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Editorial

Editorial: Science Communication in the Digital Age—New Actors, Environments, and Practices

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Abstract
Digitalization challenges science communication in theoretical as well as methodological ways. It raises questions on how scientists, organizations, and institutions, as well as citizens and actors from other fields communicate about science and how science communication affects politics and the public. This thematic issue presents a collection of articles attempting to tackle digitalization's challenge for science communication research. In this editorial, we provide a short overview of the included articles. Additionally, we outline some future avenues that research could follow to examine further the implications that digital channels could have for science communication.

Keywords
climate change; Covid-19; digital media; experts; Facebook; science communication; science literacy; social media; TikTok; Twitter; YouTube

Issue
This editorial is part of the issue "Science Communication in the Digital Age: New Actors, Environments, and Practices" edited by Julia Metag (University of Münster), Florian Wintterlin (University of Münster), and Kira Klinger (University of Münster).

1. Introduction

Science communication has undergone tectonic shifts in recent years, many of which have been introduced by or catalyzed through digitalization. On the level of social implications of digital media (Neuberger, 2009), opportunities to participate in science communication are increased by lowering participation barriers, both for communicators and audience; transparency is augmented; and the ability to select content according to individual needs is improved. Digital media has given rise to a pluralization of voices in science communication, along with individualization and, in some cases, fragmentation or even polarization of audiences (Schäfer & Metag, 2021). Other characteristics of digital information environments are also posing challenges for communication about science: misinformation and disinformation distributed on various platforms (Scheufele & Krause, 2019), hardening counter-publics online (Kaiser & Puschmann, 2017), online attacks on scientists, and a lack of institutional support for scientific communicators (Gosse et al., 2021; Nölleke et al., 2023). Many of these trends were accentuated, amplified, and accelerated during the Covid-19 pandemic. The number and types of voices and the amount of information available online have increased during the pandemic to what has been called an "infodemic" (Krause et al., 2022; Lu et al., 2021). This encompasses problematic aspects such as disinformation and conspirational thinking (Schäfer et al., 2022), as well as the crowding out of other topics such as climate change. However, it also demonstrates a strong representation of science in the public discourse.

Digital channels allow communicators to use different formats, codes, and content, combining visual, textual, and auditory elements. Science journalists use platforms like YouTube and Twitter to communicate; the visibility of scientists and science online has hence increased and received more attention (Metag, 2021).

On the level of spatial factors (Neuberger, 2009), digital media can overcome geographical boundaries and change the contexts in which people communicate. They can help with public engagement for scientists and scientific organizations, enabling them to address audiences directly using multimodal and interactive methods of communication (Schäfer, 2017). On a temporal level (Neuberger, 2009), the speed and dynamics of information diffusion are accelerated by digital media, allowing synchronous and asynchronous communication, as well as storage of communication for usage on future occasions.

Against such a background, this thematic issue presents an overview of current studies on science communication in the online sphere. The 12 articles address some of the benefits and challenges of online communication already outlined as well as the blurring boundaries between communicators, content, and audiences. Each article has a specific focus: on different scientific actors communicating online, on how audiences are affected by particular kinds of online science communication, or on how online discourse about scientific issues is structured and can be described.

2. Scientists, Scientific Institutions, and Science Influencers on Online Platforms

Scientists and scientific institutions are presented with many options for communicating through online platforms but also face various challenges when doing so. Focusing on whether a topic's history affects science communication, Kaija Biermann, Nicola Peters, and Monika Taddicken (2023) compare similarities and differences between climate professionals and Covid-19 experts regarding advocacy and assessments of policies and political actors on Twitter. They find that authorities on climate deal with politics more often in their tweets than Covid-19 specialists. A lot of research on science communication in social media relies on Twitter data. Still, Adrian Rauchfleisch, Jo-Ju Kao, Tzu-Hsuan Tseng, Chia-Tzu Ho, and Lu-Yi Li (2023) argue that, in Taiwan, scientists are more active on Facebook even in their professional roles. They analyze predictors of Facebook communication reach and demonstrate that posts that address current issues and include opinions are likely to be shared most widely. In the context of the underrepresentation of female scientists in the media, Brigitte Huber and Luis Quesada Baena (2023) explore the potential for female scholars to overcome gender stereotypes on TikTok. Using content analysis, the authors show that women scientists use TikTok to explain facts and concepts, to discuss what being a (female) scholar is like, and also, in some cases, to address gender stereotypes. Influencers have gained importance on social media, which offers the opportunity for diversification of the spectrum of science communicators. In this regard, Belén Cambronero-Saiz, Carmen Cristófol-Rodríguez, and Jesús Segarra-Saavedra (2023) study whether there are differences in the type of comments posted on Spanish science popularization channels on YouTube depending on the creator's gender. They find that women are more likely to receive negative sexist comments and that these remarks often address their intellectual ability or personality. Converse to these studies looking at single scientists or influencers, Isabel Sörensen, Silke Fürst, Daniel Vogler, and Mike S. Schäfer (2023) take an organizational perspective, conducting a longitudinal analysis of all Swiss Higher Education Institutions' communication on Facebook, Instagram, and Twitter. They present the differences between channels over time, like increased communication on Instagram but not on Facebook or Twitter, and between types of universities, with universities of applied sciences most active on Facebook and Instagram while research universities more often using Twitter.

3. Online Public Discourse About Scientific Issues

As mentioned above, communication about science on social media platforms has frequently been investigated on Twitter. Two studies in this issue provide insights into research gaps that exist in this field. Hendrik Meyer, Amelia Katelin Peach, Lars Guenther, Hadas Emma Kedar, and Michael Brüggemann (2023) explore the interplay of "triggers" and discursive features that attract attention to climate change. Combining manual and automated Twitter content analysis, they find intense politicization of climate change and calls for action in the Twitter discourse and identify causes: political events generating posts that stress the reality of climate change, and amplification of tweets about protests and cultural events if they include a call for action. The study by Hannah Schmid-Petri, Moritz Bürger, Stephan Schlögl, Mara Schwind, Jelena Mitrović, and Ramona Kühn (2023) concerns Covid-19 on Twitter. It closes a research gap by focusing on multilingual Twitter discourses, analyzing how the topic of vaccination was discussed and evaluated in German, Russian, Turkish, and Polish language communities in Germany. While the authors do not find many structural connections between the communities, they reveal that the content of the debate in the different language communities is similar.

In China, specific social media platforms like Twitter and Facebook are not available. Instead, Weibo has emerged as a virtual online platform with similar affordances. Jinghong Xu, Difan Guo, Jing Xu, and Chang Luo (2023) investigate science communication about the Omicron variant of Covid-19 on Weibo using content and social network analysis. The actors they identify show relatively consistent values and positions in their posts. Regarding the challenge of inaccurate scientific information spreading during the Covid-19 pandemic, Markus Schug, Helena Bilandzic, and Susanne Kinnebrock (2023) analyze how scientific evidence is presented and how findings are questioned using evidencing and counter-evidencing strategies in the online

content of two popular German "alternative news" media sites. They find that the coverage contradicts scientific evidence and follows a political agenda agitating against Covid-19 policies.

4. Audiences and the Reception of Science Communication Online

From an audience perspective, the question of whether people possess—or should possess—some kind of scientific literacy has been discussed in the field of science communication research for decades. Many researchers have worked on defining concepts and measurements of scientific and information literacy. In their article, Han Wang, Lina Li, Jing Wu, and Hao Gao (2023) investigate scientific information literacy and the demographic differences among the Chinese public through a cross-sectional survey. The results reveal that the Chinese public has relatively low levels of ability to assess information quality and to express opinions about science. Two other articles in this issue provide further insights into how specific characteristics of online communication about science can influence audiences. First, Anna Schorn and Werner Wirth (2023) study how explainer videos on Youtube that use exemplars (the "meet Bob" trope) affect attitudes towards voluntary carbon offsetting and perceived effectiveness. Their experiments reveal that appeals to injunctive social norms can positively influence sustainable minority behavior. Second, Jana Laura Egelhofer (2023), with an experimental design drawing on the interplay of political populism and science, analyzes how politicians' attacks addressing science and journalism on social media affect citizens' trust in journalists and scientists themselves and the information provided by them. She finds somewhat limited effects, showing that only citizens with strong anti-elitist attitudes are susceptible to disinformation accusations by politicians, indicating less belief in discredited scientific information.

5. Conclusion

In science communication research, the distinct characteristics of digital media can influence not only the methods used and theories developed but also the questions that researchers ask. Contributions to this thematic issue show that the social implications of digital media are very prominent. The studies examine users, influencers, and individual experts and their communication channels, the role of the audience in science communication, and the interplay between audience reaction and content production. In particular, the greater vulnerability of certain groups online is apparent. Aspects on the level of time, space, and characters are less present than the social aspects. However, the articles here nonetheless offer some insights. The temporal dimension is reflected in this thematic issue by research examining attention to topics on social media and a longitudinal analysis of a science communicator's social media. Regarding the spatial dimension, the studies included here illustrate that obstacles to and opportunities for science communication can differ vastly depending on the context. The level of examining characters and their use in digital media is present in a study examining the effects of visual content in this thematic issue.

This presents new avenues for future studies that could examine how the rate of information diffusion and the speed of generating scientific findings clash, the potential of digital media to expand the spatial dimensions of science communication, and how digital media can integrate different visual as well as auditory elements. Manual content analysis is still the dominant method of examining digital communication. However, longitudinal analyses that capture temporal aspects and methods combining visual and textual elements are required to enhance our understanding. In addition, these studies show that it is worth the effort to compare national contexts to identify global trends as well as local specifics. Therefore, there is potential for further development, both in terms of methods and questions.

Overall, this thematic issue provides an illustrative picture of the changing landscape of science communication in the digital age. It highlights the importance of addressing the challenges posed by digital media while leveraging its opportunities to engage with audiences effectively.

Conflict of Interests

The authors declare no conflict of interests.

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Article

"You Can Do Better Than That!": Tweeting Scientists Addressing Politics on Climate Change and Covid-19

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Abstract
Climate change and the Covid-19 pandemic are global challenges in which scientists play a crucial role, and immediate political actions are necessary. However, in contrast to climate change, strong governmental actions have been taken during the pandemic. While climate change has been on the public agenda for several decades, the pandemic is a rather new issue. In such cases, social media offer scientists the potential to disseminate scientific results to the public and express calls to action and their personal views towards politics. Thus far, little is known about the extent to which scientists make use of this option. In this study, we investigated the similarities and differences between visible German climate experts and visible German Covid-19 experts regarding advocacy and assessments of policies and political actors on Twitter. We conducted a manual content analysis of tweets (*N* = 5,915) from 2021 of the most visible climate experts (*N* = 5) and the most visible Covid-19 experts (*N* = 5). The results show that climate experts addressed politics more often than Covid-19 experts in their tweets. The selected climate experts more often expressed negative evaluations, the degradation of competence and blaming. The Covid-19 experts, however, made more political calls for action. We assume that an issue's history and context will affect scientists' public assessments of politics. Our comparative study provides insight into the interrelations between science and politics in digital communication environments and elucidates visible scientists' communication behaviours towards different socio-scientific issues.

Keywords
climate change; Covid-19; digital communication; science communication; science–politics interrelations; Twitter; visible scientists

Issue
This article is part of the issue "Science Communication in the Digital Age: New Actors, Environments, and Practices" edited by Julia Metag (University of Münster), Florian Wintterlin (University of Münster), and Kira Klinger (University of Münster).

1. Introduction

The Covid-19 pandemic and climate change are global threats, with both having high relevance for the entire population and high levels of public attention and politicisation. They represent so-called socio-scientific issues (Sadler et al., 2007), which are "controversial, socially relevant, real-world problems that are informed by science" (Taddicken & Krämer, 2021, p. 7). Although these two socio-scientific issues should not be conflated, as crucial differences exist (e.g., how long the topic has been the subject of public discussions), there is one highly relevant commonality: Scientists have become key actors in public discourses around both issues.

During the pandemic, scientists were at the centre of public discussions on Covid-19 (Leidecker-Sandmann et al., 2022; Safford et al., 2021), giving practical implications of their research for both the public and policymakers (Post et al., 2021). It is stated that the relevance of scientists in informing policy decisions has never been more noticeable than during the pandemic (Scheufele, 2022). While scientific knowledge only emerged gradually, the Covid-19 pandemic caused a high need for information (Lu et al., 2021), and the enormous impact of

the pandemic prompted scientists to communicate their expertise publicly (Leidecker-Sandmann et al., 2022). Regarding the issue of climate change, scientists had already succeeded in bringing climate change to the policy agenda in the 1980s (Schäfer, 2016).

The crucial role of scientists in both socio-scientific issues can serve as examples of the "political implications of scientific expertise" (Peters, 2021, p. 114). The close intertwining of politics and science in socio-scientific issues raises questions on how science could and should inform policymaking and public debate (Post et al., 2021). Scientific debates in modern societies often blur the lines between scientific issues being debated and the societal and moral implications of their societal applications (Scheufele, 2014). Thus, scientists become involved in politicised scientific fields (Post & Ramirez, 2018; Scheufele, 2014) where they are facing a new challenge. When engaging in politicised discourses, scientists operate in contexts determined by factors outside of science (Schmid-Petri et al., 2022). Here, scientists can be expected to not only assert established scientific knowledge and justify particular lines of policy (Pielke, 2004; Post & Ramirez, 2018; Scheufele, 2014).

At the same time, engaging has never been as easy as it is today. New digital communication environments have radically changed the communicative landscape for science communication, leading to new opportunities for scientists to communicate publicly (Taddicken & Reif, 2016). Nowadays, scientists engage in online discourses more often and can thus increase their public visibility (Metag, 2021). For instance, during the pandemic, the popularity of virologists grew very quickly, which was also reflected in their increasing number of Twitter followers (Utz et al., 2022). In general, scientists progressively use their own social media channels to communicate directly with the public (Della Giusta et al., 2021). On social media, different online public arenas intermingle (Lörcher & Taddicken, 2017), offering scientists the opportunity to communicate beyond the scientific community and directly address politics. In particular, Twitter has become a popular intersection for scientists where other scientists and science-affiliated actors, science journalists, and politicians meet (Brossard & Scheufele, 2022).

Therefore, how visible scientists communicate in digital environments is a significant question in the field of science communication. While studies have examined scientists' motives and reasons for public and policy engagement (e.g., Cologna et al., 2021; Sharman & Howarth, 2017), research on the question of whether and how scientists address politics on social media is in its infancy (e.g., Walter et al., 2017). When scientists engage in politicised controversies, their communication can serve to influence policy (Pielke, 2004; Post & Ramirez, 2018). Moreover, comparative studies in the context of scientists as public communicators are limited to comparisons between scientists and actors from other fields, such as economics (Della Giusta et al., 2021). However, it is important to better understand how visible scientists from different research areas communicate directly with the public, particularly, how they address politics. Thus, it can be assumed that these scientists may not only address but also assess and criticise policies and political actors to attract public attention.

In this study, we aim to shed light on these questions by investigating how the visible German climate experts and the visible German Covid-19 experts address politics in public discourses on Twitter. These socio-scientific issues have distinct histories in public discourses and were managed differently by politics, which may cause differences between climate experts' and Covid-19 experts' communication behaviours. The comparison is particularly interesting because Covid-19 experts had to suddenly transgress their role as researchers and deal with the public and politicians all at once (Peters, 2021), while climate experts have been dealing with the public and politics already for decades (Schäfer, 2016). Findings may help to understand the diverse communication requirements of different topics and highlight strategies of science communicators that deal with these requirements.

2. Comparing Climate Change and Covid-19

The Covid-19 pandemic and climate change can both be described as major societal challenges that have to be met with science. Thus, scientists and their communication behaviours play a decisive role. Although it is argued that the pandemic "provides a lens into how to deal with many other slow-burning crises such as the…climate crises" (van der Voorn et al., 2021, p. 8), both challenges provide a very specific context for science communication.

Climate change is a "complex and multifaceted issue with substantial policy ramifications" (Sharman & Howarth, 2017, p. 826). There is consensus among scientists that anthropogenic climate change is a major threat to humanity (Powell, 2017). While its consequences become increasingly visible, the topic remains unapproachable for most of the public due to its complexity and perceived distance (Chen et al., 2022). In Germany, climate change has been widely accepted as a "rather certain and serious societal problem" (Schäfer et al., 2014, p. 156). The challenges posed by it have received public and media attention since the 1980s (Schäfer, 2016). However, previous content analyses have shown that media coverage of climate change is driven by political events and is increasingly politicised (Chinn et al., 2020; Schäfer et al., 2014). Anthropogenic climate change is mainly portrayed as a definite threat in German news media coverage (Maurer, 2011; Schäfer, 2016). Overall, scientists in Germany are thus operating in an environment characterised by a high degree of agreement on anthropogenic climate change. A study conducted by Post and Ramirez (2018) on German climate scientists' view on climate change news coverage found that most scientists do not believe that the news media understate the issue.

The upcoming of the Fridays for Future movement in 2018 brought a new dynamic to public discourses on climate change (Rauchfleisch et al., 2021). While the movement might have led to greater visibility, the claims are not new. For decades, scientists have "sounded the alarm about global warming" (Weingart et al., 2000, p. 261). Although political actors have known of the threat for a long time, only gradual efforts have been made, and political actions have often been postponed (Grundmann, 2021). These measures, which are perceived as insufficient for coping with climate change, have created frustration among climate scientists (Pidgeon & Fischhoff, 2011). In 2020, the issue of climate change was displaced by Covid-19 in the news media and on social media (Rauchfleisch et al., 2021), which might have prompted scientists to put climate change back on the media and political agenda themselves.

During the largest public health crisis in recent history, information about Covid-19 was widely disseminated by various sources (Taddicken & Krämer, 2021). In contrast to the long history of climate change, the current pandemic only emerged at the beginning of 2020 and has had an immediate impact on societies worldwide, for example, through lockdown measures. Since Covid-19 has posed an imminent and severe threat to individuals, the issue is perceived as more urgent and less abstract than climate change (Rauchfleisch et al., 2021). The Covid-19 pandemic caused a high need for information (Lu et al., 2021). A huge reliance on scientific experts existed during the pandemic as they could explain the pandemic's cause and effects to the public and policymakers (Leidecker-Sandmann et al., 2022). This was accompanied by the increased popularity of scientists from the field of virology in Germany (Utz et al., 2022).

At the time of the pandemic outbreak, policymakers were quick to take far-reaching measures to combat the spread of Covid-19 (Lidskog et al., 2020). In Germany, extensive political decisions were also taken to prevent and contain the transmission of the virus (Sell et al., 2021). Many scientists were surprised by the speed and scale of such responses, particularly when compared to the responses to climate change (van der Ven & Sun, 2021). Especially at the beginning of the pandemic, there was a high degree of agreement between science and politics about what societal actions should be taken (Metcalfe et al., 2020).

In contrast to measures on the long-term problem of climate change, responses to the Covid-19 pandemic tended to be short-term; the two issues thus vary enormously in terms of temporality (Grundmann, 2021). However, initial content analyses have revealed a high degree of politicisation in news media coverage of Covid-19, which is similar to that of climate change (Hart et al., 2020). The political nature of scientific issues is thus visible in public discourses on both issues (Metcalfe et al., 2020).

In politicised scientific fields, different actors try to make their voices heard and pursue particular political goals, which is also assumed for scientists (Schmid-Petri et al., 2022). Research has shown that some climate scientists advocate for certain political outcomes (Pielke, 2004; Post & Ramirez, 2018). A comparative study of visible climate experts and visible Covid-19 experts holds promise because the two global challenges have aspects in common, such as their societal relevance and the dominance of scientific voices in their discourses. Still, they also differ in their perceived immediacy and political responses. Regarding the involved scientists, most Covid-19 experts have only been in the public eye for a short time; therefore, they most likely have less experience in communicating with the public than climate experts (Peters, 2021). This likely results in different communication behaviours, particularly on social media. Here, the different strategies of science communicators that deal with different communication requirements resulting from the different histories of the two socio-scientific topics may particularly become visible.

Moreover, as strong governmental responses have been taken during the pandemic, lacking to the extent of climate change (Lidskog et al., 2020), the level of frustration among climate scientists has presumedly increased. Climate scientists have long been described as "frustrated by the limited response to what they see as the greatest threat facing our planet" (Pidgeon & Fischhoff, 2011, p. 40). We suspect that these differences in the political handling of the two global threats result in different communication behaviours of climate experts and Covid-19 experts towards politics and the public.

3. Visible Scientists Addressing Politics on Social Media

While scientists often remain invisible to the public, in some situations such as climate change and the Covid-19 pandemic, they have become important public communicators acting as policy advisors to the public (Peters, 2021). During the pandemic, individual scientists played an unprecedentedly prominent role in traditional and social media (Utz et al., 2022; Wormer, 2020). The term "visible scientist" originally referred to scientists who were prominent in the mass media and distinguished by activities in "the tumultuous world of politics and controversy" (Goodell, 1977, p. 6). Visible scientists tried to influence policy through the mass media, putting issues on the media agenda while knowing that policymakers were watching (Fahy, 2017; Goodell, 1977). Therefore, visible scientists "hold some form of power" (Metag, 2021, p. 130).

Nowadays, there are many new forms to gain public visibility, especially via social media (Olesk, 2021). Scientists can become visible to the public, address political problems of society at large by warning about climate change or provide advice on health issues (Peters, 2021). However, this "boundary role" at the interface of science and media is only taken by a minority of scientists (Rödder, 2012). In this study, we operationalise the

analytical concept of visibility as scientists who are visible in digital communication environments.

The rise of digital communication environments has radically changed the communicative landscape for science communication (Taddicken & Reif, 2016), leading to "an intermingling and integration of the different partial public spheres" (Lörcher & Taddicken, 2017, p. 4). This is especially true for Twitter, where actors from different arenas intertwine, share various content and connect it via the hashtag function. This phenomenon of flattening multiple audiences into one is also known as "context collapse" (Marwick & boyd, 2011). The platform enables scientists to distribute, consume, and discuss scientific issues in a new way (Büchi, 2017). While Twitter primarily serves as a platform for many researchers to share their research findings and connect with their scientific network (Collins et al., 2016; Costas et al., 2020), Twitter's architecture enables scientists to engage in broader public discussions (Brossard & Scheufele, 2022; Della Giusta et al., 2021). Hence, the rise of social media platforms such as Twitter has changed how scientists communicate with different non-scientific actors (Roedema et al., 2021) since social media facilitate exchanges between science and politics, and media and the public (Walter et al., 2019). While in the past, scientists had to turn to the public and political actors via traditional mass media (Weingart, 2001), nowadays, they can directly address politics using their own accounts on social media platforms (Della Giusta et al., 2021).

It is important to emphasize that scientists—like other societal actors—might be motivated by their political preferences to communicate the facts and include personal preferences in their professional recommendations (Scheufele, 2022). The political dimension of science communication can become visible in scientists' engagement in public discourses on social media (Nisbet & Markowitz, 2015). Previous work has shown that scientists also use Twitter to express their own personal views, especially in highly politicised fields (e.g., Jahng & Lee, 2018; Walter et al., 2017). Digital media can even be seen as drivers of politicisation (Schmid-Petri et al., 2022). The 280-character limit on platforms like Twitter is said to create a "temptation for scientists" to communicate beyond the presentation of evidence-based information (Brossard & Scheufele, 2022, p. 614).

Since science, politics and the public are in a "continuous communication process influencing each other" (Schrögel & Humm, 2020, p. 504), scientists can participate directly in public discussions and potentially engage in stealth advocacy. So-called "informal policy advice"—formerly given by scientists through mass media coverage (Petersen et al., 2010)—might have become significantly more present on social media. This has the potential to reshape interactions between scientists and political actors, leading to a political impact (Peters, 2021).

Particularly in politicised scientific fields, the distinction between science and policy is often blurred (Post et al., 2021). Since the demand for advice from scientists has increased, they are increasingly expected to speak out in public debates (Schmid-Petri et al., 2022). Scientists might attempt to reach political actors through the general public (Tøsse, 2013). Different typologies of the roles of scientists in politics exist (e.g., Pielke, 2007), and the normative question of scientists' public policy advice has been addressed (e.g., Bray & von Storch, 2017; Donner, 2014; Lackey, 2007). Research in the early stages of the pandemic on the public's perception of the relationship between science and policy has shown that especially people who have a need for clear information, see scientific knowledge as stable and want certain scientists to dominate policymaking (Post et al., 2021). A study examining UK-based climate scientists' views on policy engagement showed that they are divided on the extent to which they should engage in policy debates and make policy recommendations (Sharman & Howarth, 2017). However, they consider a certain level of advocacy to be warranted (Sharman & Howarth, 2017). A recent study by Cologna et al. (2021) found that both climate scientists and the public in Germany believe that scientists should actively advocate for policies. While open support for climate policy affects the perception of the objectivity of scientists, it does not affect their perceived trustworthiness (Cologna et al., 2021). While the general perceptions of scientists' role in public discourses have often been discussed, if and how scientists include advice in their direct public communications has raised little scholarly attention so far (Schrögel & Humm, 2020).

In the case of climate change, a group of scientists founded Scientists for Future, in which scientists often engage as "knowledge suppliers for FFF [Fridays for Future]"—a role that can be seen as close to political activism (Merkel, 2022, p. 270). When scientists address policy advice, they transgress their role as "pure scientists" who mainly focus on their own research and do not actively engage in public discourses (Pielke, 2007). Scientists advocating for a particular policy are defined as "issue advocates" (Post et al., 2021; Schmid-Petri et al., 2022). They contribute to the politicisation of science (Schmid-Petri et al., 2022). On social media, the attempts of visible scientists to address politics are more easily documented. However, only a few studies have directly considered visible scientists' online communications in terms of advocating policies in controversial political contexts using content analysis. When investigating the role of scientists as issue advocates (Pielke, 2007), we must focus on scientists' public communication practices. Thus, it is necessary to analyse the extent to which visible scientists address politics in their tweets to gain an overview of their online communicative practices outside their scientific communities. Here, we ask whether and to what extent visible climate experts and visible Covid-19 experts publicly give political calls to action:

> RQ1: How do visible German climate experts compared to visible German Covid-19 experts advocate policies in public discourses on Twitter?

Moreover, scientists' public addressing of politics may include advocacy and assessments of policies and political actors. We can assume that scientists who publicly advocate policies may want to attract attention towards their own issues and thus increase their visibility further. When adapting to media logics, greater visibility might be reached more easily (Metag, 2021). Social media offer scientists the opportunity to take a public stand on politically relevant issues (Jahng & Lee, 2018) and to publicly criticise political actors and their policies since they can bypass traditional gatekeepers (Peters, 2013). By applying the news values of negativity and conflict (Galtung & Ruge, 1965), scientists may attract public and political attention. Scientists have been found to be interested in providing knowledge to the public and using their reach to put pressure on policymakers (McCormick, 2009). Initial research suggests that while climate scientists address other scientists more often than political actors on Twitter, their tone towards political actors is more negative than their tone towards their peers (Walter et al., 2019). However, there is a lack of more profound insight into how they assess policies and political actors in their social media communications. Thus, we pose a second research question:

> RQ2: How do visible German climate experts compared to visible German Covid-19 experts assess policies and politics in public discourses on Twitter?

In order to answer this research question, we investigate various aspects of assessment. First, we focus on negative evaluations. This is because negativity as a news value attracts attention and it has been presumedly adopted by media-experienced scientists (Peters, 2013). Climate experts have observed that, in contrast to climate change, strong governmental responses have been possible during the pandemic. This might have reinforced their concerns about politicians acting against or neglecting scientific evidence regarding climate change. Visible scientists might address this by degrading politicians' competence on social media. With the opportunity to bypass traditional gatekeepers on social media (Roedema et al., 2021), scientists' communication may become less filtered. Therefore, scientists may attract public attention by engaging in conflict. They may attribute causal responsibility to political actors for their past actions by blaming them. Research on blaming so far has focused mainly on political communication (e.g., Hameleers et al., 2016); if or to what extent visible scientists publicly blame political actors has yet to be studied.

4. Methods

In order to investigate different communication behaviours of visible climate experts and visible Covid-19 experts regarding advocating and assessing politics and policies, we conducted a manual content analysis of all tweets (original tweets, quotes, and replies) from the year 2021 that were posted by 10 visible scientists (N = 5,915). Since climate change and Covid-19 are not sciences in their own right, we use the term "visible experts" instead of visible scientists when referring to both scientist groups.

