises or socio-technical challenges. Concretely, participants acknowledged the benefits of promoting interdisciplinary practices to face complex societal (and communication) challenges. As such, more active and regular

(but never forced) collaborations between scientists and journalists were envisaged. This cooperation was expected to be based on mutual recognition and respect of each other's expertise and complementary roles (i.e., journalists as communication experts, and researchers as scientific/health experts; as stated by almost half of the participants). One-third of the participants also identified the need to create the necessary tools or environments to meet and interact to overcome shortcomings of their interactions and foster collaborations.

> *"If journalists and researchers collaborated (…) the result would probably be better. The journalist is the communication professional and, therefore, s/he is the one who has the know-how to propose certain information in the best way, on the other hand, the researcher is who knows the subject and who can provide a better idea of what aspect of a given topic may be more important and more interesting (...) collaboration would be desirable..."* (IT3)

Maintaining a sustained presence of science and scientists in the media giving visibility to science and technology in problem-solving and, contributing to promote scientific culture and interest in science were also identified as helpful practices. Furthermore, paying attention to risk management communication strategies during a crisis, but more importantly, working in the prevention (pre-crisis) and the analysis of the post-crisis were also identified as important practices to deal with future challenges by some interviewed. Finally, using emotional content was also mentioned by some participants (one in ten), although it was mentioned as a resource to be carefully used when covering topics such as a global pandemic.

In summary, our interviews have revealed that researchers who were in contact with journalists to cover COVID-19-related topics were primarily driven by a sense of commitment to fulfilling society's information needs. Researchers viewed this interaction with journalists as part of their professional responsibilities but also as a way to ensure that citizens were well-informed about evidence-based recommendations and novel findings related to the virus and vaccines. Overall, researchers reported satisfactory experiences with the media, largely attributed to the preparedness of journalists. Unsatisfactory interactions stemmed from various factors, with researchers (lack of media training) and journalists (inaccurate, superficial, or sensationalist coverage) sharing responsibility. To overcome these issues, researchers identified several practices that could facilitate productive science-media interactions. These include enhancing science coverage in the media, providing media training for researchers, and improving journalists' working conditions. Lessons learned from the pandemic highlight the importance of combating mis/disinformation and uncertainty. Researchers can play a significant role in reducing the spreading of inaccurate or false information by taking responsibility for the messages they convey and clearly distinguishing between facts and opinions; on the other hand, journalists can use reliable sources and engage in fact-checking. To address uncertainty and knowledge limitations in reporting, researchers emphasized the need to demonstrate how science works, including its limitations, timelines, and methodologies. They also stressed the importance of conveying nuances and uncertainties to prevent

false expectations. Active and frequent collaborations between researchers and journalists, with mutual recognition and respect in their respective roles, are envisioned as a means to enhance the effectiveness of science communication and effectively tackle future communication challenges.

5. Discussion

Our results show that, in the context of the COVID-19 pandemic, researchers in three Southern European countries were driven by normative expectations and professional responsibility. For most participants, ensuring citizens' right to be informed about the novel COVID-19 research and/or the action plans to fight the disease were their main motivations to encounter the media. Additionally, educational motivations, instrumental arguments, and intrinsic rewards were also stated as main motivations. Overall, these results resemble findings obtained pre-COVID-19 in Northern Europe, North America, and Australia with scientists from several research fields (Gascoigne and Metcalfe, 1997; Dunwoody et al., 2009; Besley and Nisbet, 2013; Dudo, 2013; Besley et al., 2018).

Perceived benefits and concerns derived from these interactions with the media also emerged. Survey respondents emphasized having a better-educated public, more positive public attitudes toward research, and influencing public debate as benefits regarding media contacts; conversely, the risk of incorrect quotations, the unpredictability of journalists, and the possibility of negative publicity were assessed as important factors reducing scientists' willingness to interact with journalists. These findings resonate with pre-COVID-19 results obtained by Peters et al. (2008a,b) in France, Germany, the US, the UK, and Japan with stem cell researchers and epidemiologists. The similarity suggests that regardless of external factors (e.g., research field, country, or the urgency of the situation) scientists manifest consistent reasons and incentives driving their interactions with the media also stressing the persistent nature of the worries and barriers stated by scientists when interacting with the media.