The 10 visible scientists are professors or postdoc researchers in the broad fields of climate change or Covid-19 and are affiliated with a German university or research institution. They were selected by applying a pyramid scheme, starting from the most visible German scientist from each field in terms of followers on Twitter. Based on that, we searched the accounts they followed and selected all scientists in the field who had at least 10,000 followers to ensure they reached a broad public. We continued searching the accounts the scientists followed and concluded the selection process when no further scientists were found. We found five German climate experts and 14 Covid-19 experts fulfilling the criteria. In order to be able to adequately compare the results, we selected the five most visible climate experts and the five most visible Covid-19 experts in terms of followings on Twitter. Since the two topics are multifaceted, the visible scientists came from different disciplines. Climate experts' backgrounds were in physics, oceanology, engineering, or economics while Covid-19 experts' backgrounds were in medicine, physics, or biology (see Supplementary Material).

Using Twitter's API, we collected the timelines of the selected scientists from the year 2021. The sample consists of all original tweets, quotes, and replies (N = 5,915). The vast majority of all tweets were German (81%). The remaining tweets were coded as either English (15.9%) or other (e.g., links, emojis; 3.1%). We chose the year 2021, as the German general election happened in September 2021 and there were also a few regional county elections. While Covid-19 was the overlaying topic in 2020 (Rauchfleisch et al., 2021), climate change as a political topic regained attention, especially surrounding the flood disaster in western Germany in July 2021. Furthermore, in the first few months of 2021, Germany had lockdown measures in place to prevent the spread of Covid-19 while also rolling out its vaccine campaign. By looking into visible scientists' Twitter communications in 2021, we can observe how they publicly addressed politics during the general election, coalition talks, and government formation afterwards.

In the content analysis, we first coded whether a tweet addressed politics. Here, statements or questions referred to measures or strategies in which politicians had decision-making authority or where a reference to politics was made. If that was the case, we coded advocating (calls to action) and aspects of assessment (evaluation, degradation of competence and blaming). "Calls to action" were coded when the experts suggested certain measures (e.g., politics should follow a certain strategy, specific measures should be set in place or demand towards politics to refrain from certain actions).

"Evaluation" was coded when the experts rated political measures or political actors in their tweets, we differentiated between positive and negative evaluations. We considered "degradation of competence" to occur when an expert either directly expressed that they did not ascribe competence to a political actor or when they expressed that political actors were acting against common knowledge; the contradiction had to be made clear in the experts' tweet (e.g., lack of understanding or questioning politicians' professional position). "Blaming" was coded when the experts claimed that a certain state or situation was a political actor's fault (e.g., political failures, reproach for a situation due to disregard for science or warning that a forthcoming situation is a politician's fault due to non-actions or wrong actions).

Climate experts' tweets and Covid-19 experts' tweets (N = 5,915) were coded by two coders to ensure reliability. Krippendorff's alpha intercoder reliability was calculated with a random sample of 10% of the tweets and ranged between 0.70 and 0.93 across all variables. At the lower end were more subjective variables, such as blaming and political calls to action, while other variables, such as addressing politics or the type of political actor, were above 0.85 and thus showed good reliability (see Supplementary Material). As this study analysed all the selected experts' tweets from 2021, no inferential statistics were used.

5. Results

In total, 5,915 original tweets, quotes, and replies by 10 visible scientists were analysed; 4,365 were tweeted by climate experts and 1,550 by Covid-19 experts. The selected Covid-19 experts tweeted between 71 and 633 times in 2021, while the climate experts tweeted between 453 and 1,681 times (see Supplementary Material). In total, almost every fifth tweet contained a form of addressing politics. Climate experts more often addressed politics than Covid-19 experts. Based on this, we can already observe differences in the communication behaviours of the most visible climate experts and the most visible Covid-19 experts on Twitter. Whereas climate experts addressed politics in 25.5% of their tweets, Covid-19 experts addressed politics less often, but still in 18.1% (Table 1).

5.1. Advocating Policies

To elucidate the extent to which visible German climate experts and visible German Covid-19 experts advocate policies on Twitter, we continued to analyse only the tweets that address politics (n = 1,392). We saw that 29.5% of climate experts' tweets and 60% of Covid-19 experts' tweets contain calls to action (Table 2). Thus, the Covid-19 experts made more political calls to action from a relative perspective. Taking the total amount of visible scientists' tweets into account, calls to action by climate experts were much more present in our data in absolute numbers.

5.2. Assessing Policies and Political Actors

We analysed how visible German scientists assessed policies and political actors and found differences between climate experts and Covid-19 experts, with more negative assessments by climate experts overall.

The data show that most of the tweets did not evaluate policies or political actors: 66.4% of the climate tweets and 86.8% of the Covid-19 tweets that addressed politics did not contain any evaluation. However, around a quarter (25.9%) of the tweets by the climate experts contained negative evaluations, while only 10% of the Covid-19 experts' tweets contained negative evaluations (Table 3). In addition, positive evaluations of politics or policies were found in 4.2% of the climate experts' tweets and in 2.9% of the Covid-19 experts' tweets.

We also analysed how often the visible scientists degraded the competence of political actors. In most tweets, the visible scientists neither degraded nor attributed competence to political actors. However, in 14.5% of the climate experts' tweets, the competence of political actors was degraded, while such degradation occurred in only 1.4% of the Covid-19 experts' tweets (Table 3).

Table 1. Addressing of politics in experts' tweets (N = 5,915).

	Climate experts' tweets (n = 4,365)		Covid-19 experts' tweets (n = 1,550)	
Addressing politics	n	%	n	%
Not present	3,253	74.5	1,270	81.9
Present	1,112	25.5	280	18.1

Table 2. Advocating behaviour in experts' tweets addressing politics (n = 1,392).

	Climate experts' tweets (n = 1,112)		Covid-19 experts' tweets (n = 280)	
Call to actions	n	%	n	%
Not present	784	70.5	112	40.0
Present	328	29.5	168	60.0

Table 3. Assessing behaviour in experts' tweets addressing politics (*n* = 1,392).

		Climate experts' tweets		Covid-19 experts' tweets	
		n	%	*n*	%
Evaluation	Not present	738	66.4	243	86.8
	Negative	288	25.9	28	10.0
	Negative and positive	39	3.5	1	0.4
	Positive	47	4.2	8	2.9
Competence	Not present	924	83.1	275	98.2
	Degrade	161	14.5	4	1.4
	Degrade and attribute	13	1.2	0	0
	Attribute	14	1.3	1	0.4
Blaming	Not present	1,000	89.9	273	97.5
	Present	112	10.1	8	2.5

Comparing whether and to what extent visible climate experts and visible Covid-19 experts blamed political actors, our results show little blaming overall of political actors by the visible scientists. While the Covid-19 experts blamed politics in only 2.5% of their tweets that addressed politics, the climate experts blamed politics in as many as 10.1% of their tweets (Table 3). Thus, climate experts blame politics relatively more often than Covid-19 experts.

6. Discussion and Conclusion

In this study, we aimed to elucidate visible scientists' communication behaviours on different socio-scientific issues and provide insight into the interrelations between science and politics in digital environments. More specifically, our goal was to analyse how the most visible German climate experts and the most visible German Covid-19 experts advocate and assess policies and political actors in public discourses on Twitter. A manual content analysis of tweets (*N* = 5,915) was conducted to explore the similarities and differences between the two groups of visible scientists.

Firstly, our findings indicate that both climate experts and Covid-19 experts use Twitter to address politics, albeit to varying degrees. The urgency of both socio-scientific issues tends to draw scientists into politics (Brüggemann et al., 2020). Our results suggest that visible scientists transgress the role of the "pure scientist" (Pielke, 2007) on social media in communicating beyond the scientific community and participating directly in public discourses. These findings align with previous research that scientists use Twitter to address politics (e.g., Walter et al., 2019). Overall, the behaviour of addressing politics was more pronounced among climate experts than that of Covid-19 experts in our sample. Climate experts have been concerned about the need to act for decades, while public and policy attention is rather new for most Covid-19 experts. However, Covid-19 experts' tweets included more political calls to action than climate experts' tweets. Accordingly, our findings suggest that Covid-19 experts often addressed politics to give informal policy advice by making calls to action. One possible explanation is that new scientific findings emerged almost daily during the pandemic; scientists then shared information about the consequences and necessary measures since decisions had to be made within days or weeks. Hence, the instant threat of the pandemic might have caused Covid-19 experts to use Twitter to advocate certain measures to combat the virus. Political calls to action in Covid-19 experts' Twitter communications highlight the relevance of scientists in informing policy decisions during the pandemic (Scheufele, 2022). Another explanation is a potential disenchantment with politics by climate scientists. They might have moved away from advising and calling for action due to their years of experience with perceived inactive politicians.

Secondly, our results highlight differences between visible Covid-19 experts' and visible climate experts' assessments of policies and political actors. Climate experts' tweets contained more negative evaluations—which is in line with the idea of a higher frustration level compared to Covid-19 experts. Negative assessments in connection with few political calls to action may be regarded as indicators of frustration or even resignation of climate experts due to the lack of responses from politicians. Moreover, since climate scientists have engaged in public communication for years, they might have adopted media strategies, such as the news values of negativity and conflict, in their communication styles in order to generate attention for the issue. Blaming and the degradation of the competence of political actors occurred more often in climate experts' tweets, suggesting that they focused more on long-term strategies, consequences, or past failures than Covid-19 experts. By degrading competence and apportioning blame, visible scientists attract public attention and thus may put pressure on policymakers.

Our results indicate that the histories of both issues might have influenced visible scientists' communications.

This study supports previous research that in highly politicised fields, scientists provide knowledge and express their own views (e.g., Walter et al., 2017). In particular, climate experts seem to use social media to assess policies and political actors. Accordingly, they perform roles that have in the past mainly been filled by journalists (Taddicken & Krämer, 2021).

Some limitations must be considered. Our sample consisted of only 10 visible scientists, five climate experts and five Covid-19 experts. Conclusions drawn from this analysis should be made cautiously as each individual may have a significant impact. However, we selected the most visible German scientists in terms of Twitter followers, as together they reach a broad public, and each may influence public perceptions of science, politics, and public perceptions of climate change respectively Covid-19. Notwithstanding, the generalizability of the findings to other cultures and domains is limited. This study is also limited to making only descriptive claims on a selection of assessment categories. Moreover, we only looked at tweets from one year. However, this study can make statements about the Twitter communication behaviours of the 10 most visible climate experts and Covid-19 experts contributing to the field of science communication by providing details about the similarities and differences of Twitter communication.

Our study highlights the importance of considering visible scientists' communication behaviours due to socio-scientific issues and the rise of digital communication environments. Since we did not analyse the interrelations between science and politics in more detail, future studies should also consider the reactions of political actors and the public to scientists addressing politics. Further research should also include visible scientists from other fields and countries when exploring scientists' communication behaviours on social media. Moreover, more qualitative research is necessary to gain insight into scientists' communication behaviours in different controversial areas. In-depth interviews can be useful for understanding the intentions of visible scientists when they address politics on social media.

This study has shown how important it is to draw more attention to empirical work on the boundaries of science communication, political communication, and public opinion research (Scheufele, 2014). Overall, this study strengthens the idea that social media offers a platform for scientists to engage in public discourse and directly address politics. However, the most visible climate experts and the most visible Covid-19 experts make different use of the possibilities online. Therefore, the differences between both visible scientist groups underline the relevance of further comparative research on socio-scientific issues.

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Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the author (unedited).

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Article

Maximizing Science Outreach on Facebook: An Analysis of Scientists' Communication Strategies in Taiwan

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Abstract
The internet, and especially social media platforms, offer scientists new opportunities to connect with a broader public. While many studies have focused on science communication on Twitter, surprisingly few have analyzed how scientists use Facebook, even though it is an essential platform for the general public in many countries. A possible explanation for this lack of research is that scientists keep their Facebook profiles separate from their work life and are more active on Twitter in their professional roles. Our study challenges this assumption by focusing on Taiwan as a peculiar case. Due to the local culture, Twitter is less popular there, and scientists are more active on Facebook, even in their professional roles. In our study, we analyzed 35 public pages of scientists on Facebook and assessed the factors explaining the reach of their communication using content analysis in combination with a multilevel model that allowed us to test predictors on the page level, such as the number of fans, in combination with predictors on the post level, such as the complexity of the language used. Our study shows that Facebook can play an influential role in science outreach. To effectively communicate with the audience on Facebook, it is best to use strategies that appeal to new and existing followers. Posts that address current issues and include opinions are likely to be shared widely, while humor or personal self-disclosure is likely to engage the existing audience. Our study contributes to the current debate about alternatives to Twitter in science communication.

Keywords
Facebook; science communication; self-disclosure; social media; Taiwan; Twitter

Issue
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1. Introduction

Nowadays, scientists are highly active on social media, and many studies have analyzed their social media usage. Early studies, especially of scientometrics, focused on communication on Twitter (Priem & Costello, 2010) or scholarly blogging (Puschmann & Mahrt, 2012). Since the early days of science communication on social media, new platforms have come to scholarly attention. For example, studies have analyzed science communication on YouTube (Debove et al., 2021; Yang et al., 2022), Instagram (Jarreau, Cancellare, et al., 2019), Reddit (Hubner & Bond, 2022), and even TikTok (Zeng et al., 2021). Moreover, while scientists have adapted well to the changing social media landscape, there has been a lack of engagement on Facebook, even though it is still among the most widely used social media platforms in many countries (Newman et al., 2022) and one of the primary sources from which regular citizens encounter scientific information and issues (Hargittai et al., 2018; Mueller-Herbst et al., 2020).

Facebook differs from other platforms commonly used for science communication, such as Twitter, in terms of its user base and features. Scientists often use Twitter to communicate with politicians, journalists, and other scientists (Jünger & Fähnrich, 2020; Walter et al., 2019); however, not many use Facebook for science outreach (McClain, 2017). Scientists may use Facebook

personally, but not for professional science communication. In our study, we specifically focus on Taiwan because Facebook is one of the most popular social media platforms there and Twitter is not widely used, even among scientists. Furthermore, most Taiwanese people highlight the internet as their primary source of science-related information, and besides the messenger service Line, Facebook is the most popular social media platform in Taiwan (Shih, 2021). Since prior research on Taiwan has mainly focused on blogging about STEM disciplines (Lo, 2021) or a single Facebook page (Shan, 2017), we focus our study on different forms of Facebook pages with diverse disciplinary backgrounds. We are interested in what communication strategies are most successful on Facebook and lead to higher levels of user engagement. Since only a few specific studies of science communication on Facebook are available, we look at other fields, such as political communication, of which several studies exist that specifically analyzed Facebook communication. We also derive different factors that could influence communication outcomes from the broader science communication literature.

2. Science Communication on Social Media

The internet and social media platforms offer scientists new opportunities to connect with the broader public (Metag, 2021). However, while many studies have focused on science communication on Twitter (e.g., Jünger & Fähnrich, 2020; Rauchfleisch, 2015; Walter et al., 2019), surprisingly few have analyzed how scientists and science communicators use Facebook (Pavelle & Wilkinson, 2020), even though it is an essential platform for the general public (Mueller-Herbst et al., 2020). Therefore, we begin by briefly discussing the role that Facebook plays for scientists and how this lack of academic engagement on Facebook can be explained before we discuss which factors influence the success of Facebook communication.

2.1. Scientists' Social Media Usage

Nowadays, scientists are highly active on social media, and many studies have analyzed their social media usage. From a methodological point of view, there exist different strands of research on scientists' social media usage and its impact. While there have been several studies with experimental approaches that tested the effect of communication on citizens or directly surveyed citizens and how they engaged with science (e.g., Schäfer et al., 2018; Shih, 2016), we focus here mainly on survey research and analyze the content of scientists' communication on social media.

First, a plethora of studies have already generally analyzed how scientists interact with non-scientists in different countries, including Germany (Peters, 2013), Taiwan (Lo & Peters, 2015), and the US (Dudo & Besley, 2016), and usually focused on specific fields, such as climate change research (Post, 2016). However, few studies have focused explicitly on the role of social media. Early survey research from 2007 showed, for example, that even back then, many bioinformaticians were using social media (Anderson, 2008). However, it also identified that scientists' social media platforms were not primarily mainstream ones, such as Twitter or Facebook, but often specific niche platforms created for scientists (Anderson, 2008; Van Eperen & Marincola, 2011). Still, more recent survey research has shown that most scientists are using mainstream social media platforms but are still skeptical about Facebook, as they do not believe that the platform "provides an effective form of science communication" (Collins et al., 2016, p. 5). McClain's (2017) study also confirmed these findings, concluding that "many scientists have turned to Twitter instead of Facebook for science outreach.''

Besides this survey research, there also exists a strand of research that focuses explicitly on the social media behavior of scientists. Instead of using a survey approach, studies in this strand have usually analyzed digital trace data; for example, Jünger and Fähnrich's (2020) study focused on communication scientists on Twitter. Besides these studies focusing on specific disciplines that have analyzed internal communication between scientists, some studies have strongly emphasized external communication. For example, Walter et al. (2019) identified scientists through the issue of climate change and then checked how these researchers communicated with politicians and journalists on Twitter. In addition, some studies have tried to map scientists on Twitter, covering various disciplines (Ke et al., 2017). And while there are several studies that have specifically focused on other social media platforms besides Twitter (e.g., Debove et al., 2021; Hubner & Bond, 2022; Jarreau, Cancellare, et al., 2019; Jarreau, Dahmen, et al., 2019; Yang et al., 2022; Zeng et al., 2021), Facebook seems to remain understudied.

This lack of research is surprising since Facebook's potential for science communication was recognized early on (Nentwich & König, 2014). Although universities, as organizations, have recognized the potential of Facebook as a marketing tool (Assimakopoulos et al., 2017), and they use the platform more often than Twitter (Entradas et al., 2020), individual scientists still seem to be skeptical about the platform, as we have shown above. Most survey research has shown that individual scientists use the platform, but not primarily for science communication. However, studies highlighting these findings usually also mention the untapped potential of Facebook. McClain (2017), for example, suggested that a scientist who already has strong connections with family and friends on Facebook should become a so-called "nerd of trust" and start communicating more about science. The preference for Twitter and specific niche platforms for science communication indicates that a primary goal is peer-to-peer communication with other scientists. External incentive structures can explain the preference

for platforms such as Twitter instead of Facebook. That research funders assess this form of public engagement serves as a primary external driver to use these platforms and communicate more strategically (Kessler et al., 2022). Tracking scholarly communication on Twitter is easy through so-called altmetrics that show how often a publication has been shared (Sud & Thelwall, 2014). On Facebook, on the other hand, these kinds of metrics are not publicly available, and only URLs to articles shared on public pages are tracked as altmetrics. Thus, purely for strategic communication that has as the primary goal of career advancement, Facebook is not an attractive platform.

So why should scientists use Facebook? Many still follow a public engagement model that emphasizes dialogic communication with the general public as well as the public understanding of science model, which primarily focuses on educating the public by taking a top-down approach to science (Kessler et al., 2022). Facebook is an ideal platform for science communication because it has a large public audience. According to Hargittai et al. (2018), young adults in the US are more likely to engage with science and research content on Facebook than on Twitter. Furthermore, citizens' Facebook usage can influence their awareness of scientific issues (Mueller-Herbst et al., 2020).

2.2. Successful Communication on Facebook

In our study, we are primarily interested in what factors explain scientists' communication success on Facebook. Since there are almost no studies available, we derive potential factors from the broader science communication literature and from studies of political communication, where analyses of Facebook communication are more common than they are in science communication. We identified a number of potentially positive or negative factors in the literature that could influence the success of communication via Facebook: (self-)promotion, the complexity of the communication, the use of data and infographics, emotional communication, and the disclosure of personal information.

The most apparent factor can be derived from Twitter research and clearly belongs to the strategic science communication model. Scientists may use Facebook to promote their research, targeting other scientists (Jünger & Fähnrich, 2020). They may also have blogs or podcasts and promote this content through their Facebook pages (Yuan et al., 2022).

How to cope with the complexity of issues and language when communicating with the public is a major concern in science communication (Mueller-Herbst et al., 2020; Wong-Parodi & Strauss, 2014). Regarding the language used in posts, the level of complexity may harm a communication's success. Different studies have highlighted how using jargon and complex language can overwhelm the public (August et al., 2020). Furthermore, while there is agreement that using less complex language is preferable, there is also the threat that using simplified language can lead to misinterpretations (Rice & Giles, 2017; Wong-Parodi & Strauss, 2014). Prior studies considering the complexity of language on social media platforms have measured complexity manually (Dalyot et al., 2022) or automatically (Hubner & Bond, 2022).

Like language complexity in science communication, data and infographic usage is also a double-edged sword. On the one hand, using visualizations has many benefits, such as increasing information recall and evoking more favorable attitudes towards an issue (Lee & Lee, 2022), and its potential has been recognized for science communication (Rodríguez Estrada & Davis, 2015; Ynnerman et al., 2018). On the other hand, using complex data visualization can lead to misunderstandings (Wong-Parodi & Strauss, 2014), and there may be various reasons why users choose to engage or not with data visualizations (Kennedy et al., 2016).

The potentially ambivalent role of emotions in science communication has been critically discussed in prior research (Taddicken & Reif, 2020). For example, fear appeals can increase attention to scientific issues (Lidskog et al., 2020) and lead to the intended emotional responses (Ettinger et al., 2021). Furthermore, from general Twitter research, we know that emotional messages are shared more often (Stieglitz & Dang-Xuan, 2013), a finding that also holds in political communication on Facebook (Keller & Kleinen-von Königslöw, 2018).

Humor as a specific communication style might be especially effective on social media platforms. For example, research on political communication (Keller & Kleinen-von Königslöw, 2018) and marketing research (Ge & Gretzel, 2017) have highlighted the role of humor in communication on social media platforms. The role of humor in science communication has also been analyzed. For example, scientists have used humor on Twitter to talk about their research (Simis-Wilkinson et al., 2018). In addition, research has shown that using humor on Twitter can positively influence messages' engagement levels (Su et al., 2022) and lead to a more positive evaluation of the communicator (Yeo et al., 2021).

Lastly, research has shown that scientists on Twitter also talk about political issues (Jünger & Fähnrich, 2020). In addition, many scientists use Facebook in their non-professional roles (Collins et al., 2016; McClain, 2017). But even for persons with a professional background, personal self-disclosure can be a viable communication strategy. Research on political communication on Facebook has shown that the use of personal self-disclosure can lead to higher user engagement levels (Keller & Kleinen-von Königslöw, 2018). However, Zhang and Lu (2022) showed in their experiment in the US context that personal self-disclosure on Twitter decreases the audience's perception of scientists' competence while at the same time increasing their likability.

Overall, we are interested in the following general research question: To what extent do the three forms of user engagement—likes, shares, and comments—

contribute to the effectiveness of scientists' communication on Facebook?

2.3. Science Communication in Taiwan

Survey research in Taiwan has shown that Taiwanese scientists are less mediatized than their counterparts in Germany (Lo & Peters, 2015) and that public engagement mainly happens at face-to-face events (Lo, 2021). The state of science journalism has been described in the past as concerning (Huang, 2014). The coverage of scientific issues is often done sensationally and potentially leads to misunderstandings, instead of a better-educated public. The lack of good science journalism in the mainstream media is among the reasons why many scientists have become active as bloggers on the internet (Cheng, 2014), and platforms such as *Pansci* were developed. The platform offers its own podcast and has a social media presence on every major social media platform (Shih, 2016). Even though there are good-quality science media in Taiwan, some of them are on the verge of going out of business, such as the Mandarin version of *Scientific American* and *Newton Magazine*, whereas *Young Scientist Monthly* has ceased publication (Xu, 2018). In Taiwan, the quality of journalism is generally a problem (Rauchfleisch & Chi, 2020; Rauchfleisch et al., 2022) that is also indicated by the low level of trust in the news (27%; Newman et al., 2022). Besides the messenger app Line, Facebook is the leading social media platform for news consumption (Shih, 2021). In contrast, Twitter does not appear in the list of the top six social media platforms (Newman et al., 2022). While Twitter has an essential role in many Western countries, and also for most international scientists, Taiwan is a peculiar case of science communication with Twitter being given low importance.

3. Data and Methods

To answer our research question, we collected Facebook data from the Crowdtangle platform. In our analysis, we focused on pages of individual scientists and collaborative pages run by a collective of scientists. We limited our sample in this study by only focusing on academic actors (scientists with an academic affiliation) and did not analyze professional science communicators who were not actively conducting research.

For the sampling, we started with broad disciplinary fields (e.g., social sciences, natural sciences, humanities). Besides the most-well known accounts (e.g., 陳建仁 Chen Chien-Jen, a scientist and the former vice-president of Taiwan), we identified pages for our sample with different approaches. First, we searched for the names of prominent scientists that often appear in the media. Secondly, we searched for Facebook pages that mentioned disciplines as a keyword (e.g., sociology). Thirdly, we searched for pages that mentioned "professor" (教授) as a keyword. In the last step, we checked the page recommendations shown when we added the pages identified on Crowdtangle to a dashboard. During our search, we found many public accounts of scientists that were not public pages and thus could not be included in our analysis. Furthermore, we excluded institutional academic pages as well as inactive accounts that had not published at least one post within the previous year. We did not aim to have a complete sample of all academic researchers in Taiwan on Facebook with public pages, but we ensured that we included a few pages for each of our disciplinary categories.

Our sample covered a wide range of disciplines and pages with different levels of reach in terms their number of fans (min. = 443; max. = 257,088). Thus, we had a mix of prominent and smaller pages by researchers. After filtering the pages according to the above-described criteria, we ended up with a sample of 35 unique pages (see the Supplementary File for an overview). Our sample covered various disciplines (humanities = 4, law = 2, medical and health = 11, social sciences = 11, STEM = 7), and there was a mix of individual (n = 29) and collective (n = 6) pages.

We then downloaded all the posts published on these 35 pages between 1 January 2020 and 31 May 2022. Based on the 13,146 posts, we created a stratified sample by taking either all a page's posts if that page had published fewer than 50 posts or a random sample of 50 posts per page. This approach gave us a final sample of 1,429 posts, which were used for the manual content analysis. Due to the stratified approach, this sample gave us enough power to detect even minor effects and capture enough diversity within each page. After dropping posts without textual content or any information that could be coded, we had a final sample of 1,248 posts.

The codebook was developed by all the authors in collaboration. For the content analysis, three of the authors coded the Facebook posts. All three coders were native Chinese speakers, had a background in journalism, and had different academic backgrounds (humanities, natural sciences, and social sciences), covering the diversity of the pages included in our study.

We added the factors discussed in the literature review to our codebook (for more extended definitions, see the codebook in the Supplementary File). First, self-promotion is essential for scientists using social media (Yuan et al., 2022). With the variable Promotion, we captured all posts that were done to promote any lecture, talk, podcast, or journal paper. As the level of complexity can hinder successful science communication (August et al., 2020; Mueller-Herbst et al., 2020; Wong-Parodi & Strauss, 2014), we coded the level of complexity (Sung et al., 2013) on a 10-point scale (1 = *extremely simple*; 10 = *extremely complex*). Since there is no universally agreed definition of complexity, we used the rather general definition of "features making a communicative task more or less complex" (Pallotti, 2015, p. 117). Additionally, we coded if any form of science-related statistics was reported

(including simple percentages), infographics or data visualizations were used, or if there was a direct reference to a scientific source (e.g., journal article). For the emotional variables, we used Scaremongering (at least one sentence had to include a strong expression) as well as Humorous. Scaremongering was coded when a post used language that strongly emphasized dangers (Ogbodo et al., 2020). We coded a post as Humorous if at least one sentence included a form of humor (including sarcasm) or a (visual) meme was used. For calls to action and audience engagement, we adopted two variables from Keller and Kleinen-von Königslöw (2018). We coded a Call to Action if there was a direct call to do something related to the page (page owner). Audience engagement is related to what Keller and Kleinen-von Königslöw (2018) called pseudo-discursive style. We coded Audience Engagement if the audience was directly addressed in the post, including questions directed at the audience (e.g., asking for their opinion) or asking the audience to like, share, or comment on a post. We also included Personal Self-Disclosure as a variable. Keller and Kleinen-von Königslöw (2018) called this variable privatization, which captures if a post contains details from a person's private life. More specifically, in the science communication context, Zhang and Lu (2022) defined personal self-disclosure as the "sharing of personal interests, hobbies, and other non-science-related information" (p. 3). Lastly, since prior research has shown that scientists often comment on political issues or research in general on social media (Jünger & Fähnrich, 2020), we included the variable Opinion. We coded this variable when an opinion about any political or science-related issue was mentioned.

After creating a codebook covering all potential predictors (for an overview, see Table 1 here and the codebook in the Supplementary File), we ran three rounds of test coding (n = 20; n = 50; n = 60). While the majority of variables received high intercoder reliability in the first round, we discussed bad-performing variables. Eventually, we dropped broad variables such as Personalization, since we conceptually captured it with Personal Self-Disclosure, a variable that stands for a specific form of personalization. Almost all variables reached a Krippendorff's alpha of 0.7 (n = 60). Only the Opinion (0.65) and Sentiment (0.62) scores, as rather complex variables, were lower. We additionally validated the complexity measurement with an automatic classifier based on the measures used by education scientists to assess the difficulty of textbooks in traditional Mandarin (Sung et al., 2013). Over the complete sample, the human-coded 10-point complexity scale with the automatic complexity classification reached an alpha of 0.67. This result indicates that our scale was conceptually very similar to that developed in the educational context to measure the readability of textbooks. We also considered an automatic topic classification of posts but dropped this approach because the identified topics represented the pages' disciplinary focus, which had already been captured by the discipline variable.

For our analysis, we relied on Bayesian regressions that we estimated with the *brms* package in *R*. Because our data were nested with posts nested in pages and in disciplines, we used varying intercepts for both pages and disciplines. Not considering the nested structure of our data would have yielded biased estimates. For example, since it was plausible that some disciplines would

Table 1. Overview of all variables measured in the content analysis.

Variable	*M* (*SD*)
Science-related	74.60%
Statistics	9.50%
Infographic/data visualization	7.20%
Science source	13%
Humorous	14%
Scaremongering	5.40%
Audience engagement	5.80%
Call to action	19.60%
Promotion	54.20%
Personal self-disclosure	10.90%
Opinion	21.20%
Sentiment (−3 = *negative*; 3 = *positive*)	0.31 (1.06)
Complexity (1 = *extremely simple*; 10 = *extremely complex*)	3.04 (1.77)
Likes	757.78 (2,905.86)
Shares	63.93 (464.01)
Comments	26.78 (128.60)

Note: Based on all relevant posts (N = 1,248).

receive more public attention on average, the varying intercept would account for these differences. The same holds true for pages. Some pages, even if we considered all the variables in our model, including the second-level variable number of followers, receive on average more attention. The varying intercepts captured this variation on the page level. We opted for Bayesian models because they are often more robust than frequentist multilevel models (Stegmueller, 2013). Furthermore, while frequentist p-values and confidence intervals are often misinterpreted (Morey et al., 2016), Bayesian credible intervals can be directly interpreted as the 95% probability that the true value is within the interval. For all three models, we used four chains, each with 4,000 iterations in total and 1,000 iterations for burn-in. The chains all converged, and the Rhat scores were all 1. Sentiment and Complexity were scaled before being used in the models.

4. Results

As the three outcome variables were count data, we used negative binary regression models to answer our research question (see Table 2). For all three models, we used the same set of predictors. The number of followers as well as the collective page as page type were both entered as level 2 variables into the model since they were measured on the page level.

The first model showed that including an infographic or a data visualization led to more likes (IRR = 1.46, 95% CI [1.21, 1.76]). Using scaremongering expressions (IRR = 1.3, 95% CI [1.07, 1.59]) or expressing a personal opinion (IRR = 1.14, 95% CI [1, 1.30]) also increased the chance of receiving likes. While using language to encourage audience engagement (IRR = 0.79, 95% CI [0.64, 0.97]) or promoting something (IRR = 0.82, 95% CI [0.73, 0.92]) made it less likely to receive likes, sharing some private information (IRR = 1.34, 95% CI [1.16, 1.57]) increased the chance of receiving likes. Interestingly, using more complex language led to more likes (IRR = 1.16, 95% CI [1.09, 1.23]). Lastly, having more page followers increased the chance of receiving likes (IRR = 3.23, 95% CI [2.23, 4.65]).

For shares, we observed similar results as for likes. Using an infographic (IRR = 2.26, 95% CI [1.68, 3.02]), scaremongering expressions (IRR = 1.74, 95% CI [1.31, 2.39]), or more complex language (IRR = 1.46, 95% CI [1.33, 1.61]) all made it more likely that a post was shared. Additionally, sharing personal opinions or science-related information increased the chance of it being shared. However, sharing private information (IRR = 0.73, 95% CI [0.52, 0.93]) or something negative (IRR = 0.92, 95% CI [0.84, 0.99]) decreased the chance of it being shared. At the page level, our analysis showed that the more followers a page had, the more

Table 2. Negative binomial regression models for the outcome variables of likes, shares, and comments.

	Likes		Shares		Comments	
	IRR	CI (95%)	IRR	CI (95%)	IRR	CI (95%)
Intercept	148.46*	69.38–345.74	6.65*	2.96–16.24	5.57*	2.31–13.19
Science-related	1.08	0.95–1.22	1.36*	1.12–1.67	0.90	0.71–1.14
Statistics	0.95	0.82–1.11	1.08	0.85–1.39	0.95	0.69–1.34
Infographic/data visualization	1.46*	1.21–1.76	2.26*	1.68–3.02	1.63*	1.12–2.38
Science source	0.91	0.79–1.06	0.90	0.72–1.20	0.71*	0.53–0.96
Complexity	1.16*	1.09–1.23	1.46*	1.33–1.61	1.11	0.99–1.25
Sentiment	1.04	1.00–1.10	0.92*	0.84–0.99	0.90*	0.82–1.00
Scaremongering	1.30*	1.07–1.59	1.74*	1.31–2.39	1.53*	1.06–2.23
Humorous	1.14	1.00–1.30	1.10	0.90–1.37	1.62*	1.26–2.10
Audience engagement	0.79*	0.64–0.97	0.88	0.61–1.27	1.64*	1.06–2.57
Promotion	0.82*	0.73–0.92	0.99	0.83–1.21	0.82	0.65–1.03
Call to action	1.04	0.91–1.20	1.04	0.82–1.30	0.85	0.64–1.14
Personal self-disclosure	1.34*	1.16–1.57	0.73*	0.52–0.93	1.76*	1.32–2.36
Opinion	1.14*	1.00–1.30	1.35*	1.10–1.67	1.06	0.83–1.36
Science collective page	0.88	0.35–2.13	2.00	0.73–6.00	0.85	0.24–2.90
Page followers	3.23*	2.23–4.65	2.57*	1.68–3.93	2.86*	1.75–4.65
n pages	35		35		35	
n disciplines	5		5		5	
n	1,248		1,248		1,248	
Bayes-R	0.67		0.54		0.35	

Note: Incidence rate ratios are shown with 95% CI; an asterisk (*) indicates that the 95% CI does not include 1.

likes its posts received on average (IRR = 2.57, 95% CI [1.68, 3.93]).

In our third model, we used the number of comments as the outcome variable. Again, using an infographic or data visualization (IRR = 1.63, 95% CI [1.12, 2.38]) increased the chance of receiving comments. Likewise, sharing private information (IRR = 1.76, 95% CI [1.32, 2.36]), adding humor (IRR = 1.62, 95% CI [1.26, 2.10]), or using scaremongering expressions (IRR = 1.53, 95% CI [1.06, 2.23]) made it more likely to receive comments. On the other hand, the more negative a post, the less likely it was that the post received comments (IRR = 0.90, 95% CI [0.82, 1]). Also, having a direct reference to an academic publication in the post led to fewer comments (IRR = 1.14, 95% CI [1.06, 1.24]). The number of page followers was also one of the strongest predictors for the number of comments a post would receive (IRR = 2.57, 95% CI [1.68, 3.93]).

5. Discussion

Over the years, the development of science communication in Taiwan has evolved from the early stage of "science popularization" to "public understanding of science" and then to the idea of public communication, namely "public engagement with science and technology," which emphasizes that science in society should abandon the one-way communication model and instead adopt a two-way dialogue (Chin et al., 2015; Huang, 2022). However, there are still challenges for science communication in Taiwan, such as low public participation, over-dependence on translated science news, and concern about misinformation when audiences pay attention to individuals instead of science media (Huang & Lo, 2022). Our analysis shows that many of the measured variables are substantial predictors of audience engagement levels. While we identified overall many substantial predictors that more or less indicated the same relationship for all three outcome variables, we also noted some predictors that were not the same for each of them. For example, sharing private information in a post led to more likes and comments while also making it less likely that a post would be shared. A closer reading of social media posts with personal self-disclosure confirms these findings from the quantitative content analysis. Indeed, posts with personal self-disclosure usually include pictures from traveling (e.g., a visit to Disneyland) or of food, family members, and pets. Thus, scientists still sometimes deviate from their professional role and show themselves as regular users with private lives and hobbies (Collins et al., 2016; McClain, 2017). Somehow related to personal self-disclosure is sharing opinions about political issues that are sometimes not even connected to the scientist's research background. However, unlike personal self-disclosure, posts with personal opinions led to more shares. These results show that personal opinions about current affairs can strategically increase a page's reach (more shares) and potentially recruit new followers, whereas personal self-disclosure helps to engage the existing audience since it leads mainly to more likes and comments.

There is a need for further investigation of the potential negative and positive impacts of personal self-disclosure on scientists' perceived competence. Zhang and Lu (2022) found that personal self-disclosure can lower perceived competence. However, this may not necessarily be the case when scientists, such as those in our study, are already well-known or have become more familiar to their audiences through their Facebook pages. Future research should take this into account and examine the role of gender, which has been shown to affect user reactions on social media platforms such as Facebook (Dalyot et al., 2022) and Instagram (Jarreau, Cancellare, et al., 2019). It is still an open question whether gender influences the impact of self-disclosure on perceived competence.

Emotional content also can lead to higher user engagement levels, with scaremongering a substantial predictor for all three outcome variables and Humor only for comments. This finding confirms the findings from prior research on Twitter (Su et al., 2022). It also shows that emotionalized content can indeed increase communication reach (Taddicken & Reif, 2020).

The most counterintuitive result was the substantial positive effect of language complexity. While the complexity of language has traditionally been described as a significant challenge in science communication that potentially hinders successful communication (Rice & Giles, 2017; Wong-Parodi & Strauss, 2014), our study shows that the higher the complexity in a post, the higher the user engagement levels overall. One possible explanation for this could be self-identity as the user's motivation. Prior research in Taiwan has shown that self-identity correlates with the sharing of science-related information (Shih, 2016). Another potential explanation could be cultural factors, as Taiwan is a rather peculiar case that challenges many findings from the Western context (e.g., Shein et al., 2014). Last but not least, previous research has shown that the use of visualization for interpretation, explanation, and persuasion by science communicators has become an important technique and skill in Taiwan (Lee & Huang, 2018). In our study, we also observed an overall positive effect for infographics and visualizations, which can be explained by the increasing use of data visualizations during the Covid-19 crisis and also is in line with positive results from experimental studies (Lee & Lee, 2022).

Chin et al. (2015) indicated that the communication skills of Taiwanese scientists are an important key to the realization of the "citizen scientist" and "open science." To reach these goals, the factors mentioned above could be helpful for Taiwanese scientists to better communicate with their readers and further expand their potential audience reach via Facebook.

6. Conclusion

Our findings are important in the context of the current debate on alternatives to Twitter. While some scientists have migrated to Mastodon, it is not yet a platform that is used by the general public. Therefore, if the goal is to reach a wider audience beyond just peers, Facebook may be a viable alternative to Twitter. Our study shows that science communication can be successful on Facebook and that different strategies can be combined to achieve different communication goals. For science communication practitioners and scientists on Facebook, this shows that the best communication strategy is probably to use a communication mix that tries to attract new followers by creating posts that are widely shared and include opinions on current issues and posts that use humor or personal self-disclosure as a communication style to engage the existing audience. We also show that the complexity of issues and language and the sharing of data visualizations can have positive effects. However, this is also one of the main limitations of our study. We cannot satisfactorily explain why people engage with content on Facebook. Furthermore, we also have no precise information about the audiences that follow these pages. However, at least from reading some of the comments that posts received, we know that many active followers are regular citizens, and the primary goal of scientists with public pages does not seem to rest on peer-to-peer communication with other scientists. Still, we did not include the content of the comments that the posts received in our analysis. Future research should focus specifically on the users following these pages and could also use experiments to test some of the findings in our study (cf. Zhang & Lu, 2022). Lastly, future studies could include other science communicators on Facebook without a direct academic connection and use comparative research designs that compare different platforms (e.g., Su et al., 2022) or countries.

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Conflict of Interests

The authors declare no conflict of interest.

Supplementary Material

Supplementary material for this article is available online in the format provided by the author (unedited).

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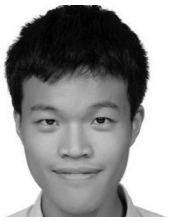

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Article

Women Scientists on TikTok: New Opportunities to Become Visible and Challenge Gender Stereotypes

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Abstract
Today, women scientists are still underrepresented in media coverage and confronted with gender stereotypes. However, social media might have the potential to challenge current gender stereotypes of scientists, foster diversity in science communication, and open new ways of becoming visible. We explore this potential by analyzing TikTok accounts of female scholars (*n* = 50 accounts). Results from content analysis (*n* = 150 videos) indicate that female scientists from a wide range of different disciplines and at different career stages are visible on TikTok. Building on previous research, we show that female scholars use TikTok mainly to explain scientific facts and concepts and to discuss what being a (female) scholar is like. Moreover, female scholars talk about private life events, give expert advice, and show science in the making. Finally, some of the videos analyzed address gender stereotypes by, for example, challenging assumptions on how a female professor should dress. Implications for science communication in the digital age are discussed.

Keywords
female scholars; gender stereotypes; science communication; social media; TikTok

Issue
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1. Introduction

"Professor Ciesek, since September you can be heard every second week alternating with Christian Drosten on the NDR podcast Coronavirus Update. Are you aware that you're the quota woman?" (Hackenbroch & von Bredow, 2020). This was the first question asked by the German Weekly *Der Spiegel* in an interview with the renowned virologist Prof. Sandra Ciesek, Director of the Department of Medical Virology at the University of Frankfurt. In the next question, Prof. Ciesek was asked how it is to be "the new one by Drosten's side," referring to her new role as expert in the podcast hosted by NDR (Norddeutscher Rundfunk; Hackenbroch & von Bredow, 2020). The podcast was launched in February 2020 with the male virologist Prof. Christian Drosten, with Prof. Sandra Ciesek joining in September 2020. Although both virologists showed similar qualifications in their research field, the way they were interviewed by the weekly magazine notably differed. While the former was lauded as a "popstar" the latter was referred to as "the quota woman." This interview, followed by a heated debate on Twitter where users criticized the journalists for asking sexist questions, is an excellent example for illustrating the problems female scientists are still facing when appearing in their roles as scientific experts in media coverage.

Not only is it irritating and offensive for women scientists when being portrayed in a stereotypical way, this also has the potential to discourage other female scientists from stepping onto the media circuit. Indeed, women scientists are underrepresented in newspaper coverage (Aladro Vico et al., 2014; Kitzinger et al., 2008; Niemi & Pitkänen, 2017). This is also true for

portrayals of scientist characters on TV: Male scientists significantly outnumbered and appeared in many more scenes than their female counterparts (Long et al., 2010). Researchers have found that media outlets focus on female scientists' exceptional status (Chimba & Kitzinger, 2010) and are more likely to report on appearance (clothing, physical characteristics, or hairstyle, for example) when writing about female scientists than when portraying male ones (Kitzinger et al., 2008).

In recent years, scientists have begun to increasingly make use of social media (Collins et al., 2016; Jia et al., 2017; Peters et al., 2014; You, 2014; Yuan et al., 2017). Jarreau et al. (2019) argue that social media has the potential to challenge and overcome stereotypes. By using hashtags such as #womenalsoknowstuff and #distractinglysexy, women scientists have used social media as a tool of empowerment and protest (Brantner et al., 2019). Following this line of research, our study aims at exploring women scientists' visibility on social media. We focus on TikTok, a platform on the rise and one that has not yet been researched in this context. By doing so, we (a) analyze *who* becomes visible on TikTok in terms of disciplines and career stages, and (b) examine whether women scientists are using the platform to challenge current *gender stereotypes*.

2. Literature Review: Visibility and Gender Stereotypes

2.1. Visibility of Female Scholars

Women scientists are underrepresented in public discourses, as evidenced by studies investigating media coverage in so-called "western" countries such as the US or in many European nations. Kitzinger et al. (2008), for instance, analyzed science coverage in 12 UK national newspapers over a six-month period and found that male expert scientific sources are much more often cited than women; from a total of 644 quotes, 84% stem from men and only 16% from women scientists. Aladro Vico et al. (2014) found a similarly low proportion when they evaluated Spanish newspaper coverage, where only 14% of the news stories they examined focused on female scientists. A recent study from Finland indicates that public expertise continues to be male-dominated in that only 28% of all experts interviewed in the news are female (Niemi, & Pitkänen, 2017). Similar patterns can be observed when it comes to television output: A content analysis of German TV programs revealed that 79% of experts were male (Prommer & Linke, 2019), and a study investigating Israeli talk shows found that 63% of the featured experts were male (Hetsroni & Lowenstein, 2014). When looking specifically at *scientific* experts on TV, the figures are even more striking—out of all the scientific experts visible on German TV news, 81.5% were male (Nölleke, 2013).

The underrepresentation of female scientists in the media has been deemed problematic from three perspectives (Crettaz von Roten, 2011): (a) From a career perspective, because public outreach is becoming increasingly important for scientific careers; (b) from a democracy-oriented perspective, a more diverse picture of scientific experts in the media would improve the quality of the discourse; (c) from an educational perspective, a greater visibility of female scientists in the public sphere allows more role models to be seen by young people—"If young people do not see women articulating science, the impression will be that women don't do science" (Manaster, 2013). Following this line of argument, it is vital that female scholars from different disciplines become visible. TikTok—as a platform targeted mainly at young people—might have a key role to play here. Accordingly, we are interested in exploring which female scholars become visible on TikTok, and pose the following research question:

> RQ1: Which female scholars are visible on TikTok in terms of disciplines (RQ1a) and career stages (RQ1b)?

2.2. Visibility of Topics

Visibility on social media has the potential to increase diversity in science communication because scientists are free to choose how they want to present themselves and what to talk about (Metag, 2021). Scientists develop different strategies for shaping their discourse practices in digital communication environments (Koivumäki et al., 2020), and emotional appeals and "edutainment"-oriented approaches in science communication are seen as having the potential to enable communicators to reach new audiences (Taddicken & Reif, 2020). Zawacki et al. (2022) argue that TikTok may function as a platform where educational science videos are able to reach a large audience without much effort. Habibi and Salim (2021) found that short lecture-style videos on TikTok had a significantly higher "watch time" compared to longer lecture-style or experimental videos. When it comes to the topics scientists talk about on social media, the boundaries between work and private life are blurring since many scientists use social media accounts for sharing both personal and professional information (Bowman, 2015). Zhang and Lu (2022) argue that scientists engage in two types of content—related self-disclosure on social media: professional self-disclosure ("the sharing of professional experiences and research related to a scientist's career," p. 3) and personal self-disclosure ("the sharing of personal interests, hobbies, and other non-science-related information," p. 3); they also point out that it matters which topics scientists decide to talk about on social media. More specifically, scientists tend to be rated as more likable when they share personal information but also as less competent. Conversely, when scientists disclose professional information, they are perceived as more competent and also as more engaging. Recent research suggests that, on TikTok as well, scientists tend to communicate both professional as well as personal information (Zeng et al., 2021).

TikTok is one of the fastest-growing social media platforms, with more than a billion users worldwide (TikTok Newsroom, 2021). TikTok has been headline news several times due to its dance routines (Page, 2020) or because of privacy concerns (Ovide, 2020). However, it is only now that the platform has started to receive scholarly attention in the field of communication studies (Hautea et al., 2021; Vázquez-Herrero et al., 2020; Zeng et al., 2021). There is hence a need to explore TikTok as a new channel for science communication. TikTok has specific features—such as a short format, community-building tools, and a so-called "duet function"—that seem to encourage a particular kind of science-oriented communication: highly visual, vernacular, and meme-friendly (Zeng et al., 2021). TikTok features such as searching, meta-voicing, livestreaming, and recommending are designed to impact users' experiences (Song et al., 2021), and creators on the platform experiment with these features by mixing, blending, and subverting content (Literat & Kligler-Vilenchik, 2019). TikTok's users are "algorithmically, digitally, and socially encouraged to consume content conducive for imitation and for the purpose of imitation" (Zulli & Zulli, 2022, p. 1884). Schellewald (2021) adds that TikTok creators use a range of communicative tropes and formats such as comedy, documentary, videos co-created with partners, family, and friends, challenges by means of the duet function, tutorials, and "life hacks." Platform characteristics like visibility, editability, and association make TikTok an especially fascinating case for research into science communication (Hautea et al., 2021).

At the same time, social media is also a space where women face hostility and misogyny (e.g., Alvares, 2018; Chen et al., 2020; Gardiner, 2018; Ging & Siapera, 2018; Han, 2018; Henry & Powell, 2016; Mantilla, 2013; Marwick & Caplan, 2018; Simões & Silveirinha, 2019). This is also the case for female scholars (Veletsianos et al., 2018; Vera-Gray, 2017). Online harassment of women has been discussed as a way of excluding women's voices from the digital public sphere (Megarry, 2014), or silencing their voices on certain topics. In one interview-based study, for example, Carter Olson and LaPoe (2018) found that "women and minority academics' fear of harassment online leads to self-censorship, creating a digital spiral of silence" (p. 271). Indeed, research has pointed to a notable gender gap in terms of the visibility of bloggers (Harp & Tremayne, 2006; Meraz, 2008; Pederson & Macafee, 2007). Similarly, researchers have also identified a gender imbalance when it comes to content providers on YouTube (Döring & Mohseni, 2018; Khan, 2017; Tucker-McLaughlin, 2013; Welbourne & Grant, 2016). Amarasekara and Grant (2019) analyzed science communication accounts on YouTube and found that only 32 of the 391 most popular YouTube channels focusing on STEM (science, technology, engineering, and mathematics) subjects were hosted by women. These accounts were found to garner noticeably more hostile, negative, and sexist comments than accounts hosted by men. Döring and Mohseni (2020) observed that female YouTubers received more sexist, racist, and sexually aggressive hate comments. To sum up, "Online spaces remain a double-edged sword for women, not only providing opportunities for self-expression but also making them vulnerable to abuse" (Eckert, 2018, p. 1284). Duffy and Hund (2019, p. 4983) refer to the "vexed nature of visibility" on social media. In line with this argument, TikTok can be conceptualized as an ambiguous digital space for women scientists. What Thompson (2005) formulated for political actors might also be true for scientists; they might be "more closely scrutinized than they ever were in the past; and at the same time, they are more exposed to the risk that their actions…may be disclosed in ways that conflict with the images they wish to project" (p. 42). Given this ambiguity inherent in the nature of social media as a digital space with silencing strategies like hostility and misogyny, but also acknowledging its potential for enabling and empowering, a key research focus here is on how women scientists express themselves in terms of what topics they talk about:

> RQ2: Which *topics* do female scholars talk about in the TikTok videos analyzed for this study?

2.3. Gender Stereotypes

Alongside the underrepresentation of women scientists in media coverage, stereotypical portrayals of women scientists in the media are increasingly being seen as problematic. In the field of psychology, gender stereotypes come in many shapes and forms (for an overview, see Cejka & Eagly, 1999; Deaux & Lewis, 1984; Diekman & Eagly, 2000; Schneider & Bos, 2014): physical stereotypes, cognitive stereotypes, and stereotypes related to personality. While for men, physical stereotypes include attributes such as muscular, physically strong, and burly, those for women are cute, gorgeous, and beautiful. When it comes to cognitive stereotypes, men tend to be characterized as good with numbers, analytical, good at problem-solving, or quantitatively skilled. Cognitive stereotypes for women are imaginative, intuitive, artistic, and creative. For women, "positive" stereotypes relating to personality include affectionate, sympathetic, gentle, and sensitive, and those for men are competitive, daring, adventurous, and aggressive. "Negative" personality traits for women include spineless, gullible, servile, subordinating self to others, whiny, complaining, nagging, and fussy, while those for men include egotistical, hostile, cynical, arrogant, boastful, greedy, dictatorial, and unprincipled. Ellemers (2018) argues that, whereas stereotypes in general and gender stereotypes in particular may be helpful when someone is evaluating certain perceived properties of large groups, they are ill-suited to assess the characteristics of individuals:

> Gender stereotypes exaggerate the perceived implications of categorizing people by their gender and

> offer an oversimplified view of reality. They reinforce perceived boundaries between women and men and seemingly justify the symbolic and social implications of gender for role differentiation and social inequality. The broad awareness of gender stereotypes has far-reaching implications for those who rely on stereotypical expectations to evaluate others, as well as those who are exposed to these judgments. (p. 278)

In the literature, stereotypes have often been discussed in relation to the roles that women and men are expected to play in "society." Hentschel et al. (2019) argue that "the persistence of traditional gender stereotypes is fueled by skewed gender distribution into social roles" (p. 3). When it comes to stereotypes for scientists, research using the "Stereotype Content Model" (Fiske et al., 2002) is relevant. This model presupposes that stereotypes are ascribed along two dimensions: perceived warmth and competence. "Traditional" women are, for instance, stereotypically perceived as warm but incompetent, and "professional" women as competent but cold (Fiske, 2010). Fiske and Dupree (2014) asked an American online sample of adults to rate warmth and competence in terms of how the respondents believed these applied to people working in particular jobs (from a list of 42 occupations). Results show that while some jobs such as nurses, teachers, or doctors were rated as being warm, trustworthy, capable, and competent (high-warmth, high-competence profession), scientists and researchers earned respect but were not necessarily trusted (high-competence, low-warmth profession). Respondents reported feeling sentiments of envy and jealousy toward people in this group, which also included lawyers, managers, engineers, and accountants. Interestingly, professors or teachers were perceived as generally "warmer" people than scientists or researchers.

Media outlets in many western countries tend to present male scientists more often as protagonists and women as a visual resource (González et al., 2017), are more likely to report on appearance (clothing, physical characteristics, or hairstyle) when writing about female scientists than when portraying male scientists (Kitzinger et al., 2008), and tend to focus on female scientists' exceptional status (Chimba & Kitzinger, 2010). Mitchell and McKinnon (2019) analyzed the profiles of scientists published in *The New York Times* and found that profiles of female scholars were more likely to mention relationship status (92% for females, 63% for males) and parenthood status (67% for females, 32% for males). Cheryan et al. (2013) suggest in their experimental study that stereotypical portrayals of scientists negatively affect young women's interest in the discipline portrayed. More specifically, college students at two US universities read newspaper articles about computer scientists that depicted the latter either as fitting the current stereotypes or no longer fitting these stereotypes. Female students who read that computer scientists no longer fit the stereotypes showed higher levels of interest in computer science than female students who read the version of the article where computer scientists continued to fit the stereotyped portrayal. Hence, overcoming stereotypes seems to be a crucial step in fostering young women's interest in science.

Research indicates that social media can be both a space where gender stereotypes are reproduced as well as one where they can be challenged. While Bailey et al. (2013) argued that young women perceive social media as a "commoditized environment in which stereotypical kinds of self-exposure by girls are markers of social success and popularity" (p. 91), they also identified initiatives to counter gender stereotyping. Referring to viral hashtags such as #distractinglysexy, Morrison (2019, p. 23) speaks of an "emerging mode of online resistance" where social media is used to gain wide-ranging visibility, hashtags for grass-roots collective action are created, content is spread virally, and humor is deployed to destabilize the institutionalized images painted by dominant groups. Brantner et al. (2019) resume that by using "unstereotypical self-stereotyping," women scientists created networked counter-publics on social media that also managed to get wide attention in traditional media discourses. So, while some users may still be conforming to (apparent) norms and disseminating stereotypes and clichés when they interact in digital spaces, counter-discourses are also springing up (Wilhelm, 2021). Building on this line of research, we are interested in exploring whether women scientists are using TikTok to challenge gender stereotyping:

> RQ3: To what extent do female scholars in the TikTok videos analyzed here counter or challenge current gender stereotypes?

3. Methods

3.1. Sample

To answer our research questions, we analyzed accounts of female scholars on TikTok. We applied two strategies to identify relevant accounts: (a) we searched by using hashtags such as #academia, #academicsoftiktok, #academictiktok, #phd, #phdlife, #phdstudent, #postdoc, #professor, #professoroftiktok, #research, #scicomm, #science, #sciencetiktok, #scientist, #socialscience, #womeninscience, #womeninstem, etc.—we started by using these hashtags and added relevant additional hashtags we encountered during our search; (b) we followed links on these accounts to other accounts. In order to be able to code the videos ourselves, we only selected English- or German-speaking accounts.