Similar to the journalists' perception of the availability of scientists to interact with the media during the COVID-19 crisis (Massarani et al., 2021), our study also shows that researchers in Italy, Portugal, and Spain believe that scientists were more frequently accessed and cited as sources of information in the media than before the pandemic. Most participants also considered that there was a higher presence of scientific topics in the general media, and a higher openness to talk with journalists and share their pre-print data in the media. These findings stress the increasing medialization of science and scientists (Olesk, 2021), particularly during the pandemic.

Even in a period of high uncertainty, pressures and tensions to respond to the COVID-19 emergency, the relationship between researchers and journalists was positively assessed. Thus, this relationship proved to be resilient to the challenges, tensions, and pressures that both parties underwent during the COVID-19 crisis.

Some of the reasons reported for these satisfactory interactions were associated with the good preparation or previous knowledge of journalists. Several authors have reported similar findings

regarding the favorable appraisal of science-media interactions in other contexts (Peters et al., 2008a,b; Besley and Nisbet, 2013; Peters, 2013; Dudo et al., 2014; Lo and Peters, 2015). This suggests that the exceptionality of the pandemic did not have a significant negative impact on scientists' perceptions of their interactions with the media in the analyzed Southern European countries. Yet, negative encounters were also reported. Practices that promoted poor interactions with the media are associated with a lack of confidence and communication skills and media training to deal with journalists (in agreement with previous works, e.g., Gascoigne and Metcalfe, 1997; Kaye et al., 2011; Dudo, 2013; Dijkstra et al., 2015; Larsson et al., 2019) and with the lack of accuracy, preparation on the topic, and sensationalism that some journalists and media perform (in particular, those not specialized in science coverage; as discussed in Peters et al., 2008b; Petersen et al., 2009).

Regardless of the existence of uneasy interactions, participants recognized the importance of joining forces with media professionals to respond to societal needs for accurate and trustworthy information to confront the COVID-19 crisis. Some of these identified collaborative actions are not novel (Nikunen et al., 2019), although the COVID-19 crisis might have evidenced the urgent need to enhance science-media cooperation based on mutual trust and mutual learning relationships. Other (pre-COVID-19) studies stated that mutual trust contributes to positive science-media relations, e.g., in the form of fruitful interviews (Geller et al., 2005; Kolandai-Matchett et al., 2021).

As shown in this work, practices to overcome some of these concerns and enlarge the mutual benefits of the science-media interactions include a necessary self-reflection of own practices (both for researchers and journalists) as well as the cooperation of both types of actors. A better understanding and reporting of scientific practices and their outcomes (e.g., presenting science as a process open to change, with uncertainties and nuances, rather than an immutable truth) and awareness of scientists' limitations (e.g., lack of formal media training) and structural problems of journalism (e.g., lack of time and resources, or lack of specialization in science coverage) can settle the ground for fruitful and trustful collaborations.

Although more collaborative practices between these actors are desirable, it is also important to consider that challenges can arise. Some of the difficulties have been already identified in literature (e.g., disappointed expectations or misunderstandings related to science news outcomes and each other's roles; Maillé et al., 2010; Kolandai-Matchett et al., 2021) together with some suggestions to overcome them, such as considering the necessary time to build mutual trust and respect as well as common views on news media coverage (Kolandai-Matchett et al., 2021).

The COVID-19 emergency has also posed specific challenges and evidenced communication pitfalls, such as the growing use of preliminary research data (i.e., pre-prints, in many cases not contextualized or identified) in media reporting (Fleerackers et al., 2021; Fraser et al., 2021), difficulties in managing increasing uncertainty (Dunwoody, 2020; Fernandes, 2021; López-García et al., 2021), and the fight of dis/misinformation and global fake news spreading (Mesquita et al., 2020; López-García et al., 2021; Naeem et al., 2021; Muresan and Salcudean, 2023). From the point of view of the participants interviewed, researchers, journalists,

but also other stakeholders (e.g., policymakers, national agencies, and the public) are co-responsible for tackling the infodemic and fighting the far-reaching spreading of inaccurate and false information. This shared responsibility to help the public identify fake news has been also suggested by other authors (e.g., Naeem et al., 2021).