All accounts where it became obvious that women were currently involved in science were included. Having a current university affiliation was not necessary for being included in our sample (for instance, not all PhD students are employed at a university). People who

had completed a university degree and moved to a different sector afterwards were excluded (e.g., coaches). We were able to identify 113 accounts. After excluding 12 accounts whose protagonists did not create their own videos, had a private account, or were no longer working in academia or in some other type of research institute, our list ended up with 101 accounts. We sorted the accounts according to the number of followers and selected the top 50 accounts (see Table 1). In the next step, we selected the three most viewed videos from the most recently posted 12 videos (the number of videos that could be viewed at a glance on the screen) on each account, which resulted in the final sample (n = 150 videos).

3.2. Measurement

We developed a coding scheme consisting of 20 categories. The coding scheme included formal categories (ID, coder name, account name, number of followers, number of videos, number of likes, number of views, etc.) and content-related categories (e.g., scientific discipline, career stage, topic, gender stereotypes).

We used two categories to code the discipline of TikTok creators: (a) An open category in order to classify the specific discipline (e.g., psychology, biology, chemistry), and (b) a closed category. For the closed category, we coded whether the discipline belonged to natural sciences or social sciences and humanities. Similarly, for capturing the career stage of female scholars, we used (a) an open category where we included the current position held by the person who created the posted content, and (b) a closed category where we assigned it to one of three levels of educational attainment (or career stage), namely—(a) PhD, comprising all creators who were currently doing their PhD or who had completed it, (b) professor or assistant professor, or (c) others. While some scholars indicated this information on their TikTok account, for others it was available when following the link tree on TikTok, and for some we consulted their professional website. Building on prior research (Zeng et al., 2021), we coded the topic of the video according to the following scheme: (a) Science in the making—videos showing experiments being done or do-it-yourself (DIY) activities in the name of science; (b) facts, concepts, phenomena explained—videos of someone presenting facts or explaining a science phenomenon; (c) expert advice/opinion—whereas the previous category comprises videos that featured scientists explaining something, this code was assigned when the content seemed to go beyond explaining something in the form of advice to the public or giving advice from a position of expertise; (d) being science students/teachers/scientists—videos showing the "behind the scenes" life of a science teacher or researcher—for example, videos of science students in school reflecting on their experience of studying science; (e) private life—family, friends, personal stories, personal (not job-related) problems and hobbies; (f) others—for all content that did not fit the other five classifications of content. In addition, we used an open category where we summarized the content of the video in our own words. When a TikTok creator talked about gender stereotypes an open category was used to capture the content in detail. In addition, a closed category was used to code whether this was the case (yes or no).

To assess inter-coder reliability, two coders coded the same 10% of material. Reliability between the two coders was calculated using Cohen's kappa. All formal categories reached perfect agreement (Cohen's kappa = 1). For the topic category, Cohens's kappa was moderate (.39), and for gender stereotype it was fair (.29). Given that this was an exploratory study and the first one to apply and expand on the categories recently developed by Zeng et al. (2021), lower coefficients are acceptable (Lombard et al., 2002).

3.3. Ethical Considerations

When analyzing content that is publicly available online for research purposes, some ethical challenges arise. Following the argument of Sugiura et al. (2017), getting informed consent is not a realistic option; rather the focus should be on guaranteeing anonymity and minimizing potential risks for the subjects of this investigation. Fortunately, most TikTok accounts investigated in this study used pseudonyms rather than real names. Hence, the risks that our study might damage TikTok creators were kept to a minimum.

4. Results

First, we were interested in seeing which female scholars are visible on TikTok in terms of discipline and career stage (RQ1). When looking at the 50 accounts selected for this study, results show that female scholars from a wide range of different disciplines and career stages are visible on TikTok (see Table 1). However, when assigning the disciplines to natural sciences vs. social sciences and humanities, the former is clearly dominant. Table 2 shows that 80% of the analyzed accounts stem from people working in the natural sciences. We also coded the different career stages of TikTok creators into three levels. Most of them (64%) are currently doing their PhD or had recently completed one. However, professors are also visible in the analyzed TikTok videos—every fourth account in our sample had been created by a professor or assistant professor.

Next, we examined which topics women scientists talk about on TikTok (RQ2). To address this, we examined the topics of the three most viewed videos on each of the 50 accounts (n = 150). Basing our typology on categories developed by Zeng et al. (2021), we distinguished between five different types of content. The results in Table 3 show that in nearly a third of the videos, female scholars explained facts and concepts. Female scholars also talked about what it was

Table 1. Sample: Selected accounts of women scientists on TikTok.

ID	Career Stage	Discipline	Number of Followers	Number of videos	First video
1	Professor	Psychology	738,000	681	2021–06–02
2	Astronaut candidate	Bioastronautics	357,700	172	2020–05–24
3	PhD	Neuroscience	240,800	668	2021–03–23
4	Professor (retired)	Microbiology	216,000	128	2020–11–26
5	Assistant professor	Bioengineering	211,300	105	2020–10–05
6	Professor	Educational Leadership	208,400	493	2020–04–19
7	PhD	Biology	143,200	86	2020–05–26
8	PhD	Molecular Biology	114,800	254	2019–10–01
9	Assistant professor	Epidemiology	100,300	275	2020–08–01
10	Researcher	Neuroscience	98,600	206	2020–04–22
11	PhD	Biology	92,200	28	2020–03–19
12	PhD	Astrophysics	87,200	731	2020–01–20
13	PhD	Neuroscience	85,300	243	2020–03–25
14	PhD	Earthquake Engineering	85,100	158	2020–03–19
15	Researcher	Chemistry	76,200	26	2018–04–30
16	PhD	Physics	65,100	25	2021–01–19
17	PhD	Genetics	61,800	127	2020–06–25
18	Assistant professor	Psychology	52,400	187	2020–03–30
19	PhD	Psychology	48,300	132	—
20	PhD	Biochemistry	45,700	224	2019–09–06
21	PhD	Molecular Ecology	44,000	155	—
22	PhD	Communication Studies	41,700	36	2020–04–10
23	PhD	Biology	41,500	59	2020–12–28
24	PhD	Molecular Science	36,600	53	2020–03–24
25	PhD	Neuroscience	35,200	91	2020–01–31
26	PhD	Biology	33,800	19	2020–10–29
27	Professor	Cell Biology	31,000	540	—
28	PhD	Psychology	30,100	51	2020–03–15
29	Researcher	Anthropology	27,800	160	2019–01–18
30	Visiting professor	Engineering	23,500	344	2019–11–10
31	Assistant professor	Information Science	21,600	219	2020–11–11
32	PhD	Astrophysics	21,200	183	2019–12–07
33	PhD	Astrophysics	20,400	97	2019–11–18
34	PhD	Aerospace	18,300	125	2020–03–19
35	PhD	Biology	16,600	96	2020–01–7
36	PhD	Biology	16,000	135	2019–05–14
37	PhD	Plant Pathology	14,500	296	2019–06–24
38	Associate lecturer	Education	13,800	18	2020–04–17
39	PhD	Planetary Sciences	13,600	81	2020–10–20
40	Instructor	Mathematics	11,800	206	2020–05–03
41	PhD	Biology	9,630	136	2020–11–28
42	PhD	Astrophysics	8,336	17	2020–03–07
43	Professor	Political Sciences	7,465	366	2020–04–08
44	PhD	Medicine	7,387	136	—
45	PhD	Astrophysics	6,414	209	2020–10–05
46	Assistant professor	Gender Studies	5,770	911	2019–02–15
47	PhD	Marine Science	5,065	216	2019–10–31
48	Professor	Chemistry	4,863	37	2020–11–14
49	PhD	Microbiology	4,344	80	2020–02–14
50	PhD	Neuroscience	3,766	57	2019–12–21

Notes: Number of followers and number of videos were retrieved from the accounts between October and December 2020. The dates of the first video posted for each account were added in December 2022; four accounts were no longer active at that time, and these are indicated by —.

Table 2. Academic discipline and career stage of the female scholars on TikTok studied.

	n	%
Discipline		
Natural sciences	40	80
Social sciences and humanities	10	20
Career Stage		
PhD	32	64
Professor/assistant professor	13	26
Others	5	10
Total	50	100

Table 3. Topics of the TikTok videos analyzed.

Topics	*n*	%
Facts, concepts, and phenomena explained	44	29
Being science students/teachers/scientists	43	29
Private life	22	15
Expert advice/opinion	20	13
Science in the making	16	11
Others	5	3
Total	150	100

Note: Categorization based on categories devised by Zeng et al. (2021).

like for them being a scientist—that is, videos showing the "behind the scenes" life of being a PhD student or a professor or reflecting on academia—which applied to 29% of the videos. The third most common topic was private life. These videos dealt with hobbies and activities, family, relationships, etc. The videos from the next category—giving expert advice—often dealt with vaccinating against Covid-19. Finally, some videos also showed "science in the making" (for instance, lab experiments).

Finally, we investigated to what extent women scientists on TikTok counter or challenge current gender stereotypes (RQ3). Results reveal that 11% of the 150 videos analyzed made reference to gender stereotyping. In the following, we present three examples to illustrate the ways this happened: The first example relates to physical appearance. In this video, a professor talks about a common stereotype—being judged by physical appearance and clothing. She responds to users who criticized how she was dressed. In the video, she wears different band shirts, and the text in the video says: "Common insults from trolls is that I'm 'unprofessional for a doctor.' I work at a university, I'm a PhD, & tiktok isn't my office." She challenges the stereotype that female scientists need to be dressed in a certain way in order to be credible and professional. The second example is about role expectations and role conflicts. In the video, a molecular scientist works out on a treadmill and captions appear that indicate her different roles: molecular scientist, educator, rapper, PhD, model. We first see her wearing a large coat. Next, she appears wearing a crop top and miniskirt. She is challenging stereotypes by claiming that different roles do not need to exclude one another: "I do it all." The third example relates to stereotypes that females in tech encounter. An assistant professor of information science picks up on a TikTok trend to call out stereotypical thinking in different fields. The following texts appear: "Now this is going to be a bit technical," "could someone else weigh in on this?," "oh could you take meeting notes?," "I don't know how you balance this job with family," and "you must be in marketing." She concludes: "Things much more rarely said to men in the tech industry."

5. Conclusions

This study aimed to explore TikTok as a platform for science communication. More specifically, we were interested in investigating how female scholars use TikTok. This study focused on assessing *who* becomes visible on TikTok in terms of disciplines and career stages, which *topics* are addressed, and whether the platform is also used to *counter stereotypes*. Results from an exploratory content analysis of selected TikTok accounts suggest that natural sciences are dominant on the platform. When looking at creators' level of educational attainment, or career stage, PhD students are the most active on TikTok. This might have to do with their age which comes closer to the target group of the platform. It might also be that scholars at this career level see the value in making themselves visible on different platforms to improve their chances of employment or tenure

by, for example, connecting with potential colleagues in their research field, or by becoming involved in public debates. However, professors also use TikTok to gain visibility. In our sample, for instance, the account of a retired professor was the fourth most watched and followed. This finding points to the need to examine the use of social media platforms by older people in more detail (Nguyen et al., 2022). Our study also generated insights into the topics female scholars address on TikTok. By analyzing the three most viewed videos on each of the selected accounts (n = 150 videos), our findings suggest that female scholars use TikTok mainly to explain facts and concepts and to talk about their experiences of being a (female) scientist which entails reflecting on what goes wrong in academia. This finding is in line with Schellewald's (2021) argument that TikTok is a space where users can also take meta-perspectives. Moreover, female scholars talk about their private lives, show science in the making, and give expert advice. Some of the videos that belong to the latter category also dealt with Covid-19 vaccines and debunked disinformation. Accordingly, future studies need to investigate science-related disinformation on TikTok as well as what motivates people to counter the distortions of some user-generated content (Basch et al., 2020; Wintterlin et al., 2021). In our sample, some female scholars used TikTok to counter stereotypes they faced in their jobs and areas of research or had encountered in their everyday social lives. Future research could explore the effects of movements similar to #womenalsoknowstuff or #distractinglysexy (Brantner et al., 2019) on TikTok. Similarly, a promising line of inquiry could also be to investigate whether or not career stage influences people's willingness to challenge stereotypical thinking on TikTok.

This study does not come without limitations. One limitation concerns our sample. Because we identified accounts of women scientists on TikTok by using hashtags, female scholars who did not use these hashtags were not part of our sample. We encountered a lot of hashtags related to natural sciences during our search, which might have biased the sample. Similarly, female scholars communicating in a language other than English or German were not included in the sample, which represents another limitation of this study. Hence, future research into TikTok accounts of female scholars who use other languages—which would entail inputting different search terms—are needed so that people can explore female science communication on the basis of a larger sample of science communicators. It will also be advisable to look at different cultural contexts; because most creators did not share their location, we were unable to take this variable into account. In addition, it would be useful to determine the percentage of male vs. female scientists presenting themselves and their work on TikTok in order to ascertain whether or not the platform indeed contributes to overcoming the underrepresentation of female scholars in public discourses. Moreover, a more nuanced analysis of stereotypes is needed since our attempt to investigate these by using a quantitative approach was limited, and this is reflected in relatively low reliability. Here, an in-depth qualitative analysis would be a better-suited approach. Additionally, when creators talk about having different roles and point out that these roles do not need to be mutually exclusive, this might convey different messages: while some followers might interpret this as an empowering message that women scientists *can* "do it all," others might feel pressured by the idea that women scientists *need* to do it all and to be successful in different roles. Hence, research is needed to explore the effects of such messaging. It is important to note that social media can be both—an empowering tool for women scientists as well as a space of hostility and misogyny: "Scientists must navigate the tension of creating visibility for themselves and their work more easily through online communication and the potential dangers of online visibility (e.g., reputational harm, misuse of scientific knowledge, and public criticism or even hostility)" (Metag, 2021, p. 138). Examining this viewpoint by means of content analysis is a challenge considering that one common strategy to deal with hate comments is to delete them (Eckert, 2018). A fruitful approach to investigating TikTok as a space that enables hostility and misogyny would involve carrying out interviews with the TikTok account owners we came across in our work for this article. Another question that deserves attention is: How do young women thinking about becoming researchers react to hostile and misogynistic comments directed at female scientists on TikTok and other platforms? Might the visibility of female scholars on such occasions also have negative implications by, for example, dissuading young women from pursuing a career in science? In this context, we should also look at what social media platforms and governments can do, not only to increase the visibility of women (and women scientists) on social media but also to make online spaces less hostile and more inclusive (Wilhelm, 2021). Finally, future studies should explore (new) science audiences on TikTok by, for example, investigating to what extent different science communication audience segments (Klinger et al., 2022) can be reached and engaged by (female) scientists on TikTok.

Despite these limitations, this study was able to offer initial insights into the science communication of female scholars on TikTok. Findings from this study suggest that this platform might (at least to some extent) be a tool that allows and empowers female scholars to present themselves according to their own self-definitions, raise awareness for important topics, and draw attention to and talk about current stereotypes.

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Conflict of Interests

The authors declare no conflict of interests.

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Article

Content Analysis From a Gender Perspective of Comments Received by Spanish Science YouTubers

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Abstract
One of the main features of videos that popularise science on YouTube is the ability to interact with the videos and the YouTubers who generate them. However, some types of interaction are often not gender neutral. In order to identify whether there are gender differences in the type of comments posted on YouTube channels that popularise science, a content analysis of nine such channels hosted by Spanish macro influencers was conducted. A total of 221 videos and 18,873 comments were analysed to identify and classify comments of a personal nature relating to physical appearance, tone of voice, or intellectual capacity, among other aspects. The results show that 7.5% (1,424) of the total number of analysed comments were comments of a personal nature addressed to the channel's host. Of the videos hosted by women, 95.3% contained at least one positive comment related to their physical appearance, compared to 27% in the case of men. Gender differences were mainly found in negative comments regarding the presenter's intellectual ability or personality, with women most likely to receive them. These results show that women who face media exposure are more vulnerable to negative sexist comments, which may deter them from professionalisation in this area.

Keywords
gender; science communication; sciencetubers; sentiment analysis; YouTube

Issue
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1. Introduction

Massarani and Moreira (2004, p. 1) follow Raichvarg and Jacques's (1991) idea that the evolution of science popularisation is:

> An indispensable complement to the history and philosophy of science, since it raises new questions: Why, for whom and how a science, at a certain moment, was disseminated in the social fabric of an era; which [kind of] people appropriated this science at a given time and by what means.

For García Rizzo and Roussos (2006), in the current context of total transparency of knowledge, it makes sense that science popularisation—which in natural circumstances would take place among scientists—moves to a more basic and less trained and formal context. It also makes sense for it to be disseminated through non-scientific channels and through a journalistic discourse whose main characteristics are topicality, novelty, veracity, attraction, and public interest (Fontcuberta, 1993). By doing so, scientific communication and journalistic dissemination can complement each other to popularise scientific knowledge (García Rizzo & Roussos, 2006).

Both non-scientific media and mass media have become excellent vehicles for this type of knowledge. In this sense, Buitrago et al. (2022) point to the social enrichment that a collaboration between YouTube outreach and the education sector could generate. This

study focuses on the popularisation of science on YouTube and, specifically, the gender perspective that can be glimpsed from the comments posted by followers.

1.1. Profile of Consumers of Scientific Information Via YouTube

According to the second wave of the General Study of Media (Asociación para la Investigación de Medios de Comunicación, 2021), the internet has a market penetration rate of 84%, and YouTube has a total of 28 million users. Tutorials (74%) and humour videos (53%) make up the most popular content, while scientific content captures the interest of 22% of users (Webedia, 2018). This means that the popularisation of science through YouTube has led to millions of people using these channels as sources of information on science and technology (Fundación Española para la Ciencia y la Tecnología, 2018).

Although its ultimate aim is still to increase knowledge about the findings of the scientific community and to contribute to the creation of an informed and critical citizenry (Davis et al., 2020; Della Giusta et al., 2020), this new format breaks with the rigidity of regular scientific communication and represents a disruptive change in several aspects: firstly, in its use of a more informal language and tone, which allows a greater number of people to engage with science; secondly, in its audio-visual format, halfway between information and entertainment (infotainment style; Davis et al., 2020); and thirdly, in the narrative formulas used, such as storytelling, which aim to provide an answer to a scientific question formulated at the beginning of the video, with a twist during the development of the plot and a final revelation at the end (Huang & Grant, 2020). These features had already been put into practice by conventional media's popularisation of science through the press, radio, or television. But it is on the internet, and specifically on YouTube, where they all converge and have proven effective strategies to increase the impact and popularity of videos among the profile of consumers of popular science content, who are mostly male, aged between 15 and 24, and with a high level of education (EPSCYT, 2018; Velho & Barata, 2020). Hence, if one of the obvious functions of science popularisation is to promote science as a vocation among young students (Calvo Hernando, 1997; Olmedo Estrada, 2011), gender-biased communication will undoubtedly negatively affect future generations (Fernández Beltrán et al., 2019).

In scientific literature, women's lack of interest in consuming such content has been explained from various perspectives, including cultural studies. These studies point to the influence that culture has on how individuals interpret their experiences (McNeil, 2008; Urteaga, 2009). This implies that culture conditions the perception of reality and may explain why arguments such as a negative self-perception of their ability based on social stereotypes (EPSCYT, 2018) and the lack of female references in which they can see themselves reflected appear among the reasons given by women for not consuming this type of content (Welbourne & Grant, 2016).

For Villegas-Simón and Navarro (2021), female digital producers who achieve greater recognition on the internet are still linked to typically feminine activities, such as beauty, fashion, or food, which reproduce and perpetuate traditional gender roles, while females continue to make up the majority of the audience for this type of context. Moreover, sexism and male domination continue to be reproduced in the harassment and objectification of women online. Despite the fact that women make up more than half of digital media users, they tend to be represented as consumers and passive subjects, while men tend to be represented as producers and active subjects (Van Zoonen, 2001).

1.2. The Role of Women Producing and Popularising Scientific Content

In addition to pointing to the role of culture in making sense of experiences, cultural studies also point to the conditioning that occurs in the way people act according to norms and stereotypes that are considered correct (Vaast, 2020). The lack of referents, which discourages the consumption of scientific content, may also influence women's interest in producing and popularising said content (Amarasekara & Grant, 2018; Regueira et al., 2020; Velho & Barata, 2020). It has been shown that the occupational preferences of adolescents are often linked to perceptions of gender appropriateness, which are acquired, among other ways, through the representations disseminated by the media (Steinke et al., 2007; Yammine et al., 2018).

In the beginning, social networks were seen as tools that would allow women to access certain jobs that men would have traditionally occupied. This made it possible to create a more democratic space open to perspectives that are usually excluded, although still underrepresented (Loverock & Hart, 2018; Wotanis & McMillan, 2014).

The lack of participation of women as content producers is particularly worrying because this content is consumed primarily by younger people. This may perpetuate a biased view (Amarasekara & Grant, 2018; Velho & Barata, 2020) which would eventually result in maintaining old stereotypes in new media, hinder social progress, and limit access to science for a large number of people (Yammine et al., 2018).

1.3. Interactions With Channels of Popular Science

In addition to the aforementioned particularities, social networks also allow interaction. The bi-directionality of scientific communication on YouTube enables more active participation by the viewers, who may interact with the content of its creators (Davis et al., 2020; Hargittai et al., 2018; Vizcaíno-Verdú et al., 2020).

Viewers can express emotions directly or indirectly associated with the scientific debate and generate cognitive and emotional interactions with the content or the YouTuber. This plays a decisive role in promoting greater engagement.

In this sense, it is interesting to distinguish behavioural engagement (which on YouTube would manifest itself through views, likes, dislikes, and comments) from emotional engagement (which seeks, through sentiment analysis or qualitative analysis, to find the meaning of the text in context), and finally, from cognitive engagement (that focuses on the argumentation of replies or the exchange of information to disprove the arguments of the channel host or other users; Dubovi & Tabak, 2021).

From a gender perspective, several studies have focused on reviewing behavioural and emotional engagement depending on the gender of the host of the science popularisation channel. They have shown that this factor can become a disadvantage for women. One of the possible reasons for this is precisely the socio-participatory base on which YouTube operates, which, with a largely male audience, replicates the same ways of interacting and the same problems women face in other areas (Yammine et al., 2018).

The results of some of these studies showed that interactions through comments with the channel host are often not gender neutral, and women are more vulnerable to receiving negative comments about their personality or physical appearance than their male counterparts (da Costa & de Carvalho, 2020; Kitzinger et al., 2008; McDonald et al., 2020; McKinnon & O'Connell, 2020; Velho & Barata, 2020).

Along the same line, the work developed by Amarasekara and Grant (2018) showed that channels hosted by women inspire more participation from viewers (behavioural engagement) but also a large number of negative reactions. These negative comments may take the form of sexist remarks, comments of sexual nature, or statements related to physical appearance (emotional engagement). Likewise, Tsou et al. (2014) and Veletsianos et al. (2018) conclude by stating that when educational or scientific communicators are women, a polarisation of emotional engagement is observed in the responses. They detected that female YouTubers received a greater number of positive and negative comments than male, who received a greater number of neutral comments (Tsou et al., 2014; Veletsianos et al., 2018).

2. Objectives and Hypothesis

The general objective of this article is to compare popular science channels on YouTube hosted by Spanish men and women to identify whether there are differences that could deter women from becoming professional popularisers of science. The specific objectives are:

1. To analyse the presence and content production of science popularisation channels hosted by Spanish science popularisers (men and women) on YouTube;
2. To explore the frequency of interactions on each of the videos (likes, dislikes, and comments) of all analysed channels;
3. To identify the number of science popularisation videos that contain personal comments addressed to the channel host and to classify them according to the type of comment and their valence.

Based on these objectives, the research hypotheses are as follows:

H1: The participation of Spanish male science popularisers is higher than that of their female counterparts due to the lack of female references in this field.

H2: The way the audience acts according to norms and stereotypes accepted within a society leads to a higher number of interactions (likes, dislikes, and comments) in channels whose scientific communicators are women.

H3: The way the audience acts according to the norms and stereotypes accepted within a society leads to more personal comments (positive and negative) being posted on science communication channels organised by women, thus diverting attention away from the scientific subject matter addressed in the videos.

3. Methodology

First of all, we selected the science popularisation channels, applying the following inclusion criteria: (a) being an active channel (at least one video in the last month), (b) being classified as a popular science channel in the YouTube channel description, and (c) being hosted by a Spanish presenter. In order to make the analysis operative, only the active science popular science channels with the largest audience were chosen as the study sample, which, based on the definition of "macro influencer" determined by Baramidze (2018), are those channels with more than 100,000 subscribers.

The results were extracted on 17 September 2020, and the analysis period was from 1 August 2019 to 31 August 2020. The period was selected to ensure that the data was as up to date as possible and that the videos could have been viewed by a wide audience in a study conducted in 2021.

Once the channels had been identified, and in order to meet Objectives 1 and 2, a content analysis (Krippendorff, 1990) was carried out, taking into account different dimensions associated with: (a) aspects related to the populariser (gender and thematic specialisation of the host of the nine channels found), (b) analysis of the channel (year of creation, number of subscribers, and number of uploaded videos), and (c) quantitative analysis

of the interactions (views, likes, dislikes, and comments obtained in each of the 221 videos found; see Table 1).

Finally, for the identification and classification of possible personal comments, sentiment analysis was carried out using the web scraping software Octoparse. This software collects and exports the comments from each of the videos to Microsoft Excel, thus facilitating the sentiment analysis of the data. Due to the high number of comments in some of the videos, and applying the methodology previously used by Amarasekara and Grant (2018), a maximum of 100 comments per video were selected randomly. To ensure the validity of the sample, the selection was made through Excel's random number generation formulas. This way, a total of 18,873 comments (see Table 1) were read so personal comments could be manually identified and classified. Each comment was single coded for sentiment analysis according to a rubric developed by other authors (Amarasekara & Grant, 2018; Kitzinger et al., 2008; McDonald et al., 2020), making reference to:

1. The YouTuber's physical appearance: Comments either slighting or favourably discussing the physical appearance of the video creator;
2. Their tone of voice: Complimentary or critiquing comments regarding the accent, intonation, or rhythm in the voice of the video creator;
3. Their intellectual capacities: Comments related to the cleverness, intelligence or of the channel's host or offenses related to their intellectual capacity;
4. Their personality: Comments either slighting or favourably discussing the channel host's manner, behaviour, or reactions;
5. Their clothing: Comments either slighting or favourably discussing the way the YouTuber is dressed or how the clothes suit them;
6. The feelings they generate in the viewers: Sexual nature (declarations of love, desire, proposals of marriage or a sexual nature) or hostile comments (statements of hatred, antipathy, or animosity) directed towards the YouTuber.

In turn, each of these personal comments was attributed a valence that allowed us to identify its intentionality (positive or negative) within the context in which it was written. This means that the same word could be classified with positive or negative valence depending on the sender's intention towards the content creator, which can be known from the context in which the word or expression was found.

To avoid inter-observer variation when coding the information, we performed a concordance analysis (Epidat, 2014) on a sample of 20% of the total universe studied, obtaining 94.2% agreement (Carmen Cristófol-Rodríguez and Belén Cambronero-Saiz).

For the statistical analyses, the information was exported to the SPSS programme, version 25. A univariate analysis was performed for the frequency distribution calculation, while a bivariate analysis was performed for the contingency tables and correlations. The chi-square test was used to interpret the variable cross, with results considered statistically significant when $p \leq 0.05$.

4. Results

Nine popular science channels hosted by Spanish macro influencers were identified, 66.7% hosted by men and 33.3% by women. The women's channels produce considerably fewer videos ($n = 43$ vs. $n = 178$), and all of them were founded more recently (2017–2018; see Table 1).

4.1. Interactions With Popular Science YouTube Channels

Regarding the interactions of the 221 videos analysed, the data shows how, in percentage terms, female YouTubers obtain a higher number of interactions in all indicators, both likes and views (9.2% vs. 8.1%), dislikes and views (0.4% vs. 0.1%), and comments and views (1.1% vs. 0.4%; see Table 2)

By channel, La Gata de Schrödinger has the highest percentage of comments/views (1.3%), followed by La Hiperactina (0.9%) and finally Antroporama (0.5%), which has the same number of comments as the C de Ciencia channel (0.5%; see Table 3).

4.2. Distribution of Personal Comments According to the Type of Comment and Valence

With regard to the appearance of personal comments in the videos, it should be noted that although they accounted for only 7.5% (n = 1,424) of the total number of comments analysed (n = 18,873), they appeared in 92.3% of the videos (n = 204).

The valence of personal comments was mostly positive, accounting for 80.5% (n = 1,147), while just 277 were negative. Of these, 21.7% (n = 309) were comments related to the YouTuber's physical appearance, 271 with positive valence (PV) and 38 with negative valence (NV), 7.4% were comments related to their tone of voice (PV: n = 54; NV: n = 51), 17.6% were romantic or hostile statements (PV: n = 245; VN: n = 6), 31.9% were either flattering or intellectually offensive (VP: n = 416; VN: n = 38), 12.6% were comments related to personality (VP: n = 121; VN: n = 58), and lastly, 8.8% were related to clothing (VP: n = 40; VN: n = 86; see Table 4).

Focusing on the positive comments (n = 1,147) and the differences by gender, we see that 65.1% of the personal comments found were addressed to male YouTubers (PV: n = 722; NV: n = 205) and 34.9% to female YouTubers (PV: n = 425; NV: n = 72). Most of the positive comments posted on the channels of female popularisers are related to their physical appearance (43.5%) or are romantic declarations (27.3%), while in the case of men, most of the personal comments they receive are intellectual compliments (50.6%) and, to a lesser extent, comments related to their voice (6.4%; see Figure 1).

Table 1. Descriptive information on YouTubers/channels and science popularisation videos on YouTube with more than 100,000 subscribers in 2020.

Channel (year of creation)	Gender of the host	No. of subscribers	No. of uploaded videos (2019–2020)	Views	Likes	Dislikes	Comments
Quantum Fracture (2012)	Male	2,350,000	33	23,472,390	2,072,280	28,484	91,643
CienciadDe Sofá (2012)	Male	314,000	22	5,339,169	392,902	3,894	16,695
C de Ciencia (2014)	Male	1,380,000	33	7,025,656	1,197,418	24,044	69,200
Derivando (2015)	Male	1,040,000	20	6,508,656	430,046	4,913	16,286
Date un Voltio (2015)	Male	893,000	23	3,650,673	292,009	3,446	10,237
Ciencias de la Ciencia (2016)	Male	172,000	47	1,327,391	55,296	1,099	6,257
Antroporama (2017)	Female	542,000	6	1,936,308	205,285	1,574	8,772
La Hiperactina (2018)	Female	176,000	9	1,020,329	120,673	1,129	8,652
La Gata de Schrödinger (2018)	Female	457,000	28	6,802,817	576,654	32,752	94,017

Table 2. Percentage of views vs. likes, dislikes, and comments by gender (2019–2020).

Gender of the YouTuber/views (*n*)	Likes/views (*n*)	Dislikes/views (*n*)	Comments/views (*n*)
Females (*n* = 9,759,454)	9.2% (*n* = 902,612)	0.4% (*n* = 35,455)	1.1% (*n* = 111,441)
Males (*n* = 55,321,309)	8.1% (*n* = 4,439,951)	0.1% (*n* = 65,880)	0.4% (*n* = 207,617)

Table 3. Percentage of views vs. likes, dislikes, and comments per channel (2019–2020).

Channel/views (*n*)	Likes/views (*n*)	Dislikes/views (*n*)	Comments/views (*n*)
La Hiperactina (*n* = 1,020,329)	11.8% (*n* = 120,673)	0.1% (*n* = 1,129)	0.9% (*n* = 8,652)
Antroporama (*n* = 1,936,308)	10.6% (*n* = 205,285)	0.1% (*n* = 1,574)	0.5% (*n* = 8,772)
Quantum Fracture (*n* = 23,472,390)	8.8% (*n* = 2,072,280)	0.1% (*n* = 28,484)	0.4% (*n* = 91,643)
La Gata de Schrödinger (*n* = 6,802,817)	8.5% (*n* = 576,654)	0.5% (*n* = 32,752)	1.3% (*n* = 94,017)
C de Ciencia (*n* = 14,720,912)	8.1% (*n* = 1,197,418)	0.2% (*n* = 24,044)	0.5% (*n* = 69,200)
Date un Voltio (*n* = 3,650,673)	8.1% (*n* = 292,009)	0.1% (*n* = 3,446)	0.3% (*n* = 10,237)
Ciencia de Sofa (*n* = 5,339,169)	7.4% (*n* = 392,902)	0.1% (*n* = 3,894)	0.3% (*n* = 16,695)
Derivando (*n* = 6,508,656)	6.6% (*n* = 430,046)	0.1% (*n* = 4,913)	0.3% (*n* = 16,286)
Ciencias de la Ciencia (*n* = 1,629,509)	5.1% (*n* = 55,296)	0.1% (*n* = 1,099)	0.4% (*n* = 3,556)

Table 4. Personal comments and valences identified in the science popularisation videos disseminated through YouTube (2019–2020).

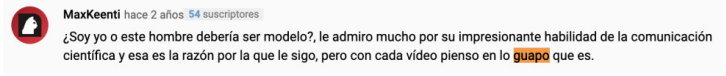
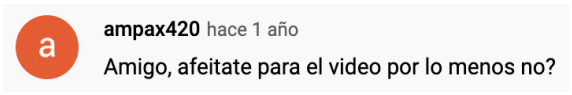
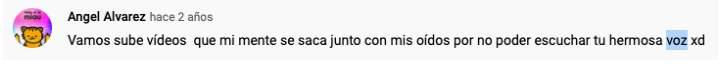
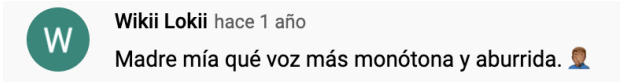
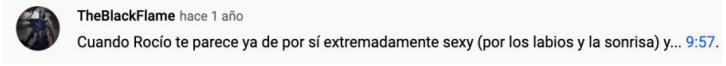
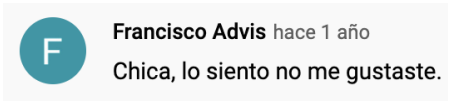
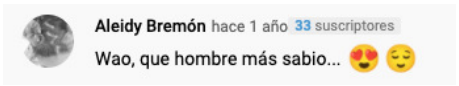
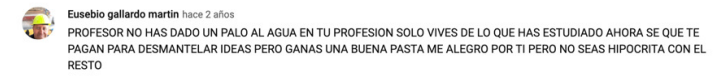
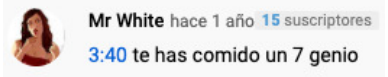
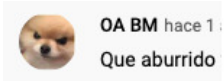
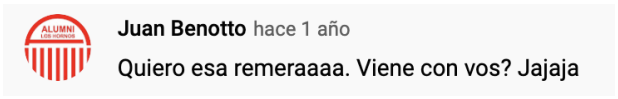
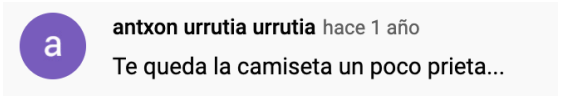
Personal comment and description		Valence examples
Physical appearance (+) Appearance-related comments, such as compliments on a YouTuber's physical appearance (−) Negative comments related to the physical appearance of the YouTuber	Positive	 Is it just me, or should this man be a model? I admire him a lot for his impressive scientific communication skills, and that's the reason I follow him, but with every video, I think how handsome he is.
	Negative	 Dude, shave for this video at least, no?
Voice (+) Compliments related to the YouTuber's accent, voice volume, musicality, expressions, or intonation (−) Comments related to low voice volume, wrong expressions, or poor intonation	Positive	 Come on, upload videos, my mind is racing, and my ears are pounding from not being able to hear your beautiful voice.
	Negative	 My goodness, what a monotonous and boring voice!
Feelings (+) Declarations of love, desire, proposals of marriage, or comments of a sexual nature (−) Statements of hatred, antipathy, or animosity towards the YouTuber	Positive	 When Rocío is already extremely sexy (because of her lips and smile) and…
	Negative	 Girl, I'm sorry, I didn't like you.
Intellect (+) Comments related to the cleverness, intelligence, talent, insight, or wit of the channel's host (−) Insults or offenses related to their intellectual capacity	Positive	 Wow what a wise man…
	Negative	 Professor, you "have not lift a finger" in your profession, you only live on what you have studied. Now, I know you are paid to dismantle ideas but you earn a good paste. I am happy for you but do not be hypocritical with the rest.
Personal comment and description		Valence examples
Personality (+) Comments related to the channel host's manner, behaviour, or reactions (−) Negative comments related to the YouTuber's personality (e.g., provocative, misrepresentative)	Positive	 You ate a 7, genius.
	Negative	 How boring.

Table 4. (Cont.) Personal comments and valences identified in the science popularisation videos disseminated through YouTube (2019–2020).

Clothing		
(+) Complimentary comments related to the way the YouTuber is dressed or how well the clothes suit them	Positive	 I want that t-shirt. Does it come with you? Hahaha.
(−) Negative statements related to the clothes worn by the YouTuber or how bad a certain piece of clothing looks on him/her	Negative	 The t-shirt is a bit tight...

4.3. Distribution of Personal Comments on Videos

Regarding the distribution of comments per video, it is observed that 95.3% of the videos conducted by women contained at least one positive comment related to their physical appearance, compared to 27% in the case of men (see Table 5).

This same difference by gender is also observed in the love declarations, as 88.4% of the videos uploaded by women have at least one such comment, and only 33.7% in the case of the videos uploaded by men (X^2 = 41,933; p = 0.000). Among the positive comments, intellectual compliments are also very frequent, being present on 71.5% of the videos, with no statistically significant differences by gender between the number of videos that include at least one intellectual compliment. In the case of men, the positive comments focus much more on clothing, with statistically significant differences to the videos conducted by women when the chi-square test was applied (X^2 = 5.758a; p = 0.016; see Table 5).

On the other hand, despite the fact that few videos have negative comments, differences by gender have also been detected in the probability that a video hosted by a woman receives negative comments related to her intellectual capacity (X^2 = 13.058a; p = 0.000) or her personality (X^2 = 50.893a; p = 0.000; see Table 6). In the case of men, the most frequent negative personal comments are those related to their voice, which appear in 12.9% of the cases, compared to 2.3% in the case of women communicators (X^2 = 4.017a; p = 0.045; see Table 5).

In general terms, the words that appear most frequently are *guapa* (pretty) and its derivatives or synonyms (*hermosa*, which means beautiful), as well as expressions of love. Adjectives related to the channel host's intellectual capacity are also frequently mentioned through adjectives such as *crack* (ace), *genio* (genius), *grande* (great), or *inteligente* (intelligent), or their way of being, through terms such as *bueno*/*buena* (good) or *encantador*/*encantadora* (charming).

5. Discussion

The study's results indicate that there is a lower number of female Spanish science communicators on YouTube. This confirms the study's first hypothesis, which is based on the premise that women are underrepresented on this social network, much like in mass media. As cultural studies point out, the lack of female representation

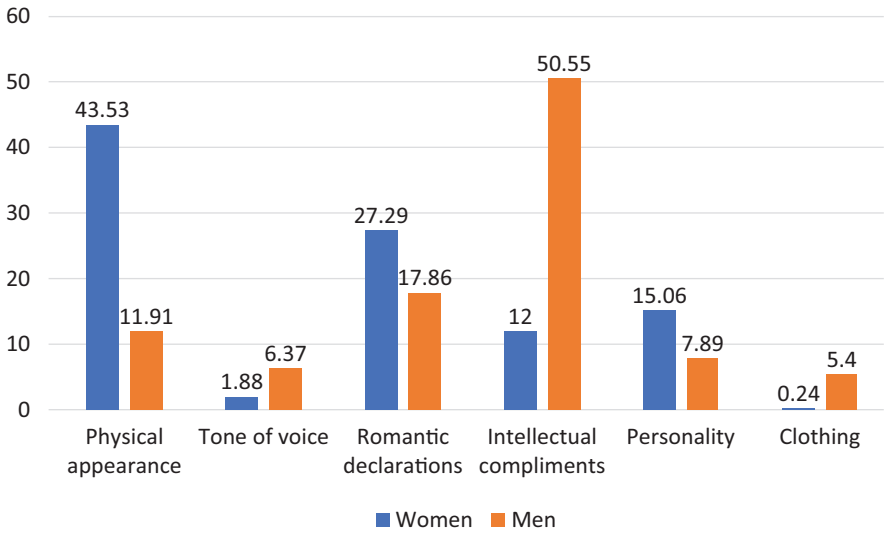


Figure 1. Differences by gender in the positive personal comments in science popularisation videos (%).

Table 5. Popular science videos in which positive and negative personal comments are posted, differentiated by the gender of the YouTuber (with respect to the total 221 videos).

		Videos by women (*N* = 43)		Videos by men (*N* = 178)				
Comments	Valence (+/−)	*n*	%	*n*	%	X^2	*df*	*p*
Physical appearance	+	41	95.3	48	27.0	67.330	1	0.000
Tone of voice	+	6	14.0	24	13.5	0.007	1	0.936
Romantic declarations	+	38	88.4	60	33.7	41.933	1	0.000
Intellectual compliments	+	29	67.4	129	72.5	0.430	1	0.512
Personality	+	34	79.1	38	21.3	52.534	1	0.000
Clothing	+	1	2.3	29	16.3	5.758	1	0.016
Physical appearance	−	8	18.6	16	9.0	3.308	1	0.069
Tone of voice	−	1	2.3	23	12.9	4.017	1	0.045
Hatred statements	−	1	2.3	5	2.8	0.031	1	0.861
Intellectual affronts	−	14	32.6	19	10.7	13.058	1	0.000
Personality	−	21	48.8	11	6.2	50.893	1	0.000
Clothing	−	3	7.0	24	13.5	1.367	1	0.242

Notes: $p < 0.05$.

in the field may mark the occupational preferences of adolescent girls linked to the perception of gender appropriateness.

Despite the fact that macro influencers own all the channels studied, there are notable variations by gender in absolute terms of subscribers and views, both of which are key indicators for positioning on this social network (Google, 2023). One of the possible causes is the late incorporation of women into the popularisation of scientific content through YouTube, which also directly impacts the lower levels of content production observed in this study. This implies that their male colleagues' channels are also more likely to be better positioned since they have been active for longer.

However, it should also be noted that the popularity of the channel may be influenced by the charisma or personality of the YouTuber, as well as, among other reasons, the topics covered, the approaches presented, collaborations with other YouTubers, their appearance in conventional media, and the use of other social networks that redirect users to YouTube channels. In turn, these perceptions may be conditioned by the channel owner's fit with gender stereotypes. The lack of correspondence with traditional female stereotypes may provoke rejection among some viewers. This is reinforced by the higher percentage of negative comments towards women about their personalities (Döring & Mohseni, 2019, 2020).

Our results also confirm the second hypothesis since, in terms of relative frequencies, the three popular science YouTube channels hosted by Spanish female macro influencers have a higher number of interactions than those hosted by men, coinciding with the results obtained in previous studies conducted in different countries (Tsou et al., 2014; Veletsianos et al., 2018).

This is true both for positive interactions (measured in likes/views), negative interactions (dislikes/views), and the number of comments (comments/views). This can lead to greater emotional engagement on the part of the viewers, which could be the basis for generating greater involvement in the scientific debate. The importance of emotional engagement, expressed through positive or negative emotions, stands out as a determining element for generating trends in posting comments, and even for triggering behavioural and cognitive engagement that leads to more in-depth interventions (Dubovi & Tabak, 2021).

Finally, the third hypothesis is confirmed, as it shows that popular science YouTube channels hosted by women produce, in relative terms, a greater number of both positive and negative personal comments. Thus, personal comments towards women are usually related to the YouTuber's physical appearance, mostly in the form of compliments or romantic declarations, which does not happen with the same frequency in the case of men. As pointed out at the beginning, two factors that may explain this behaviour are, firstly, the mostly male audience of popular science channels and, secondly, the socio-participatory base of the social network. Both factors contribute to replicating the same behaviours in accordance with the norms and stereotypes considered correct and acceptable in society (Yammine et al., 2018).

These interventions contribute to the promotion of gender stereotypes, the perpetuation of the objectification of women, their being discredited as experts or specialists in the subject matter, and the lowering of

their credibility or authority to generate knowledge and discussion about a topic since, as some authors have pointed out before, the nature and tone of the comments influence the audience's perceptions of the quality of the video content (Amarasekara & Grant, 2018). In addition, the fear of being judged by factors unrelated to the content has led many women who make popular science videos to emphasise their legitimacy, taking care of aspects such as clothing or the topics to be covered, avoiding those that could provoke sexual or sexist comments (McDonald et al., 2020). The increased number of negative emotional responses, sometimes unrelated to the topic of discussion, can also have a deterrent effect on the professionalisation of women as science communicators, as it can affect the credibility or popularity of a channel (EIGE, 2020). This contributes to reinforcing the Matilda effect, in which women scientists suffer underestimation and insufficient and systematic recognition of their work (Reif et al., 2020), leading to a lower number of subscribers, a lower channel impact, and less visibility.

In the case of men, an opposite trend is detected, as the frequency of positive personal comments is focused not so much on physical praise but intellectual praise.

The main novelty of this work lies in incorporating the gender perspective in the analysis of the comments of scientific communicators through online communication channels. Although similar works had already been carried out internationally, this is the first work of this type in Spain. Among the main results, the verification that sexist behaviours continue to be repeated in the new communication channels stands out. Specifically, our results show that women who face media exposure are more vulnerable to negative sexist comments, which may deter them from professionalisation in this area.

Despite the differences detected, it is important to highlight that only 7.5% of the videos studied have personal comments, which shows that only a minority of viewers make this type of intervention. As a line of future research, it would be interesting to study and classify all the comments in order to determine their pertinence or relevance to the topic addressed in the video analysed.

It should also be taken into consideration that one of the main limitations of the study is the bias of YouTube's recommendation algorithms, which can benefit the visibility of certain videos and perpetuate the position of the most consolidated channels, as well as encourage the recommendation of gender-biased content (Bishop, 2018). Furthermore, we have not considered the sociodemographic variables of the viewers related to gender, age, or educational level that can shed new light on the topic of study. One limitation of the study is that it did not consider the potential ideological biases of the YouTube content creators, which may arise due to their own political and ideological stances and could lead to controversies outside the scientific debate. This implies that the comments may not only be conditioned by the video's content but also by the very approach with which the YouTuber talks about the content. Also, the study's results may vary over time since the channels studied are still active and, therefore, interactions with the videos can continue to be made. Finally, as the methodology used had not been previously tested, there may be important categories that had not been taken into account by this article.

6. Conclusions

The under-representation of women in popular science also persists in social networks such as YouTube. This implies that the barriers to participation come not only from factors specific to the work field, such as the glass ceiling, but may also be the result of the internalisation of socially shared values and beliefs that serve as the basis for the social construction of reality. These ideas can also be reinforced through the personal comments to which women are exposed. Stereotypical evaluations, which emphasise aspects traditionally valued more in one gender than in the other, such as beauty in the case of women and intellectual capacity in the case of men, show that critical media education is necessary to continue fighting against gender stereotypes.

Although the higher number of interactions with female-hosted channels may contribute to strengthening the audience's commitment to the scientific debate, it is also true that if these interactions have an NV, they can be a deterrent to women's professionalisation as communicators, as they might rather not be exposed to value judgments that are unrelated to the scientific debate.

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Conflict of Interests

The authors declare no conflict of interests.

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Article

Higher Education Institutions on Facebook, Instagram, and Twitter: Comparing Swiss Universities' Social Media Communication

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Abstract
Public communication has become more important to higher education institutions (HEIs), with many HEIs using social media to communicate with stakeholders. However, scholarship on the subject is scarce and mainly based on single-platform studies and small datasets. Therefore, we conducted a cross-platform study to examine the communication of all Swiss HEIs on Facebook, Instagram, and Twitter. The results were based on two datasets: an automated analysis on data for all Swiss HEIs (n = 42) and their social media accounts from 2004 to 2021 (337,232 posts from 207 accounts), and a manual content analysis on 1,500 posts per platform. By including all HEIs in one country, this study allowed for a comparison of the results by HEI type: universities of applied sciences, universities of teacher education, and research universities. Results show that, in recent years, HEI communication increased on Instagram, but not on Facebook or Twitter. Twitter was used the most by research universities, while most Instagram and Facebook posts were from universities of applied sciences. Universities of teacher education were least active across all platforms. The content of communication across all HEI types was primarily self-referential. Our analysis of how well HEIs used the affordances of social media communication relative to hypertextuality and multimodality revealed a generally high level of adaption. Moreover, our data showed no substantial impact of the Covid-19 pandemic on posting activities and engagement with social media posts by HEIs for the two first years of the pandemic.

Keywords
higher education institutions; new media technology; public relations; social media; strategic communication; Switzerland; university communication

Issue
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1. Introduction

As actors, topics, and platforms for science communication are diversifying (Swiss Academies of Arts and Sciences, 2021), higher education institutions (HEIs) are challenged to remain important voices in public debates (Entradas & Bauer, 2022). As a result, strategic communication is becoming increasingly important for HEIs (Scheu & Blöbaum, 2019). Although scholarly interest in the public relations efforts of HEIs is on the rise (VanDyke & Lee, 2020), particularly with respect to social media communication, scholarship shows three main shortcomings. First, most studies on the social media communication of HEIs have not accounted systematically for different types of HEIs. Moreover, many focused on high-ranked, elite research universities and often assumed that developments occurred across all HEI types (e.g., Bonilla et al., 2022; Fähnrich et al., 2020). Second, scholarship mainly consists of single-platform studies (e.g., Peruta & Shields, 2018; Stuart et al., 2017), overlooking that most HEIs operate on several platforms. Third, studies investigating developments over time are almost absent. The current study was designed to address these gaps through

a nationwide, cross-platform study encompassing the three most prominent social media platforms: Facebook, Instagram, and Twitter. We analyzed a complete dataset representing all Swiss HEIs (n = 42) for 18 consecutive years (2004–2021), including research universities, universities of applied sciences, and universities of teacher education (sometimes also called colleges of education), thus enabling us to compare different types of HEIs. The study focused on the adoption of social media by Swiss HEIs, their use of social media, and user engagement with their content, as well as on the characteristics, topics, and stakeholders mentioned in social media content by Swiss HEIs.

2. Literature Review

Research on HEI communication has gained momentum in recent years (Schäfer & Fähnrich, 2020; VanDyke & Lee, 2020). Such investigations shed light on the changing structures and practices in HEI communication departments stemming from digitalization and a changing relationship between science and society (Fürst et al., 2022a).

2.1. Changes in Higher Education and Communication

Recent decades saw changes in the raison d'être of HEIs. In addition to fulfilling their core tasks of teaching and research, HEIs are increasingly expected to fulfill a "third mission" and thus engage with society's needs, respond to market demands, and involve the public in science and its outcomes (Krücken, 2021; Scheu & Blöbaum, 2019). Moreover, the higher education sector has grown and has become more competitive, with most HEIs across OECD countries striving to increase student enrollment, third-party funding, public visibility, and reputation (Entradas & Bauer, 2019; Friedrichsmeier & Fürst, 2012). Accordingly, studies from various countries have demonstrated the increased importance of HEIs' external communication (e.g., Davies, 2020; Elken et al., 2018; Entradas et al., 2020; Leßmöllmann et al., 2017; Schwetje et al., 2017). Indeed, central communication departments produce more output for various channels, including digital media and social media platforms, and have become more strategic in their communication over recent decades (Fürst et al., 2022a; Metag & Schäfer, 2019).

2.2. Strategic Communication of HEIs Online

In line with Raupp (2017, p. 149), we understand the strategic communication of HEIs as their "intentional, internally and externally directed communication that serves to maintain and expand their organizational legitimacy." However, as mentioned previously, in the context of increasing expectations from society to fulfill the "third mission," HEIs not only pursue organizational goals but also societal goals, such as fostering dialogue and supporting open science initiatives (Fürst et al., 2022b). Social media platforms have become an integral part of the strategic communication of HEIs across the world. Platforms such as Facebook, Instagram, Twitter, and YouTube offer organizations a variety of advantages, including the bypassing of journalistic gatekeepers, low-cost dissemination of information, and the tailoring of paid and owned content to multiple stakeholder groups (Davies & Hara, 2017; Metag & Schäfer, 2019). Early studies, however, showed little adoption of social media among HEI communication departments, and when they employed social media, they rarely used it for two-way communication (Beverly, 2013; Linvill et al., 2012; McAllister, 2012). More recent studies indicated that HEIs are catching up on Facebook (Fähnrich et al., 2020; Peruta & Shields, 2017), Instagram (Bonilla et al., 2022; Robinson et al., 2019; Stuart et al., 2017), Twitter (Kimmons et al., 2017; Rutter et al., 2016; Vogler, 2020), YouTube (Meseguer-Martinez et al., 2019; Ros-Gálvez et al., 2021), and WeChat (Feng, 2019). Nevertheless, very few studies (e.g., Witzig et al., 2017) have compared HEI communication across multiple platforms. In fact, scholars recently called for more research to investigate HEIs' use of social media, particularly through more cross-platform studies (Fähnrich et al., 2020; Hansen, 2016; Metag & Schäfer, 2019).

Also, little is known about how different types of HEIs communicate online, with the vast majority of existing literature focusing on research universities (e.g., Metag & Schäfer, 2017). Research on media coverage of research universities and universities of applied sciences in Germany suggests that the size, type, and external funding of HEIs impact the visibility of HEIs in news coverage, in a way that favors large research universities with high third-party funding and research in social sciences and humanities (Friedrichsmeier et al., 2015). Research from Switzerland has revealed differences in educational profile, subject specialization, student profiles, and research involvement of different HEI types (Lepori et al., 2014) as well as in their orientation towards societal and organizational goals (Fürst et al., 2022b), but not concluded on how such differences might affect online communication practices.

2.2.1. Adoption, Use of, and Reactions to Social Media Among HEIs

The adoption and use of social media can be analyzed either at the micro-level of individuals or the meso-level of organizations (Moreno et al., 2015). Kelleher and Sweetser (2012) studied the adoption of social media by US university communicators at the micro-level. At the meso-level, several studies examined the social media adoption of high-ranking universities worldwide (e.g., Valerio-Ureña et al., 2020) or of universities in one country, for instance, UK universities related to Instagram (Stuart et al., 2017), Canadian universities related to Twitter (Veletsianos et al., 2017), and more

recently, Portuguese universities related to Facebook and Instagram (Almeida & Morais, 2020). Findings related to differences between HEIs generally showed higher adoption rates among highly ranked research universities (e.g., Valerio-Ureña et al., 2020) and private universities compared to public HEIs (e.g., Bauer, 2019).

The intensity of HEIs' social media activity—how much content is being posted by HEIs—has been frequently discussed but rarely researched. Scholars have assumed that HEIs in continental European countries use social media rather occasionally and mostly for mimetic reasons (e.g., Marcinkowski, 2022). However, the few empirical studies on this subject produced inconclusive results and were based on small datasets (e.g., Veletsianos et al., 2017). In general, studies have uncovered a wide variety in the extent to which social media was adopted by HEIs, as shown by Bauer (2019) on a broader sample of German HEIs, and in the extent to which social media was used, as shown by Bélanger et al. (2014) for Canadian universities.

Research on user engagement (i.e., likes, shares, and comments) with content published by HEIs on social media is richer and revealed clear differences between "non-elite" and "elite" universities. While "non-elite" HEIs typically experienced low levels of user engagement (e.g., Bélanger et al., 2014; Stuart et al., 2017), "elite" universities tended to receive much higher rates of response—some even comparable to those of larger private sector companies (e.g., Fähnrich et al., 2020).

Existing scholarship on the adoption, use of, and engagement with social media communication tends to neglect small and medium-sized HEIs, as well as specialized HEIs, such as universities of applied sciences or universities of teacher education. The latter provide an interesting case because they have been given equal status in higher education in Switzerland through the accreditation of Swiss universities as a result of the Bologna reform. A research gap is also evident in the analysis of recent developments, with no studies tracking trends and changes across multiple years.

In light of these gaps in scholarship, we asked the following research questions:

> RQ1: How has communication by Swiss HEIs on Facebook, Instagram, and Twitter changed over time?

> RQ2: Does the adoption, use of, and engagement with content differ across social media platforms and types of HEIs?