Researchers consider that their contribution to dealing with the problem of misinformation and fake news lies in their responsibility toward the message sent. Participants stated that making a clear distinction between facts and opinions and acknowledging their lack of knowledge and/or capacities on the topic are crucial to avoid sending confusing messages or causing misunderstandings. Showing availability and willingness to respond and clarify any doubts that could emerge when covering COVID-19 research and the possibility of making corrections were also reported as practices that could tackle the dissemination of inaccurate information. These results align with some of the recommendations by Swire-Thompson and Lazer (2020) who proposed that all health communicators (including scientists, the media, governmental bodies, and health practitioners) should actively spread truthful information and increase the correction of misinformation to dispel fake news.

Participants also referred to practices that are indispensable in any journalistic work and that conform the basis of journalists' deontological code, i.e., the distinction between facts and opinions, ensuring reliable and verified information, the inclusion of relevant and reliable sources, and the responsibility of the media toward the information published or broadcasted. As discussed by Mauri-Ríos et al. (2021), following some of these practices was indeed recommended by several international organizations at the beginning of the pandemic. Additionally, fact-checking practices in traditional and new media were also acknowledged as crucial to fight the spreading of rumors and hoaxes and reduce uncertainty related to this novel disease, which aligns with the recommendations of several authors (e.g., Dunwoody, 2020; López-García et al., 2021).

6. Limitations

One of the limitations of our study is its limited scope to the perspective of researchers, thus disregarding the views of journalists. However, although focusing only on one of the actors may narrow our view of these interactions, this allowed us to deepen the analysis of the beliefs, opinions, and experiences of researchers directly involved in COVID-19 research. Second, the group of researchers addressed by our study (i.e., academics and scientists from different fields, including clinical researchers and medical doctors) represents a small (although specific) sample of respondents, allowing us to draw general and specific conclusions about the science-media relationship in three Southern European countries in the context of COVID-19 communication. Future work can address some of these limitations by exploring the perspective of journalists in these three countries, complementing previous work published on this topic (Massarani et al., 2021). Also, enlarging the sample to other scientific fields or emerging research topics, such as artificial intelligence, human-machine interfaces, or renewable energy generation and storage, can also provide insights

into fruitful ways to address the communication of some of these present and future challenges.

7. Final remarks

Taking the perspective of researchers involved in COVID-19 research in Italy, Portugal, and Spain, our findings provide valuable insight into how their interactions with the media developed and into ways to facilitate their consolidation in the future. This study shows that, in comparison with previous studies, the motivations, concerns, and benefits perceived by the scientific community from their encounters with journalists have not substantially changed as an effect of the pandemic. On the contrary, researchers in Southern Europe rated their interactions with the media positively and revealed their openness to maintain a trustful and fruitful cooperation with journalists to ensure citizens' rights to be informed. In the interviews, researchers also provided relevant reflections about their role and the role of journalists, suggesting individual and common practices (addressed to scientists, journalists, or both actors) that could facilitate mutual learning and support their cooperation. Finally, in a context of uncertainty, spreading of fake news, high demand for information and great expectations in science and technology, researchers recognized the opportunities that collaborating with the media can offer to tackle current and future communication challenges. Overall, these results help to advance the understanding of how critical moments, in this case, the COVID-19 pandemic, may affect the science-media relationship and suggest ways to advance in the construction and strengthening of fruitful relationships between scientists and journalists. Moreover, these findings aim to support current and future communicative challenges such as health, environmental and social crises that require joint efforts from multiple societal actors.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by the Ethics Committee of the Faculdade de Ciências da Universidade de Lisboa (CEC/1/2022). The patients/participants provided their written informed consent to participate in this study.

Author contributions

EM-G, AMD, and CL contributed to the conceptualization of the study. EM-G, AMD, ADJ, and CL contributed to the methodology. EM-G and IN collected data. EM-G, IN, and CL conducted data analysis. EM-G wrote the first draft of the manuscript. All authors contributed to the manuscript revision and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomm.2023.1231301/full#supplementary-material

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