2.2.2. Characteristics of Social Media Content by HEIs

Studies on the social media content of HEIs come from a variety of research fields, such as higher education, marketing, and strategic communication, and employed quantitative (e.g., Bélanger et al., 2014) and qualitative methods (e.g., Veletsianos et al., 2017). Typically, such studies examined content characteristics and how they related to users' reactions, such as likes and shares (e.g., del Rocío Bonilla et al., 2020). A study aiming to categorize the topics of social media communication content by Fähnrich et al. (2020) found that the research universities listed on Shanghai Ranking's Top 50 strongly focused on research when posting content on Facebook. Other studies have revealed that HEIs in the US disseminate a lot of promotional and marketing-related content on social media (Peruta & Shields, 2018). Early studies indicated that the public and students were the stakeholders most often mentioned in HEIs' social media posts (Bélanger et al., 2014; Beverly, 2013; Linvill et al., 2012). More recently, scholars have argued that HEI communication on social media platforms needs to become more stakeholder-specific in order to foster engagement (Bauer, 2019).

Research has also analyzed how well HEIs have used the affordances provided by social media platforms. Most studies focused on two aspects (e.g., del Rocìo Bonilla et al., 2020; Peruta & Shields, 2018; Stuart et al., 2017): the multimodality of posts (i.e., using visuals to make the content richer and more appealing to audiences) and the hypertextuality of posts (i.e., embedding links in posts to allow for more interconnected communication).

Studies comparing content characteristics across platforms and between different types of HEIs are greatly needed, as existing studies of this type are rare. To close this gap in the literature, we, therefore, addressed the following research question:

> RQ3: How do content topics, stakeholders mentioned, hypertextuality, and multimodality differ across different types of HEIs and different social media platforms?

3. Methods and Data

To answer RQ1 and RQ2, we analyzed all Facebook, Instagram, and Twitter posts of all Swiss HEIs (n = 42) over 18 consecutive years (2004–2021). The sample included three types of publicly funded HEIs: research universities, universities of teacher education, and universities of applied sciences. Given the focus on the meso-level of organizations, we established two criteria for the inclusion of a social media account: (a) it had to be operated in the name of the HEI as a whole, and (b) the account had to be operated by the central communication department. While the first criterion was validated by looking at the description of the account, the second was validated by interlinkage between the website of the communication department and the social media account. Not all HEIs were present on all three platforms, and some HEIs operated from more than one account per platform. Overall, we analyzed 69 Instagram accounts managed by 36 HEIs, 79 Facebook accounts managed by 39 HEIs, and 59 Twitter accounts managed by 33 HEIs. We used CrowdTangle—a public insights tool owned and operated

by Facebook—to gather Facebook and Instagram data, and the Twitter API (academic product track) to collect Twitter data.

The following measurements were employed:

- Adoption: To analyze the social media adoption patterns of all Swiss HEIs, the date of creation for each account was aggregated per platform per year and plotted as a percentage of all HEIs.
- Intensity of use: To analyze the intensity of social media communications by Swiss HEIs, the total number of published posts was calculated for each platform per year and plotted on a timeline.
- Engagement: To analyze the engagement of users with social media communications by HEIs, the average number of user reactions to posts per account was calculated for each year and per platform. User reactions were quantified as follows: (a) Facebook—Total sum of likes (including reactions such as "love," "wow," "ha ha," "sad," "angry," and "care"), comments, and shares per Facebook post; (b) Instagram—Total sum of likes and comments per Instagram post; (c) Twitter—Total sum of likes, retweets, quotes, and replies per tweet.
- Hypertextuality: To analyze if posts contained hypertextual elements, we operationalized two separate variables with binary coding. We coded whether or not a post contained URLs or hashtags. If a post contained URLs, it was also coded where the first or most prominent URL was pointing to.
- Multimodality: To analyze multimodal features, we operationalized three variables with binary coding. We coded whether or not a post contained images, videos, or emojis.

To answer RQ3, we conducted a manual content analysis based on a sample of all Facebook, Instagram, and Twitter posts published by all accounts officially managed by Swiss HEIs that existed in 2019. This translated into 14,930 Facebook messages posted by 75 accounts, 6,671 Instagram posts by 62 accounts, and 20,405 tweets by 51 accounts. The year 2019 was chosen as the best fit for the content analysis, because the data for RQ1 showed a saturation of social media adoption after 2018 across all three platforms, thus making comparisons more valid and findings more reliable after this period. Additionally, at this time communication had not yet been impacted by the Covid-19 pandemic. Due to the multilinguistic nature of Switzerland, the dataset contained posts in German, French, Italian, and English. For analysis, a random sample of 1,500 posts per platform was drawn from the dataset. Based on an established codebook used for previous studies (Vogler, 2020; see Supplementary File), two trained coders conducted the manual coding independently from each other. To code the full sample, the two independent coders continued to double-code content throughout the coding process. Neither coder was told which content was being double-coded. They coded the main topic of a post, distinguishing between research, teaching, and organizational topics (cf. Vogler, 2020), and the main stakeholder mentioned in a post, distinguishing between internal stakeholders of HEIs, students, science actors, societal actors, and posts with no mentions of stakeholders (cf. Vogler, 2020). Intercoder reliability was tested with a random sample of 180 unique posts (60 per platform) coded by both coders. Krippendorff's alpha was very satisfactory for multimodality (.98) and hypertextuality (.96) as well as satisfactory for topic (.80) and stakeholders mentioned (.75).

4. Results

In the following, we present the results of the study, explaining how Swiss HEIs communicate on Facebook, Instagram, and Twitter and how this has changed over time, structured in four sections: adoption of the platforms (Section 4.1), use of the platforms (Section 4.2), user engagement with the content (Section 4.3), and differences in topics and stakeholders mentioned in content (Section 4.4).

4.1. Adoption of Facebook, Instagram, and Twitter Among Swiss HEIs

Our findings with respect to RQ1 show that when the University of Fribourg—a mid-sized research university in the heart of Switzerland—joined Twitter in 2007, it was the first Swiss HEI to do so (Figure 1). Within three years, by 2010, 17 HEIs (36%) had joined as well, including research universities, universities of applied sciences, and universities of teacher education. By 2011, a majority of Swiss HEIs were on Twitter (52%). This number slowly increased over the following 10 years until 2021 when nearly two-thirds of Swiss HEIs (72%) had joined Twitter.

The first Swiss HEIs—two research universities and three universities of applied sciences—joined Facebook in 2009. Within one year, 15 HEIs (32%) had created Facebook accounts, including the first university of teacher education. In 2011 the majority of HEIs (63%) were on Facebook. This number gradually increased until 2018, by which time most Swiss HEIs (84%) were communicating via Facebook. Since 2018, no new HEI joined the platform.

In 2012, two research universities and one university of teacher education became the first among their peers to join the Instagram platform. Within two years, nearly one-third of HEIs were on Instagram (30%), including all types of universities. In 2016, the majority of Swiss HEIs (54%) were on Instagram, with numbers steadily rising until 2021, when more than two-thirds of all HEIs (78%) were present on Instagram.

Regarding RQ2 about differences across social media platforms and across HEI types, the results displayed in Figure 1 show that Facebook is the most widely used

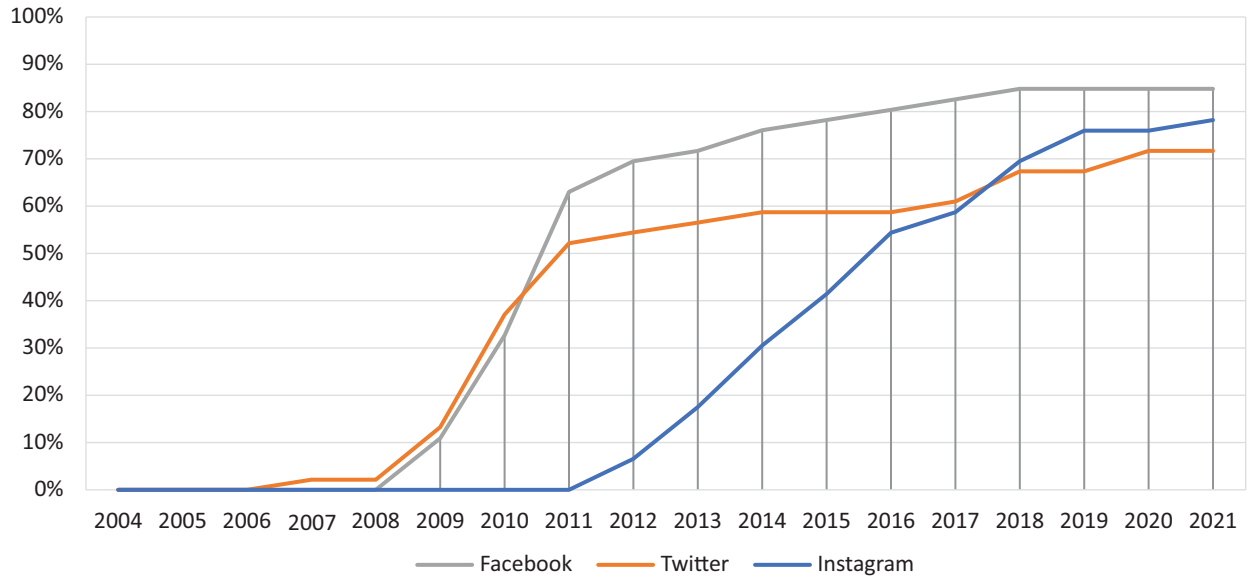

Figure 1. Adoption of Facebook, Instagram, and Twitter among Swiss HEIs. Note: Yearly percentage of HEIs on Facebook, Instagram, and Twitter from 2004 until 2021.

platform (85%), followed by Instagram (78%) and Twitter (71%). The adoption rate on Facebook was the fastest as well, with the vast majority (63%) of Swiss HEIs adopting this channel within a two-year period. The same level of diffusion took twice as long for Instagram and Twitter. The initial uptake was fastest on Instagram, with the first HEI accounts created only a few months after the launch of the platform in October 2010. The adoption rates for Facebook and Twitter were exponential in the beginning, then slowed down after 2011. In contrast, diffusion on Instagram was linear for the period of measurement (2012–2021).

4.2. Use of Facebook, Instagram, and Twitter Among Swiss HEIs

As shown in Figure 2, Swiss HEIs first posted content on Twitter and Facebook in 2010 and on Instagram in 2012. On Twitter, the amount of content posted by research universities showed a steep increase for six consecutive years (2010–2016). The use then stabilized from 2016 and climbed steadily above 1,000 tweets, on average, each year until 2021 (2.7 posts, on average, published by research universities per day). The number of tweets by universities of applied sciences increased for three consecutive years (2010–2013), stabilizing at around 500 posts, on average, for five years (2013–2017). In 2018, the number of tweets by universities of applied sciences rose to 797 on average. From 2019 to 2021, that number decreased, with an average of 522 tweets in 2021. The use of Twitter by universities of teacher education varied across the years, peaking in 2015 with 228 posts published, on average.

On Facebook, universities of applied sciences increased their activities during the first five years (2011–2015)—starting with an average of 146 posts in 2011 and increasing to 447 posts in 2015. After a slight decrease in 2016, the activity of universities of applied sciences jumped and then stabilized at around 650 posts, on average (1.8 posts, on average, published per day since 2017). Research universities started at a low level and increased their Facebook activity during the first five years (2011–2015), starting with an average of 73 posts in 2011 and increasing to 269 posts in 2015. Hereafter, the activity of research universities stabilized at slightly less than 300 posts published a year (0.8 posts, on average, per day). The use of Facebook by universities of teacher education increased slowly to the peak of activity at 139 posts in 2021 (0.3 posts per day, on average).

The first Swiss HEI posted content on Instagram in 2012. Research universities published content 284 times, on average, during their first year, 2013, on Instagram. Afterward, the activity level dropped to half and stabilized at close to 150 posts a year. In 2013, universities of applied sciences started posting on Instagram. Since then (2014–2021), the activity level for universities of applied sciences has shown a linear increase each year, until the current peak of 436 posts was reached in 2021. Universities of teacher education's use of Instagram peaked in 2015 with 135 posts per year, on average, after which the number of posts, on average, decreased until it stabilized after 2018 at around 70 per year.

Concerning RQ2, universities of applied sciences were the most active Swiss HEIs on Facebook and Instagram, while research universities were most active on Twitter, as shown in Figure 2. Clear differences in the intensity of use among HEI types and across platforms also emerged over the years. Swiss HEIs generally preferred Twitter, followed by Facebook and Instagram. During the initial years, research universities and universities of applied sciences posted similar numbers of messages on Facebook and Twitter, respectively. Universities

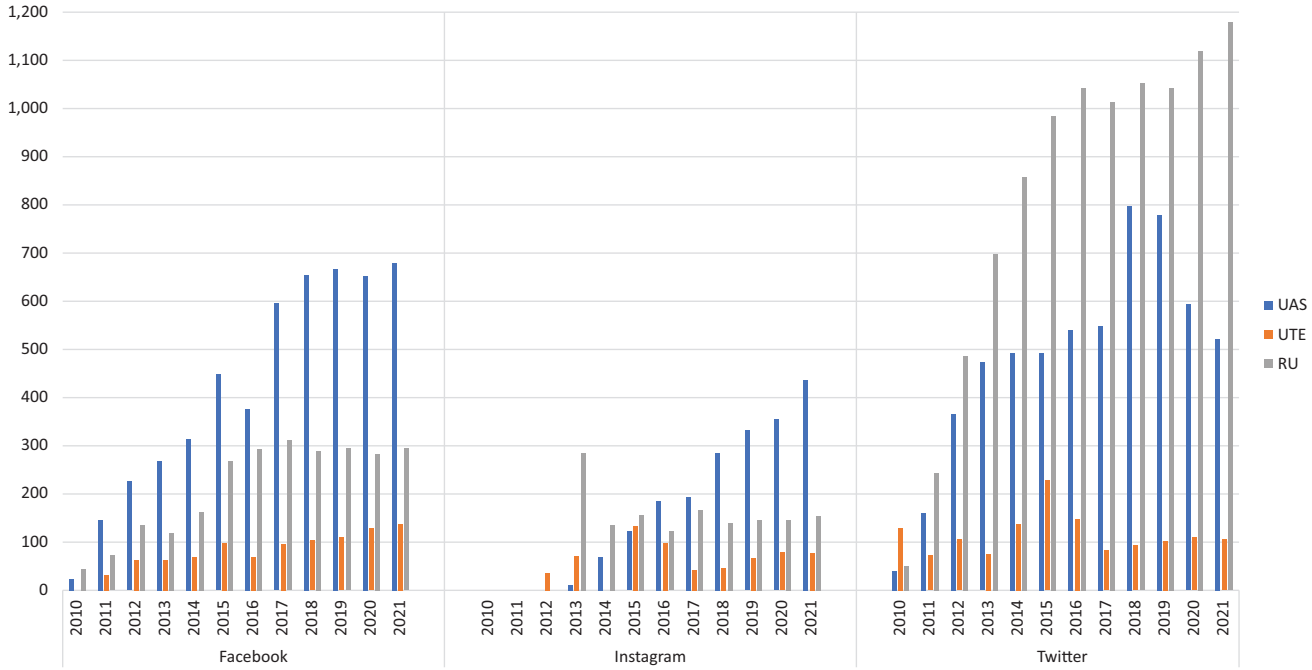

Figure 2. Yearly average number of published posts by HEI type on Twitter, Facebook, and Instagram. Notes: UAS = universities of applied sciences; UTE = universities of teacher education; RU = research universities.

of teacher education used social media significantly less than universities of applied sciences and research universities but more recently have slightly increased their activities across all platforms. Most other trends show continuous growth in or stabilization of social media activity.

4.3. Users' Engagement with Content Published by Swiss HEIs on Facebook, Instagram, and Twitter

About RQ1, user engagement on Twitter as measured by the total sum of likes, retweets, quotes, and replies was low until 2014 when it increased considerably for universities of applied sciences and research universities to an average of 7,207 and 8,080 reactions per annum, respectively (see Figure 3). Engagement with universities of applied sciences' tweets dropped by 80% in 2015 before slowly increasing again in the subsequent three years. Since 2019, engagement with universities of applied sciences' tweets again decreased, leading to a rather low average of 1,768 reactions in 2021. Similarly, engagement with research universities' tweets dropped in 2015 by 56% but increased since then, resulting in a considerable average of 14,008 reactions in 2021. Users' reactions to the tweets of universities of teacher education were very low during the first years and increased slowly since then, to an average of 1,254 reactions in 2021.

On Facebook, users' reactions to content (i.e., the total sum of likes, shares, and comments) were low until 2015, when engagement increased rapidly for universities of applied sciences and research universities, to an average of 8,844 and 11,406 reactions, respectively. Engagement with research universities' Facebook posts increased for three consecutive years, with a peak of 14,692 reactions, on average, in 2017. Afterward, this engagement steadily decreased, leading to 7,960 reactions, on average, in 2021. Engagement with Facebook posts by universities of applied sciences increased over the years, with a peak of 13,523 reactions in 2018. Hereafter, this engagement decreased steadily, resulting in a total of 8,016 reactions, on average, in 2021. Universities of teacher education received a very low yet slowly increasing level of engagement on Facebook until 2019, when it peaked at 2,649 reactions, on average. From 2019 to 2021, this engagement decreased by 60%, leading to an average of 1,033 reactions in 2021.

On Instagram, users' reactions to content (total sum of likes and comments) for research universities were comparably high in 2013 with an average of 3,909 reactions. Afterward, engagement numbers for research universities rapidly increased, with a peak of 59,182 reactions in 2020, as shown in Figure 3. Universities of applied sciences achieved a steady and considerable increase in responses on Instagram over the years, arriving at 52,666 reactions in 2021. Universities of teacher education received their first user reaction on Instagram in 2013. Afterward, user engagement increased slowly until 2020, when it stabilized at around 3,500 reactions per year, on average.

Regarding RQ2, results show that engagement on Instagram was much higher than on Facebook and Twitter (see Figure 3). While engagement with HEIs content on Instagram has risen over the years, it has declined on Facebook in recent years. Twitter data provided no evidence of a general trend across different types of HEIs. The comparison of engagement levels across HEIs showed that research universities were most successful

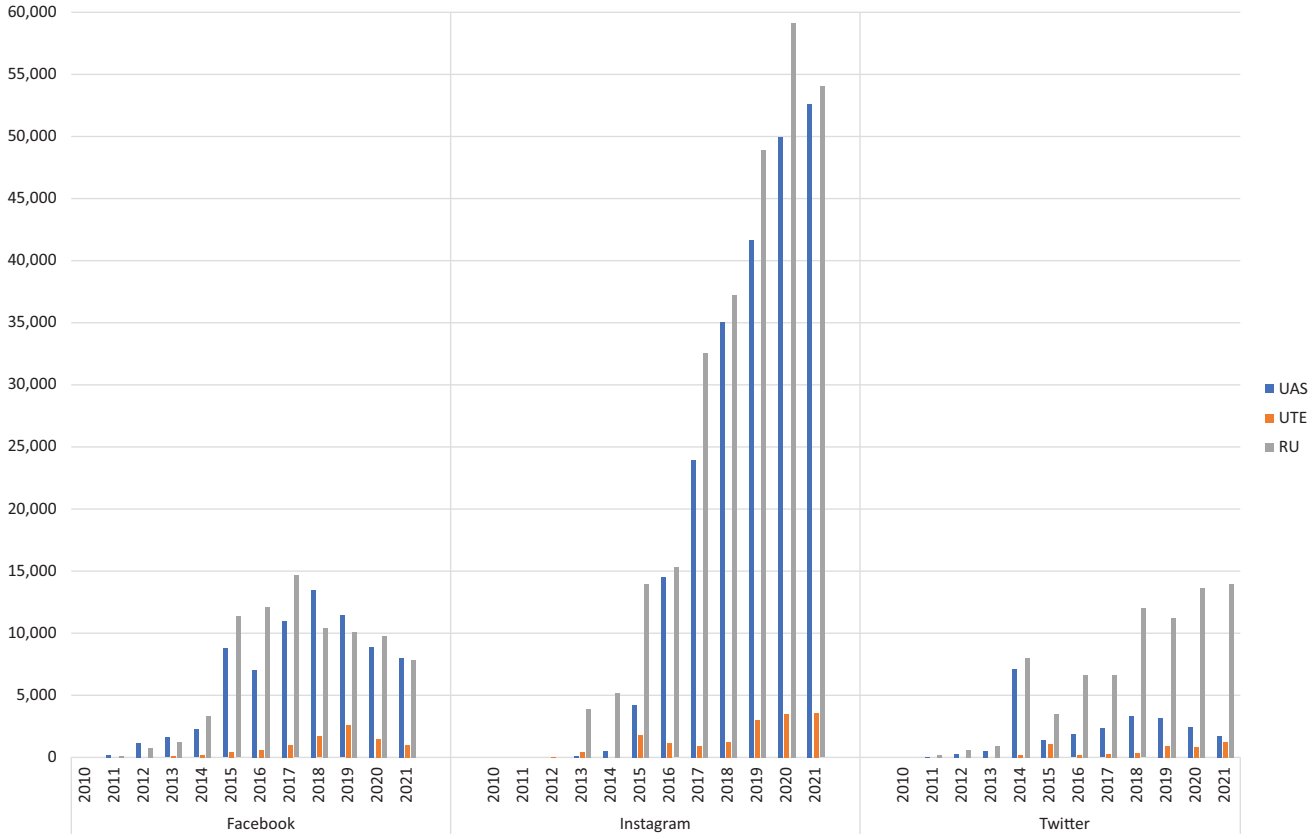

Figure 3. Yearly average number of user reactions to social media posts published by Swiss HEIs on Twitter, Facebook, and Instagram. Note: The mean value (*M*) and the standard deviation (*SD*) were both calculated for each value and are available in Tables I and II in the Supplementary File; UAS = universities of applied sciences; UTE = universities of teacher education; RU = research universities.

in generating reactions across all platforms. Universities of applied sciences received the most reactions on Instagram, followed by Facebook, but attracted rather low engagement on Twitter. Universities of teacher education received much less engagement across all three platforms compared to universities of applied sciences and research universities.

4.4. Differences in Content Topics and Stakeholders Mentioned Among Swiss HEIs on Facebook, Instagram, and Twitter

Examples of content topics coded as "organization" include social media posts related to financing, staff, and governance; topics coded as "research" include scientific results, scientific projects, collaborations, scientific conferences, and applied research with a product or service nature; topics coded as "teaching" include courses, schedule announcements, new teaching offerings, student achievements, and student projects.

Regarding RQ3, Figure 4 shows that 50% of all content posted by research universities on social media focused on organizational matters, followed by posts about research (30%) and teaching (20%). Similarly, universities of applied sciences most often posted about organizational matters (53%). Compared to research universities, however, they attributed more importance to communication about teaching (32%) and less importance to research topics (15%). Universities of teacher education gave equal weight to content about teaching (43%) and organizational matters (41%) while communicating considerably less about research (16%). These differences between types of HEIs held across all three social media platforms, albeit with some variations. Generally, the three topics were more evenly distributed on Twitter and Facebook compared to Instagram. Posts about research were the least frequent on Instagram (7.3% of total share) and most frequent on Twitter (32.4%). Teaching was most frequently talked about on Instagram (38.5% of total share) and least on Twitter (17.7%). Overall, research-related topics across all social media platforms were low for universities of applied sciences (15%) and universities of teacher education (16%), while research accounted for almost a third of the content (30%) posted by research universities.

RQ3 also asked which stakeholders were mentioned in the posts of different HEI types. After coding the main stakeholder of each social media post (including those mentioned directly in the text, via @-mentions or replies) results showed that the most frequently mentioned stakeholders in social media posts by Swiss HEIs were internal actors (see Figure 5)—the HEI staff including

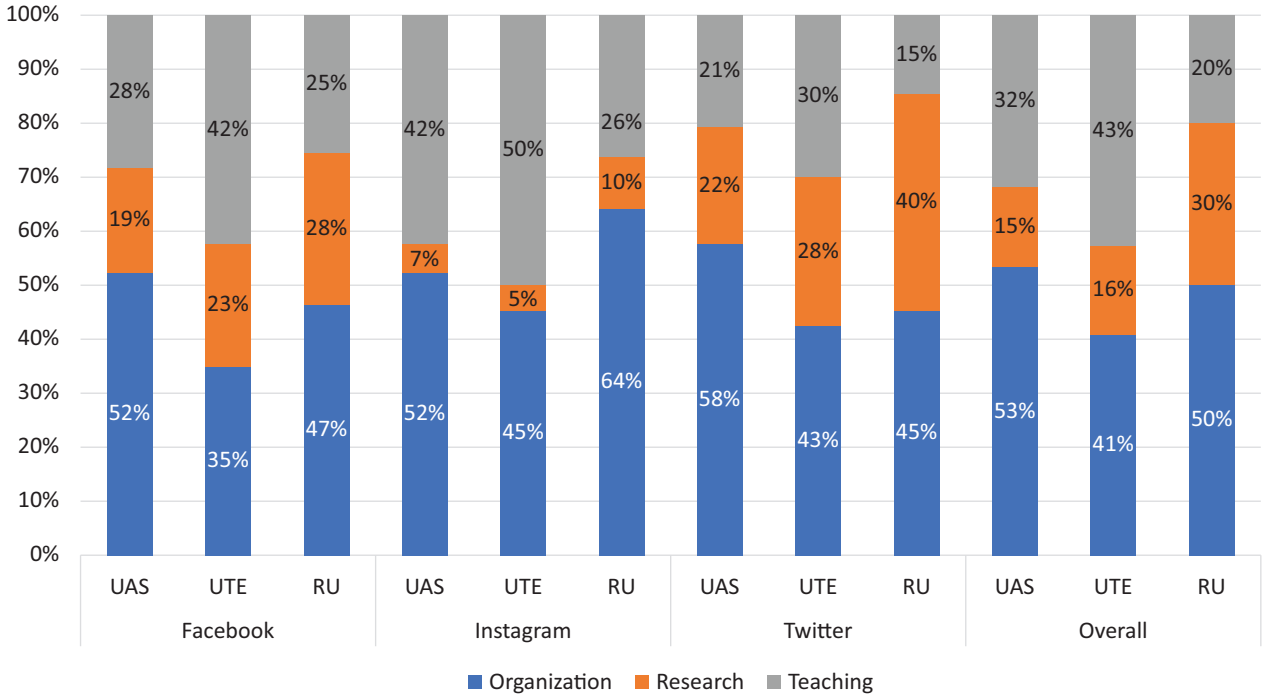

Figure 4. Topics mentioned in social media posts by Swiss HEIs on Facebook, Instagram, and Twitter (*n* = 4,500). Note: UAS = universities of applied sciences; UTE = universities of teacher education; RU = research universities.

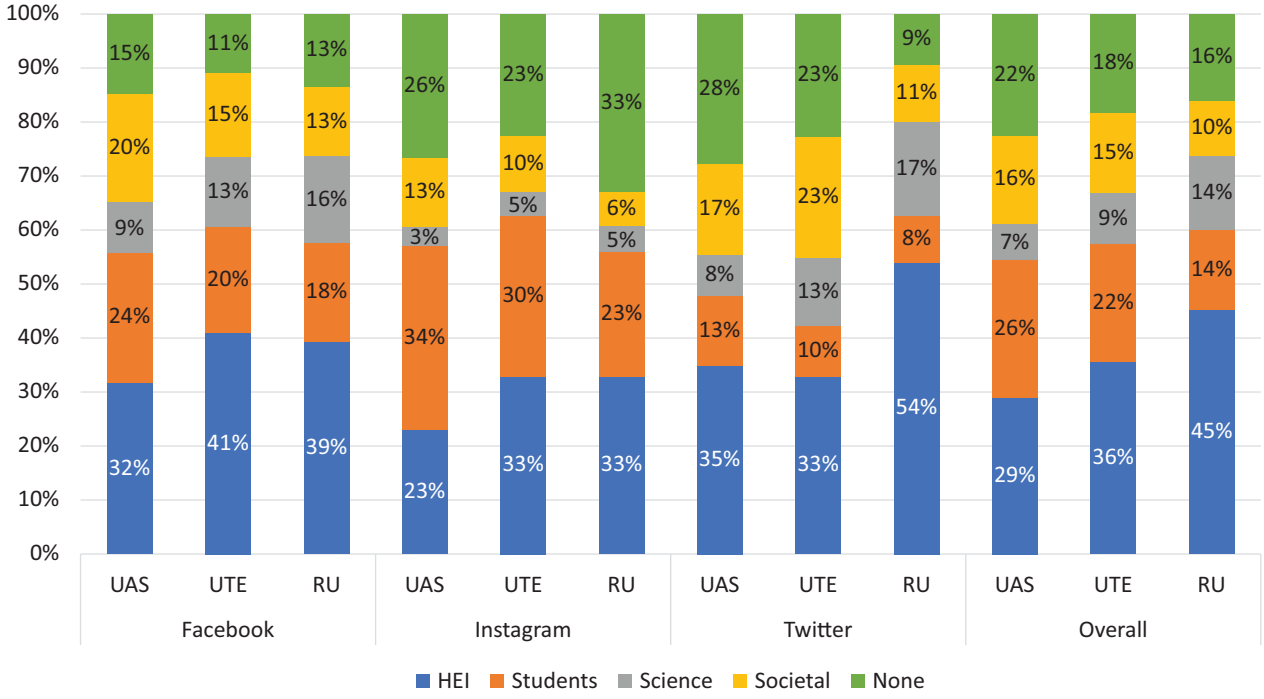

Figure 5. Percentage of total stakeholders mentioned in social media content published by Swiss HEIs on Facebook, Instagram, and Twitter (*n* = 4,500). Notes: Stakeholders coded as "HEI" = individuals or groups who were academic employees or administrative staff; "Students'' = prospective, current, or former students of the university; "Science'' = individuals or organizations that were not "HEIs" themselves but were active in academia, e.g., visiting professors; "Societal" = actors and organizations from politics, media, the arts, culture, and industry; "None" was coded if no identifiable stakeholder was included in the post. UAS = universities of applied sciences; UTE = universities of teacher education; RU = research universities.

its academics. The second largest stakeholder group differed across HEI types: former, current, or prospective students were the second most frequently mentioned stakeholders for universities of applied sciences and universities of teacher education, mentioned in 26% and 22% of all posts, respectively. Research universities' posts gave equal weight to the mentioning of their students and the wider science community beyond the HEI (14%). In comparison, science stakeholders received the fewest mentions by universities of applied sciences (7%) and universities of teacher education (9%). The group of societal stakeholders, such as media, politics, business, the arts, and culture, received the fewest mentions by research universities (10%).

Results for RQ3 related to the differences in the stakeholders mentioned across platforms showed that former, current, and prospective students were the most frequently mentioned stakeholder group on Instagram, while least mentioned on Twitter. The scientific community was the least mentioned group on Instagram. For universities of applied sciences, this was also true for Facebook and Twitter. Societal stakeholders were mentioned moderately across all platforms.

To answer RQ3 regarding hypertextuality, our results displayed in Table 1 showed that embedding links in social media posts was most common on Facebook (61%), followed by Twitter (52%). As expected, the number of URLs posted on Instagram was low (5%) since they are not clickable on the platform.

The URLs themselves were mostly self-referential: Across all platforms and HEI types, they linked most often to the HEIs' websites. This share of self-referential links was highest on Instagram with an average of 75%, followed by Facebook (65%) and Twitter (57%). Links to news media were much less frequent across HEI types, with 16% on Twitter, followed by 13% on Facebook, and only 2% on Instagram. Links to social media content were overall least frequent for all HEI types, with 12% on Twitter, followed by 5% on Facebook, and only 2% on Instagram. URL sources were most differentiated on Twitter and least differentiated on Instagram. More detailed results are available in Table III as part of the Supplementary File of this article.

Hashtags—an additional aspect of hypertextuality—were, by far, most common on Instagram with 90%, on average, followed by Twitter, with 58%, and low on Facebook with only 20% of content including one or more hashtags.

Our results on the multimodality of social media communication by HEIs show that the use of pictures was the most common audio/visual feature used across all three platforms. Instagram had the highest share with an average total of 86% of posts including at least one picture, followed by Facebook with 40%, on average, and Twitter with only 29%. The use of videos was also most common on Instagram with videos included on an average of 14% of posts, followed by Facebook with 12%. Emojis were used frequently by all HEI types on Instagram, with an average total of 38% across HEI types, and were somewhat common on Facebook, with an average total of 22%. Both emojis and videos appeared very rarely in HEI Twitter posts, with 8% and 3%, respectively. Our results showed no significant differences between HEI types with respect to both hypertextuality and multimodality.

5. Discussion and Conclusion

The study at hand is the first to examine an entire country's HEI's social media communication, on the three most used platforms, over a longer period of time. It analyzes all 42 Swiss HEIs including research universities, universities of applied sciences, and universities of teacher education over 18 years. We combined large-scale automated analysis and manual content analysis. In doing so,

Table 1. Hypertextual and multimodal features per platform and HEI.

n = 4,500		Hypertextuality		Multimodality		
		URL	Hashtags	Picture	Video	Emojis
Facebook	Total	61%	20%	40%	12%	22%
	UAS	57%	20%	44%	10%	25%
	UTE	72%	13%	49%	12%	10%
	RU	65%	22%	29%	17%	18%
Instagram	Total	5%	90%	86%	14%	38%
	UAS	6%	87%	84%	16%	36%
	UTE	1%	95%	92%	8%	34%
	RU	4%	95%	87%	13%	46%
Twitter	Total	52%	58%	29%	3%	8%
	UAS	63%	65%	31%	3%	9%
	UTE	45%	55%	39%	4%	16%
	RU	45%	54%	27%	3%	7%

Note: UAS = universities of applied sciences; UTE = universities of teacher education; RU = research universities.

the study provides comprehensive and robust descriptive data on a major facet of organizational science communication that has risen in importance recently (Schäfer & Fähnrich, 2020; Vogler, 2020).

In international comparison, Swiss HEIs show similar adoption rates as Portuguese HEIs on Instagram and Facebook (Almeida & Morais, 2020), Canadian HEIs on Twitter (Veletsianos et al., 2017), and British HEIs on Instagram (Stuart et al., 2017). However, other countries had a faster adoption rate, such as Australian HEIs on Twitter (Palmer, 2016), Italian HEIs on Facebook and Twitter (Oppici et al., 2014), as well as HEIs in the US on Twitter (Linvill et al., 2012).

We found the initial uptake for Instagram—the latest of the three platforms to go live—to be the quickest, with the first accounts created only a few months after the platform was launched, and a steady increase in diffusion in the following years. However, Facebook showed the quickest adoption rate, with most Swiss HEIs creating an account between 2009 and 2011. By now, the diffusion of all platforms among Swiss HEIs has reached a high level and, possibly, a point of saturation.

First, these findings align well with those of other studies (Fürst et al., 2022a; Marcinkowski et al., 2013) reporting on the diversification of HEI communication, including the use of more social media channels. Our data also clearly demonstrate that most HEIs are active on multiple social media channels.

Second, despite the widespread diffusion of all three social media among Swiss HEIs, we found no general increase in the intensity of communication. Regarding the past few years, we only observed a slight increase in the communication of research universities on Twitter and of universities of applied sciences on Instagram. Otherwise, intensity stabilized or decreased across platforms and HEI types. We found clear differences in the intensity of social media communication between different HEI types. Twitter was used most by research universities, while most Instagram and Facebook posts were from universities of applied sciences. Universities of teacher education were much less active across all platforms compared to universities of applied sciences and research universities. These findings align well with similar studies revealing structural variety in communication (e.g., Bélanger et al., 2014) and studies indicating a strong presence of research universities on Twitter (Vogler, 2020). To explain these differences, the affordances of the social media platforms and their user groups as well as the strategic aims of HEI communication may play a role. Nevertheless, recent research on the goals of HEI communication found only small differences between HEI types (Fürst et al., 2022b), insinuating that aims of communication are an implausible explanation. Further research into the influence of social media platforms on HEI communication is needed to confirm and better understand structural differences in communication.

Third, our study demonstrated similarities and differences in HEIs' social media content. Most content across all platforms focused on organizational matters, followed by topics related to teaching. This is a stark and notable contrast to news media coverage about HEIs in Switzerland (Fürst et al., 2021) and beyond (Friedrichsmeier et al., 2015), which has been shown to strongly focus on research.

Fourth, our results on stakeholders mentioned in content showed that the most frequently mentioned stakeholder group across all social media were internal actors (HEI staff), followed by students. Results on hypertextuality and multimodal features show a high adaption of HEI communication to basic platform logic: HEIs use a high variety of visuals and frequently employ hashtags and links combined with the mentioning of relevant stakeholders. Future studies could look into the interplay of such factors and how to optimize communication for better engagement on social media platforms.

Fifth, our results on user engagement showed that it varies between platforms. Considerably more users reacted to HEI posts on Instagram compared to Facebook and Twitter.

Overall, results show a widespread adoption of social media among Swiss HEIs, with a broad portfolio and an intensive and platform-specific use that generates increasing amounts of user interaction and engagement. Earlier, more pessimistic diagnoses about a lack of professionalism and adequate use of social media among HEIs (e.g., McAllister, 2012) seem less warranted based on these results. Nonetheless, the results also suggest pockets of untapped potential within HEIs social media communication: While Instagram is used less, particularly by research universities and universities of teacher education, it is the platform that shows the most user engagement. It would therefore be a potentially fruitful endeavor for HEIs to invest more in communication on this platform.

In addition, our results also suggest that HEIs no longer only use social media as mere extensions of traditional communication formats or to distribute content produced for news media on more channels. Swiss HEIs seem to use social media as more complementary to news media coverage, i.e., as a channel designed for different audiences and focused on topics that legacy media are less likely to pick up. This finding should be verified by future studies systematically comparing news media coverage of HEIs with their social media content.

Notably, however, the strong focus on student marketing reported for HEIs from the—considerably more commercial—higher education systems in the US, the UK, or Canada (e.g., Bélanger et al., 2014) is not as pronounced in Switzerland with its strong publicly funded universities. The primary focus of social media communication by Swiss HEIs is self-referential, directed towards their staff and students, geared towards community and reputation-building, and often referring to organizational and teaching matters. Promotional content still plays a role on their social media but is less pronounced than elsewhere.

Finally, our results show that Swiss HEIs social media communication was surprisingly stable during the Covid-19 pandemic. We did not find a pronounced impact of the pandemic on the intensity, content, or engagement with social media content published by Swiss HEIs during the first two years of the pandemic except for higher engagement with posts of research universities in 2020. This seems to contrast case studies reporting differences in HEIs' social media use during the pandemic (e.g., Bularca et al., 2022) but may also be due to the broad quantitative measures used in our study to facilitate a broad census of all Swiss HEIs.

It must be mentioned that our study also has a number of limitations. While it provides comprehensive and longitudinal data for the most used platforms in Switzerland, it still does not cover the entire spectrum of social media communication. We omitted YouTube, which has gained importance for HEIs communication in the past few years (Meseguer-Martinez et al., 2019; Ros-Gálvez et al., 2021), TikTok, where an increasing amount of science-related content can be found as well (Zeng et al., 2021), as well as other platforms like LinkedIn or Reddit. Moreover, our data collection was limited to Switzerland, which adds a country case to the international scholarship but limits conclusions for other countries. However, the basic measurements used in this study can be applied in future research, thereby allowing comparisons across countries and continents. We used quantitative measurements to analyze the content characteristics and user engagement. By applying qualitative methods, future studies could shed light on user comments and dialogues between HEIs and their stakeholders on social media. Both qualitative and quantitative methods can also enrich our understanding of whether HEI communication on social media has become more professionalized over the years, for instance, by making full use of the available tools and formats of the respective platforms.

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Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the author (unedited).

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Article

Between Calls for Action and Narratives of Denial: Climate Change Attention Structures on Twitter

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Abstract
The threats posed to society by climate change often fail to become priorities for voters and policymakers. Nevertheless, it has been shown that merely paying online attention to climate change can increase the perceived severity of the associated risks and thus encourage climate action. Therefore, we focus on public discourse on Twitter to explore the interplay of "triggers" and discursive features that stimulate attention to climate change. We collected data from 2017 to 2021, identified each year's top five "peak" events of climate attention, and applied manual content (*N* = 2,500) and automated network analyses (*N* = ~17,000,000). The results show that while specific events and actors may not trigger and maintain attention permanently, there are discursive features (types of domains, discourses, users, and networks) that continuously shape attention to climate change. Debates are highly politicized and often call for action, criticize administrations, stress negative future scenarios, and controversially debate over the reality of climate change. Attention thereby is amplified within hybrid discourses which merge different triggers, being dominated by political, cultural, and journalistic media accounts: Political events trigger posts that stress the reality of climate change, whereas tweets on protests and cultural events are amplified if they call for action. However, antagonism and backlashes to such posts are essential features of the peaks investigated. Accordingly, attention is often connected to controversial debates regarding focusing events, polarizing figures (such as Greta Thunberg or Donald Trump), and the formation of counter-public networks. Which content is amplified highly depends on the subnetworks that users are situated in.

Keywords
climate change; content analysis; discursive features; network analysis; politicized debates; Twitter

Issue
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1. Introduction: Attention to Climate Change

Climate change poses a serious threat to society, yet the topic has long struggled to rank highly on the public and political agendas. Agenda-setting proposes that the amount of attention an issue receives in the media influences how high it ranks on the public and political agendas (McCombs & Shaw, 1972). For example, Sampei and Aoyagi-Usui (2009) found that increased levels of news media attention to climate change can influence public concern about the issue. More recently, the rise of social media has revived considerations of reverse and intermedia agenda-setting (Neuman et al., 2014). Instead of news media determining which issues get put on the agenda, issues are put on the agenda through a dynamic interaction between news media and social media (Neuman et al., 2014). For example, when investigating the intermedia influence between Twitter's and newspapers' agendas on the topic of climate change, Su and Borah (2019) found that when it comes to breaking news, Twitter is likely to influence newspapers' agendas. In contrast, during non-breaking news periods, newspapers guide Twitter's agenda. It was also found that cross-media agendas of news media articles and

political actors on Twitter are interrelated (Gilardi et al., 2022). While debates on Twitter are often only led by a loud minority of users, we argue that the specific composition of highly relevant and influential users, as well as cross-media receptions beyond the platform, make climate discourses on Twitter relevant objects of study to understand how climate change is publicly negotiated.

Bruns and Burgess (2011) suggest that the affordances of the platform make it possible to quickly form collectives. These moments of collective attention can provide momentum for environmental movements and allow them to demonstrate the public support they receive to policymakers (Thorson & Wang, 2020). Public discourses on social media platforms such as Twitter have thus become "too important now to ignore" (Veltri & Atanasova, 2017, p. 4) and can be an indicator of attention given to specific topics over time.

Twitter is used by a diversity of highly relevant journalistic, scientific, and political actors and is particularly relied on during spontaneously emerging events (Hu et al., 2012). Therefore, it is relevant to find out which focusing events (Birkland, 1998) trigger attention to climate change debates in which way. Mediated attention, however, does not necessarily reflect ideological unity on issues: the emergence of "ad-hoc publics" (Bruns & Burgess, 2011) of climate change may allow an easier proliferation of (mis-)information and potentially results in polarized communities (Tyagi et al., 2020).

By combining automated and manual analyses, this article seeks to discover which types of issues, events, discourses, and actors attract, shape, and sustain attention to climate change on Twitter. The findings are then clustered and combined with network analysis to identify underlying structures of the debate. Thus, this article's overarching research question is: What are the general patterns and structures of peak attention to climate change on Twitter?

2. State of Research

Mediated climate change attention can be an important proxy to measure how societal climate action is negotiated. Therefore, we try to address the social media perspective of this field of research from two perspectives: The relevance of accumulated attention in the form of focusing events and the community-centered perspective of networked gatekeeping of attention and (counter-)publics regarding these issues beyond the sheer event and amount of attention.

2.1. Focusing Events Producing (Social) Media Attention to Climate Change

Studies on both news media and social media show that focusing events trigger peaks in attention to climate change. In the context of agenda-setting, Birkland (1998, p. 54) defines climate-change-focusing events as relatively rare sudden events that are "harmful or revealing the possibility of potentially greater future harms," potentially influencing agenda policies and mobilizing the public. Liu et al. (2011) apply a broader definition of focusing events which includes organized events, such as high-profile international conferences, the publications of scientific reports, or the release of movies. We use the term "focusing events" from here on following Liu et al.'s (2011) expanded definition, thus, to broadly refer to any event which focuses attention on climate change.

On social media, like for traditional news media, the most important focusing events for climate attention include political events (e.g., elections), scientific publications (e.g., reports from the Intergovernmental Panel on Climate Change [IPCC]), and high-profile international conferences (e.g., Conferences of the Parties [COP]; Abbar et al., 2016; Kirilenko & Stepchenkova, 2014; Thorson & Wang, 2020). In addition, social and cultural focusing events also trigger attention, such as climate protests or the Pope's Encyclical (Chen et al., 2022; Thorson & Wang, 2020). Nevertheless, the similarity of issue attention triggers between news media and social media becomes more complex regarding weather events (Neuman et al., 2014). There is consensus in the literature that weather and climate characteristics are not such important drivers of attention in traditional news media (Brulle et al., 2012). In contrast, various empirical studies have shown that social media attention to climate change is triggered by temperature anomalies (Pearce et al., 2019) or extreme weather events (Abbar et al., 2016).

However, a synergy of multiple factors is often responsible for a peak's magnitude (Boykoff, 2007; Hase et al., 2021), and these factors differ significantly between media types and platforms. It has been shown that, when debating climate change protests, news outlets highlighted political and economic implications of climate change, "while movement actors focused on action-oriented mobilization," such as voting and climate strikes, on Twitter (Chen et al., 2022, p. 406). As features of posts that trigger attention to climate change on Twitter can deviate strongly from news media coverage of an issue, it is not only crucial to ask *what* events trigger attention, but also *who* generated amplification *in which way*: for example, Newman (2016) found that during the release of the fifth IPCC report, most amplified tweets came from individuals and bloggers. Attention to information distributed via Twitter may also differ depending on user types: Scientists, journalists, ordinary users, or politicians are relevant at different times and for different communities (Walter et al., 2019). Ripberger et al. (2014) found Twitter activity peaks to be dominated by "public" rather than "expert" tweets on severe weather events. Still, traditional news sources were predominantly shared in discussions about climate change on social media (Pearce et al., 2019). Additionally, Lörcher and Neverla (2015) investigated *how* attention was being drawn during peak events and found that communication during the release of the IPCC report centered mainly around science, whereas posts about

COP19 incorporated a diversity of domains such as politics, economy, science, and activism.

Accordingly, attention triggers cannot be reduced to mere focusing events. People may react to tweets regarding events based on whether they contain hoax narratives (Jang & Hart, 2015), imaginations of "climate futures" (Guenther et al., 2022), "discourses of climate delay" (Lamb et al., 2020), evaluations of the role of economies and governments (Murali et al., 2021), calls for action (Chen et al., 2022), or other aspects. Tweets and retweets can then be understood as a proxy for attention and amplification regarding societal issues (Zhang et al., 2018). Nevertheless, Thorson and Wang (2020) found that spikes in attention to specific climate change events on Twitter have short lifespans, "peaking and dying out quickly" (p. 351) with low rates of repeated participation. Gallagher et al. (2021) also stress that retweet-count analyses are just a measure of short-lived attention peaks to topics and do not necessarily represent "sustained amplification" (p. 2). The authors, therefore, argue that amplification of content should be investigated with a focus on distinct and potentially diverging ideological publics that could be situated in the very same debate.

2.2. Networked Gatekeeping: Oppositional Publics of Climate Change Attention

Such real-time, competing evaluations of phenomena such as extreme weather events can temporarily increase the network polarization and controversy of Twitter discourses (Tyagi et al., 2020), which can then positively influence the magnitude of attention peaks (Garimella et al., 2017). Users would then, through "networked gatekeeping," form separate communities that "collectively amplify" content "trough their individual acts of curation and filtering" (Gallagher et al., 2021, p. 2). This results in ideologically-opposing "ad-hoc publics" of attention, either acknowledging or denying climate change reality or the need for mitigation. Consequently, (re-)tweet counts cannot be understood as a universal form of amplification permeating a general public sphere on Twitter. Instead, research should consider which diverging publics are (not) reached, as "different publics amplify different information sources, meaning that different publics crowdsource different elites" (Gallagher et al., 2021, p. 1). Therefore, (uncommented) retweeting practices are an effective proxy to measure ideological homogeneity within and heterogeneity between politically and ideologically opposing user networks (Barberá et al., 2015).

Pearce et al. (2019) review several studies which found evidence of the formation of echo chambers and polarization on social media, often based on political ideology. These skeptics, however, may not be located within echo chambers that generally ignore the mainstream discourse but rather a *counterpublic* "that is in opposition to the mainstream hegemonic public sphere" (Kaiser & Puschmann, 2017, p. 373). This suggests that counterpublics regularly attend to the mainstream discourse, aiming to change it in their interest, resulting in counterpublics more frequently targeting the mainstream than vice versa. Kaiser and Puschmann (2017) found that in an analysis of climate-change-related blogospheres, counterpublics depended heavily on the mainstream, both for keeping track of the debate and reaffirming their contrarian identity. Their work is supported by the findings of Tyagi et al. (2020), who identified polarized retweet networks on Twitter, with "believers" demanding to combat climate change and "disbelievers" attacking them (p. 5).

3. Research Aims and Research Questions

Based on the insights presented above, it appears crucial to identify overarching patterns and structures of attention to climate change on Twitter. Attention may, in fact, be generated in relatively short-lived peaks. Nevertheless, these peaks may incorporate compositions of focusing events, discourses, and user networks that continuously reemerge. For this purpose, it is important to ask not only which events triggered attention, but also how climate change issues are debated by which user networks.

To shed light on these aspects, we analyzed 25 peak moments of activity/attention to climate change on Twitter spanning over five years, from 2017 to 2021. Assuming that social media posts are not only amplified because they refer to relevant event types but also how they contextualize those events, we associated the most-shared posts with domains (e.g., nature, politics, civil society), evaluative discourses (e.g., climate change as a hoax, calls for action, negative future scenarios), user types, and their networked interaction.

Understanding (re-)tweets as a proxy for (amplified) attention, we conducted automated network analyses (N = ~17,000,000 posts) and a manual, quantitative content analysis of the 100 most retweeted posts per peak day (N = 2,500). We initially identified the five peaks of attention per year (concerning tweets, retweets, and replies) and then classified them in order to answer our first research question:

> RQ1: Which types of focusing events are associated with attention to climate change on Twitter?

Then, we dissected the tweets posted during these events to identify characteristics of highly amplified tweets:

> RQ2: Which domains, discourses, and users are most dominant and amplified during peak days of climate change attention on Twitter?

We then aimed to cross-reference all of our coding to find overarching clusters of discourses, users, and events throughout the timespan of data retrieval:

RQ3: Which clusters of events, discourses, and actors lead to attention during peak days of climate change attention on Twitter?

Finally, this distribution of clusters was investigated from a network perspective in order to find out whether processes of networked gatekeeping between opposing ideological publics could be found:

RQ4: To which extent do network structures and amplified content within them represent opposing ideological publics during peak days of climate change attention on Twitter?

4. Methodology

4.1. The Data Sample

Our data collection combined two sources: the Online Media Monitor (OMM, University of Hamburg) and Twitter's Academic Research API via the academictwitteR R-package (Barrie & Ho, 2021). The API for Academic Research allows retrospective access to Twitter's public data and "delivers very good samples" (Pfeffer et al., 2022, p. 10). However, the API does not provide researchers with content that has been deleted or banned from the platform. The OMM collected all tweets on climate-change-related issues from 2017 onwards on a daily basis. However, this database did not collect tweets containing the term "climate crisis" which started to emerge within recent years. Also, the OMM only collected information on tweets but no information on who retweeted. Therefore, we combined academic research API search queries with the OMM dataset in order to obtain a more detailed image of the discourse based on tweets containing "#climatechange," "climate change," "#globalwarming," "global warming," and "#climatecrisis,'' or "climate crisis" between 2017 and 2021 (for more info on search strings and data retrieval, see Section 4.1 in the Supplementary File).

4.2. Peaks of Attention

From this accumulated number of tweets and their retweet count, resulting in a total activity of 144,996,316 (re)tweets over five years, we defined 25 peaks of collective attention to climate change (see Figure 1). These peak events were chosen as five independent days of the highest activity per year. As some events caused peaks that lasted longer than a day, we merged neighboring days if they had a tweet count within a minimum of 10% of the initial peak day's tweet count.

4.3. Manual Coding of Content, Users, and Event Types

To gain an overview of what users were referring to during times of high activity, we applied manual coding of four main variables: event types (RQ1), domains, discourses, and user types (RQ2). We decided to manually analyze the posts because Twitter debates are highly contextual and often only implicitly refer to relevant events, topics, or actors. Also, posts often referred to news items, images, memes, or other material attached. Additionally, our understanding of discourses demanded contextual knowledge about climate change debates beyond automated analysis of textual data.

Through inductive and deductive processes, we established two broader concepts for coding the content of the tweets (RQ2): People were not just tweeting about government decisions, deniers, protesters, or future scenarios, but evaluated and described them in particular ways. Our codebook, therefore, included "domains" such as nature, science, politics, and culture, as well as "evaluative discourses" (e.g., climate change denial or debates on societal inequality) that were deemed relevant in the aforementioned literature. We then started coding from an inductive perspective: Two coders categorized the content of 500 randomly sampled tweets

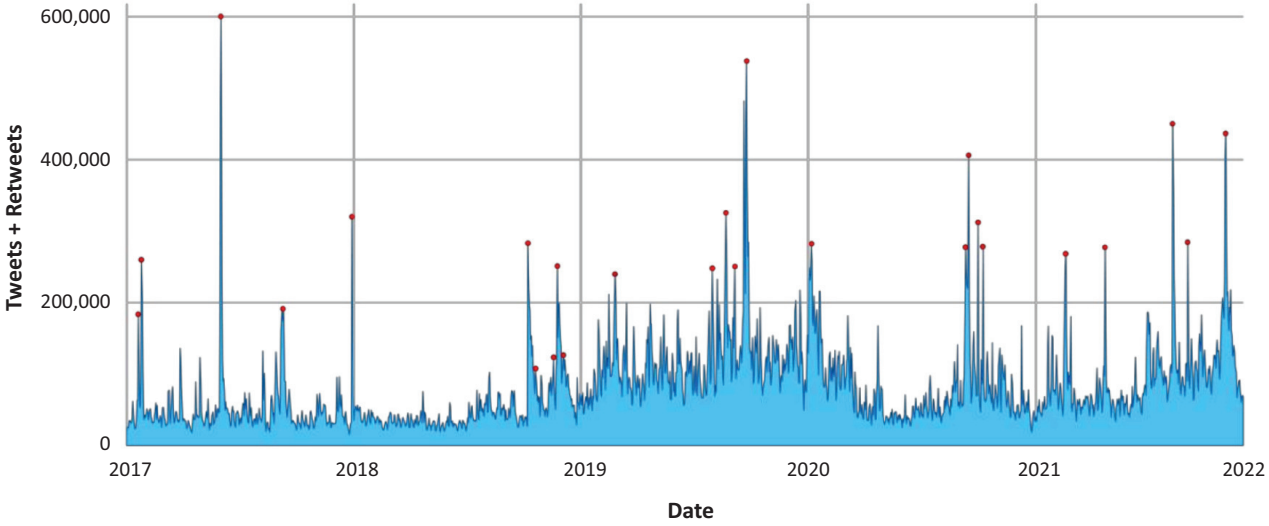

Figure 1. Climate activity on Twitter from 2017–2021 by the number of (re-)tweets and replies.

in intervals of 100 items. After each interval, the coders re-evaluated and modified the codebook. We then categorized the user types that posted the most-amplified tweets along a domain differentiation (e.g., politicians, scientists, or media).

After having gathered specific knowledge about the attention peak's most relevant tweets through the coding process, we labeled each event (RQ1) according to event types on the basis of discussion and mutual agreement (e.g., elections/campaigning, extreme weather events, or releases of scientific reports).

For a list of all the coded categories and inter-/intracoderreliability tests, see Section 4.2.1 of the Supplementary File.

4.4. Cluster Analysis of Manual Coding

As part of RQ3, we performed a cluster analysis to identify patterns of composition between domains, discourses, actors, and event types. First, we checked for appropriate frequencies of categories (i.e., more than 5%) and, in some cases, recoded variables. In total, 35 variables were included (see Table 2.2 of the Supplementary File). Second, as is common in cluster analysis, we applied single-linkage clustering to identify outliers and had to remove one tweet from the sample. To estimate the number of clusters (i.e., compositions), we applied the most common method in cluster analysis, Ward's method, in hierarchical cluster analysis. For a long time, Ward's method was known to provide robust solutions (see Morey et al., 1983), even for binary variables (see Matthes & Kohring, 2008). The elbow criterion recommended a six-cluster solution, which we deemed a good fit for the data after checking the four-, five-, and seven-cluster solutions. Due to the high number of tweets, we then decided to apply *k*-means cluster analysis, specifying the number of clusters as six. The decision for *k*-means cluster analysis was due to its robustness and its advantage of creating not only cluster identification per tweet but also its distance from the cluster center. Means and *t*-values were exported and considered when naming and describing the clusters (see Table 2.3 of the Supplementary File); for dichotomous variables, means represent the frequency and *t*-values indicate the over- or under-representation of variables within the cluster. Taking these two measures into account, the naming of clusters was done due to the relevance of variables within the specific cluster and the dissimilarity to other clusters. *F*-values were used to check cluster homogeneity (which was the case). A discriminant analysis was applied for validation, indicating that 92% of the tweets were clustered the same way, showing a good fit.

4.5. Automated Analysis of User Interactions

Additionally, we conducted a series of automated analyses of user mentions and retweets in order to find the actors that were most attended to and amplified. First, we extracted users mentioned via @-signs in the text to determine the most relevant actors addressed or talked about (RQ2). As has been illustrated, uncommented retweeting can be used as a proxy for affirmative amplification within ideologically-aligned communities. Therefore, we conducted a network analysis of uncommented retweets (RQ4) of all peak events and visualized ten networks (two per year) that were archetypical for the different event types we investigated. Different algorithms, implemented in Gephi (Jacomy et al., 2014), have been applied for analysis and visualization: The ForceAtlas2 algorithm determines the position of user profiles (as nodes) within a network based on interconnections (as edges) to one another. This force-directed layout simulates physical systems: "Nodes repulse each other like charged particles, while edges attract their nodes, like springs" (Jacomy et al., 2014, p. 2). ForceAtlas2 thereby spatializes communicative interaction and transforms them "into a map" (Jacomy et al., 2014). We then calculated community modularity as value per node based on the density of interaction with other users (Blondel et al., 2008). For some more in-depth analyses, network visualizations were filtered by the *k*-core parameter to uncover tightly connected parts, hierarchies, and "influential spreaders" (Qin et al., 2020). *K*-core decomposition partitions a network into levels from loosely connected to more central nodes where each node has at least *k* neighbors. In order to increase comprehensibility and simultaneously avoid excessive distortion of network visualizations, we have only filtered nodes that have coreness 1. These calculations were then combined with data from our manual content analysis to show whether different user networks attended to/amplified different types of tweets. Going beyond questions of ideologically-homogenous amplification, the findings on retweet-based modularity classes were then cross-referenced with analyses of @mention-/reply-practices across communities to measure the degree of intergroup contact between (counter-)publics.

5. Results and Discussion

5.1. RQ1: Beyond Scientific Reports: Synergetic Focusing Events of Attention to Climate Change

When looking at the results from the manual content analysis, seven general types of events appeared to trigger the vast majority of attention and/or amplification within the Twittersphere, mainly supporting earlier findings (Hase et al., 2021; Thorson & Wang, 2020): Governments' Actions/Decisions (e.g., White House deleting information about climate change from their website), Extreme Weather Events (e.g., Australian bushfires), Releases of Scientific Reports (e.g., IPCC), Campaigns/Elections, Protests, Cultural Events (e.g., Oscars), and Climate Conferences (e.g., COPs).

Most posts from days of high activity had to be assigned to multiple event types: Except for four days

in 2017 and the releases of two scientific reports, the peaks could be assigned to multiple types of events. The data thereby may imply a discursive shift: while in the past, particular events or actions were enough to trigger climate change attention, this changed from 2018 onwards. Supposedly, discourses became more diverse, and climate-change-related protests, political acts, and extreme weather events appeared to be discussed at a higher frequency and in connection with each other. When comparing the results to Thorson and Wang (2020), a striking difference is the occurrence of extreme weather events, which only contributed to one attention spike in their data (i.e., Hurricane Sandy). In our data, extreme weather was much more dominant. However, it is hard to tell whether they are discussed more or whether they simply occur more often and/or with higher impact. Also, our coding scheme allowed multiple codings of a day, contributing to higher occurrences of each event type. Still, this implies a new diversity of topics triggering climate attention, not being limited to scientific reports but permeating all kinds of societal life (politics, culture, civic engagement, and nature in general).

Figure 2a shows the frequency of different event types, while Figure 2b shows the average tweet and retweet count associated with each peak event type. Government Actions/Decisions are the most common triggers of attention. Similarly, they account for the

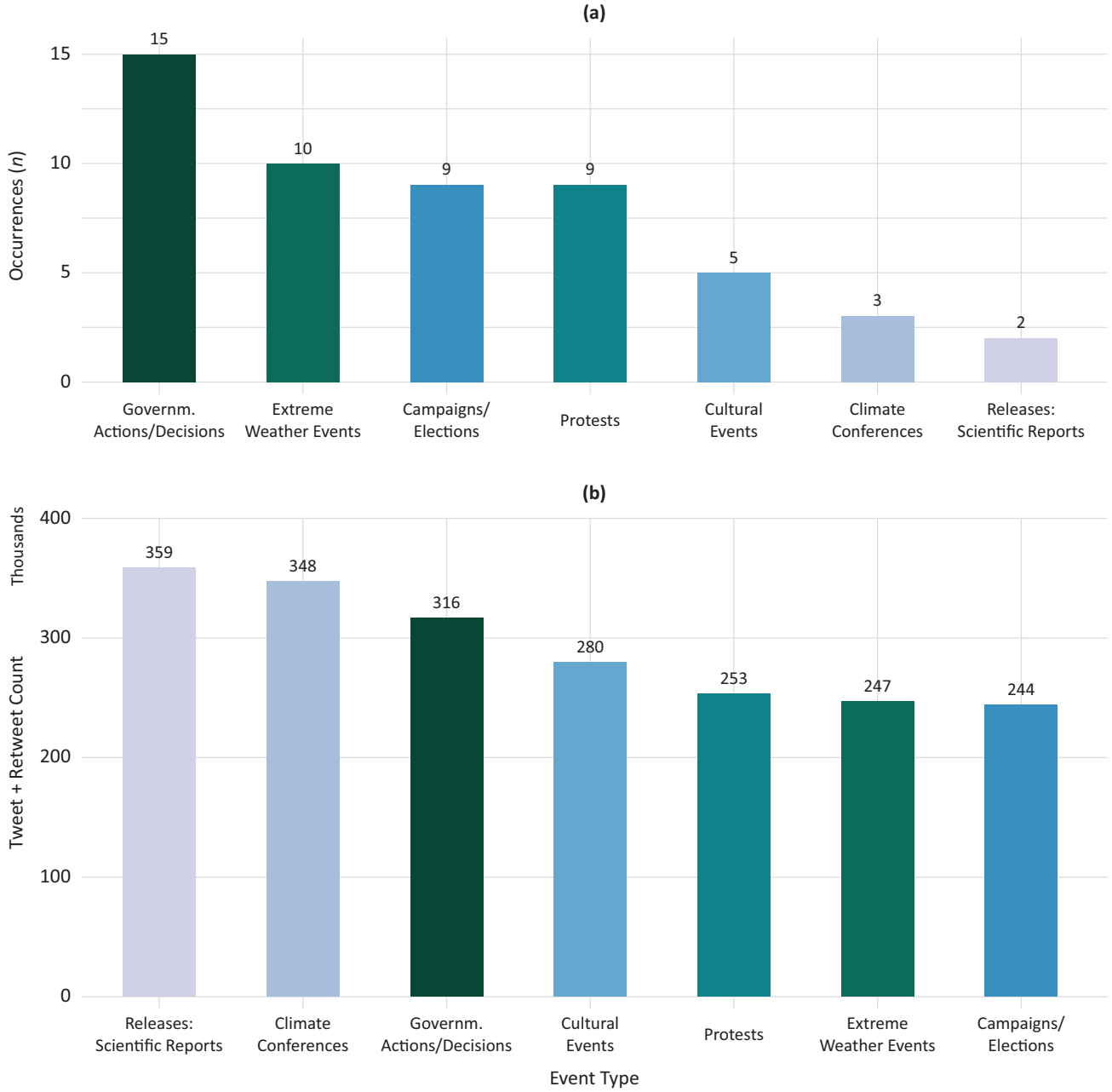

Figure 2. Comparison of different focusing event types: **(a)** Frequency of focusing event types associated with the 25 peak events (*N* = 53, multiple coding was possible); **(b)** Average tweet and retweet count for each event type.

third-highest volume of tweets and retweets (see Figure 2b). However, while campaigns and elections were relatively frequently associated with peak events, they were also associated with the lowest volume of tweets and retweets of all the recorded event types. On the other hand, international climate conferences served as relatively rare triggers of Twitter attention to climate change; however, they were associated with the second-highest volume of tweets and retweets. Various peaks in attention were dually associated with Climate Conferences and Protests or Civil Society actions. In particular, multiple speeches by Greta Thunberg caught the attention of Twitter users, namely, her speeches at COP in Katowice (December 2018), the French Parliament (July 2019), and when she testified in front of the US House of Representatives on Earth Day (April 2021). Similarly, there was a large turnout of climate activists involved in the Shut Down DC protests in Washington D.C. ahead of the UN Climate Action Summit in New York (September 2019).

Outside the world of politics and activism, many other focusing events were also associated with peaks in attention to climate change. Extreme weather events fell towards the lower end of the spectrum in terms of incidences of tweet and retweet counts; however, they were the second most frequent triggering event types. Releases of major scientific reports showed an opposite trend. Despite only triggering two major peaks during the 5-year window, as shown in Figure 2a, the releases of scientific reports were associated with the highest tweet and retweet volume of any focusing event type, averaging 348,000 per associated peak day (see Figure 2b). These events included the release of the IPCC special report on the impacts of global warming above 1.5° in October 2018 and the release of the IPCC 6th assessment report in August 2021.

5.2. RQ2: Most Dominant Domains, Discourses, and Users—Debating Climate Change Reality and Political Actions

To answer RQ2, we utilized our manual coding categories to consider to which extent domains, discourses, and actors played a role for activity and amplification of posts.

As can be seen in Figure 3, National Politics was the most dominant domain across the sampled tweets, with Nature, Media, and Science as distant second, third, and fourth. Regarding the discourses, expressions of climate change belief, government criticism, and calls for action against climate change effects were the most frequent. Still, Climate Change Denial and Narratives of Delay were mentioned relatively often (for detailed definitions of the categories, see Appendix 4.2.3).

From a user perspective (see Figure 4), individual journalists and politicians were responsible for the greatest proportion of tweets (20% and 18%, respectively) and were also widely amplified, receiving 21% and 23% of all retweets, respectively. Religious actors were inactive throughout, contributing the lowest number of tweets and receiving the least amplification. Finally, scientists, international organizations (e.g., UN), and economic actors only minorly contributed in terms of tweet frequency and retweets received.

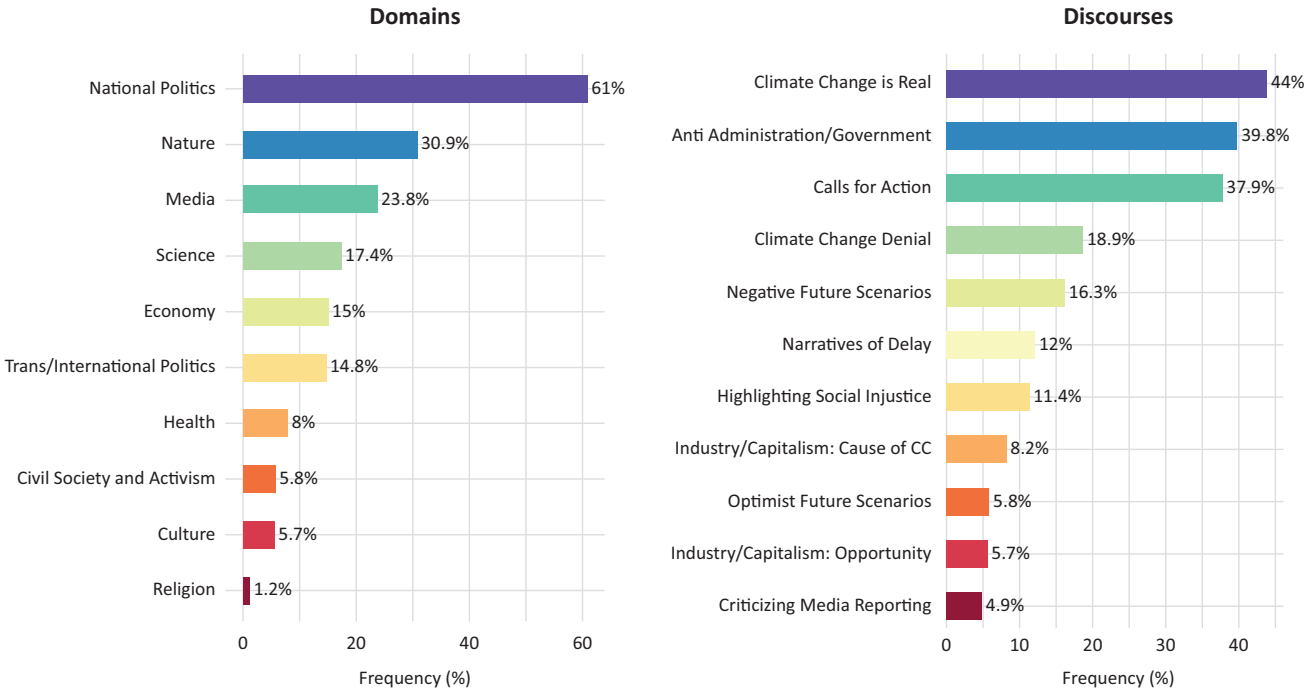

Figure 3. Distribution of domains and discourses explicitly mentioned in coded tweets. Notes: CC = Climate change; Pro Administration/Government (2.44%) and Denying Social Injustice (1.40%) are not listed.

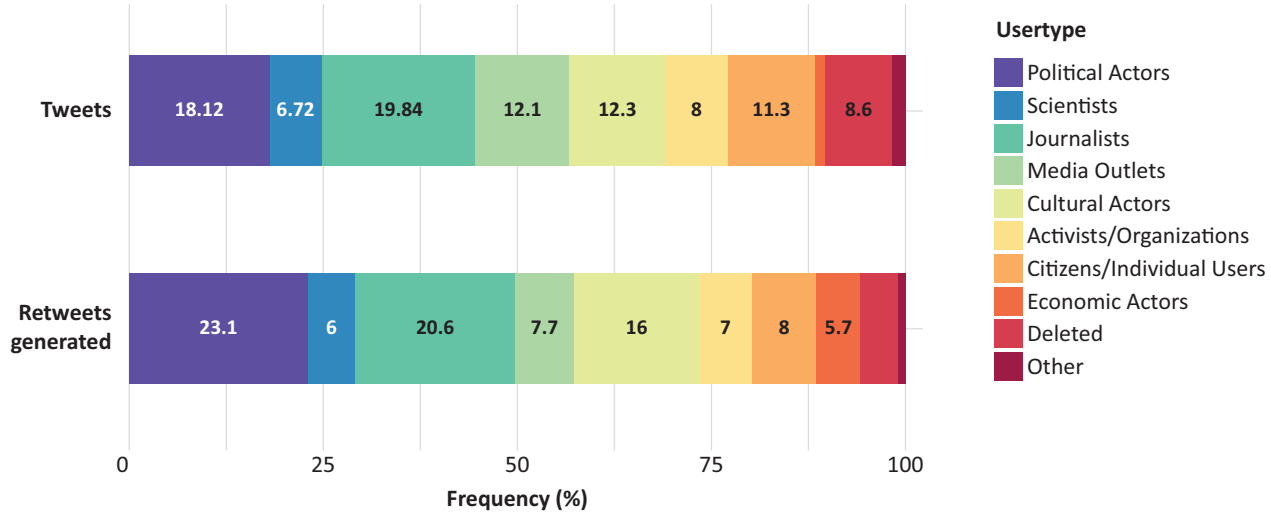

Figure 4. Distribution of user types for tweets and retweets. Note: Values below 5% are not highlighted in the plot.

Our findings support Thorson's and Wang's (2020) earlier findings on climate debates on Twitter: Users rarely return to the discursive site. We found that out of the 896,600 unique users in our dataset, only 161,261 (17.9%) wrote a tweet during two or more peak events. When looking at specific accounts (see Figure 5), analyses showed that potentially polarizing actors such as Donald Trump and Greta Thunberg were often mentioned in tweets, while not or only rarely participating in the discourses: Donald Trump's tweets were never part of the Top 100 amplified posts of a peak event, while Thunberg's tweets only occurred five times in our data. They were addressed and discussed but were not part of the discursive peaks from a user perspective. Still, there were other users—particularly political actors—who were continuously discussed and mentioned while simultaneously distributing highly-amplified tweets themselves, such as Alexandria Ocasio-Cortez (14 tweets) and Bernie Sanders (20 tweets). Here, agenda-setting processes of political actors in networked publics seem to work in two regards: While conservative political actors who potentially delayed climate change action, such as Donald Trump or Boris Johnson, were mainly talked about and did not participate in climate debates themselves, actors that made climate change part of their own political agenda actually took part in the debate, making the Twitter activity of such accounts a potential proxy for their political agenda (see e.g., Gilardi et al., 2022).

5.3. RQ3: Clusters of Climate Change Discourses That Generated Attention

Investigating overarching patterns, we found clusters composed of domains, discourses, actors, and event

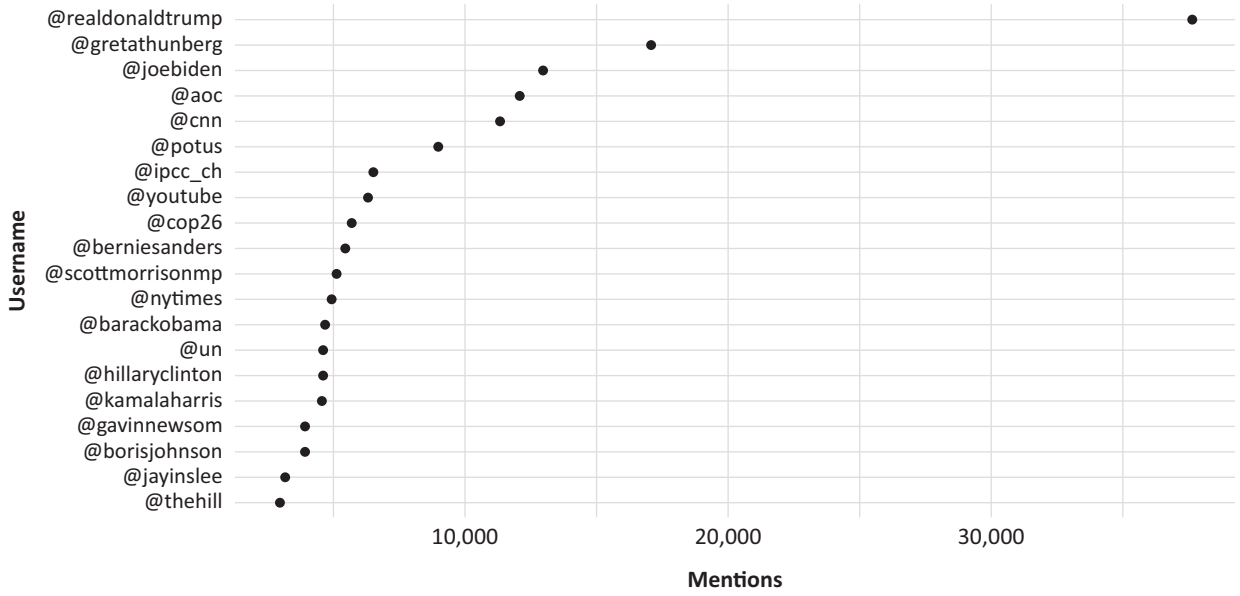

Figure 5. Most mentioned user accounts during the 25 peak events.

types that were spread along the dataset, showing patterns that went beyond the individual properties of those particular categories (see Section 2 of the Supplementary File for an overview of means and *t*-values).

5.3.1. Cluster 1: "Universal Calls for Change" (19% of Coded Tweets)

The first cluster is mainly composed of relations to nature—however, this cluster generally comprises a wide variety of domains. More significantly, it comprises call-for-action discourses (64%) and, in relative scale to general distribution, significantly higher rates of future scenarios (25%), references to the role of corporate actors and current economic structures for climate change (22%), and social injustice (15%). Despite a lack of explicit references to "civil society" actors, this cluster is strongly related to occurrences of protests (76%), yet also extreme weather and cultural events (45%), all of those being a trigger for people demanding change and taking action. The biggest event-related triggers, however, are governmental actions and administrative decisions taking place, causing many users—with political actors contributing to a significantly higher degree (28%)—to take a stance on these processes.

5.3.2. Cluster 2: "Scientific Calls for Change" (12% of Coded Tweets)

The second cluster is comparable to the "universal calls for change" cluster regarding the diversity of domains addressed in the tweets. However, in this cluster, science is highly amplified (54%) in comparison to its overall sample distribution (only 17%). Therefore, it is no surprise that posts associated with this discursive cluster are mostly related to days of releases of scientific reports (59%) and represent disproportionately high participation of scientific actors (12%). These posts also often stressed the reality of climate change (41%) and the need to act (50%) against it. Negative futures that may arise from this climate reality are depicted much more frequently (40%), potentially mirroring how the climate reports triggered climate attention—at least for a short period—through their negative portrayal of what humanity will face.

5.3.3. Cluster 3: "Narratives of Denialism" (14% of Coded Tweets)

This cluster comprised mainly of (international) politics (88%) and contained the most references to civil society actors and protests (13%) of all clusters. Tweets following this pattern, however, are far from reflecting and appreciating the climate protesters' demands: climate skeptic and denialist discourses (87%), as well as narratives of delay (35%), shaped this cluster, often mirroring backlashes to (inter-)national politics and protests being described as indicators of "globalist" or "socialist" agendas of "climate scams." Therefore, such tweets mainly occurred during times of government actions (98%) or during protests (25%) and climate conferences (28%), as these events bring forward the discussion of potential actions against climate change and their potential antagonists, such as Donald Trump. Tweets from this cluster, therefore, take an antagonistic stance towards debates mirrored by other clusters. This cluster appears to be mostly represented by individuals rather than organizations: individual citizens (14%), deleted accounts of (mostly) individual citizens (14%) and individual journalists (29%) made up for the majority of the posts.

5.3.4. Cluster 4: "Believers Criticizing the Administration" (23% of Coded Tweets)

The fourth cluster is the most dominant one and mainly incorporated tweets from "anti-hoaxers" or climate "believers" (86%) and those criticizing the government's (in)action (85%) on climate change mitigation. These posts were almost all political (95%) and still associated with a relatively high degree of calls for action (28%). Accordingly, it is not surprising that—compared to the whole sample distribution—relatively high numbers of activists (10%) and cultural actors (19%) are associated with this cluster, almost always referring to events of governmental actions (98%). As the discourse is dominated by US-American communication, this cluster may not appear extraordinary at first glance: Governmental decisions could often be associated with Donald Trump's administration. However, even after changes of administration in the US, as well as during events that refer to other countries (e.g., during Australian elections), the same patterns occurred (e.g., peak event 24, Section 4.2.2 of the Supplementary File).

While the clusters that were introduced thus far mirrored interrelations of discourses, events, and actors that could clearly be attributed to a particular stance towards climate change debates, the following two clusters represent attention to more controversial debates and events.

5.3.5. Cluster 5: "Contested Weather Debates" (15% of Coded Tweets)

Tweets that were assigned to this cluster have a strong relation to the nature domain and thereby, not surprisingly, always relate to extreme weather events (100%), which often co-occurred with cultural events (74%) or political campaigning (73%). However, these natural events—such as wildfires, hurricanes, or floods—do not only trigger one ideological stance in the climate debate. While there is a high number of "believers" (48%) associated with posts from this cluster who also appear to be warning about the implications for future generations (22%), this cluster also involves many climate change deniers (22%) joining the conversation on extreme weather events. These actors then are not mainly triggered by the event itself but by the "believers''

evaluation. While a diverse range of actors—not so many scientists, supporting Pearce et al.'s (2019) earlier findings—participate in these discourses and utilize extreme weather events to illustrate what that might imply for humanity's future, skeptic actors aim to deny this relationship between the event and climate change reality. They state that, for example, wildfires are the result of "bad forest management" or "arsonists," denying that this has anything to do with global warming. Similar patterns are seen in the discussions of cultural events. Often, these events—such as the Oscars, which resulted in a lot of reporting on actors' pledges to do something about climate change—appear to generate a backlash rather than accelerate calls for action in a productive manner. The most amplified posts were most often stressing the hypocrisy of cultural actors rather than supporting their demand to acknowledge climate change reality. It, therefore, is of no surprise that this cluster, just as the "narratives of denialism" cluster, is relatively often associated with deleted accounts (12%) and individual journalists (18%).

5.3.6. Cluster 6: "Contested Political and Social Debates" (17% of Coded Tweets)

The sixth cluster mirrors a similar pattern yet focuses on other events. Posts from this cluster are always related to days that accumulate debates about protests and political campaigning (100%), often also relating to cultural events (53%). Again, a diverse range of domains occurs within this cluster, mainly politics (66%) and media events (43%), yet also mentioning civil society and activism to a slightly higher degree than average (7%). This cluster contains a high degree of calls for action (46%) and "believer"-discourses (32%). However, it also contains a disproportionally high representation of the antagonistic discourses: narratives of delay (20%) and denial (19%). Here, it seems, discussions of social injustice and the role of industry and politicians are triggered by protests and political campaigning, resulting—to a certain degree—in backlashes of people positioning against these demands. Again, the relatively high number of denialists participating in this discourse appears to be reflected by a relatively high proportion of individual accounts (15%), deleted profiles (13%), and individual journalists (19%) distributing content associated with this cluster.

In conclusion, the separation into seven general event types—despite frequent multi-coding per attention peak—was the main cluster-determining category of our coding scheme. Here, the cluster analysis uncovers patterns of highly homogenous attention to some events (releases of scientific reports) and synergetic effects of controversy during others. We found clusters determined by tweets that mix different entities within their posts (e.g., Donald Trump visiting an international climate conference while Greta Thunberg is protesting against the world leaders, or people talking about California wildfires and relating that to upcoming elections). Most clusters can thus be interpreted as patterns that mainly occur during (combinations of) certain event types.

5.4. RQ4: Networked Gatekeeping—The Uneven Distribution of Climate Change Debates

These discursive clusters, however, were not evenly distributed across one public sphere. Rather, the amplification of certain clusters reflected particular communities. We combined content data with network analyses (see Figure 6) to investigate whether stances towards climate change were amplified by ideologically oppositional communities and how that affected the overall discourse's structure (RQ4).

We created retweet networks of 10 archetypical peaks (referring to all event types and years) to investigate which communities were amplified. Three networks were selected for content-related analysis and visualization purposes of the article, referring to protests, government action, and political campaigning (for an overview of all additional peak networks, see Section 3.1 of the Supplementary File). To get a better overview, the visualization is filtered by *K*-Core 2, recursively removing nodes that have a degree less than two (see Section 4.5). The distribution of the manually coded content within the retweet-network was then compared with automated community detection that only considered interaction, but not content, in order to determine to what extent homogenous amplification structures were overlapping with distribution patterns of ideological content (see Section 4).

The networks' structures imply that climate change debates are more politically charged and contested than general Twitter debates (Barberá et al., 2015). We found that different publics amplified oppositional stances on the issues: For most of the days, network structures were polarized, separating into a mainstream debate and a fairly small, respective counterpublic. Supporting findings from Tyagi et al. (2020) and others, these networks appear to be polarized along a line of "believers" and "skeptics." Generally, retweeting denialist content is the main predictor of belonging to the counterpublic network (e.g., 83% of users that amplified Narratives of Denialism during Peak Day 21, see Section 3.1.2 of the Supplementary File). However, it is interesting that narratives of delay, which are not explicitly denying the reality of man-made climate change but argue against mitigating its effects, sometimes have a bigger probability of being amplified within mainstream networks (see Section 3.1.2 of the Supplementary File) and thereby overcome processes of "networked gatekeeping" (Gallagher et al., 2021) with a higher frequency.

Generally, mainstream communities appear to consist of groups that dynamically switch between different attention patterns, amplifying different discourses, depending on the event (e.g., demanding government

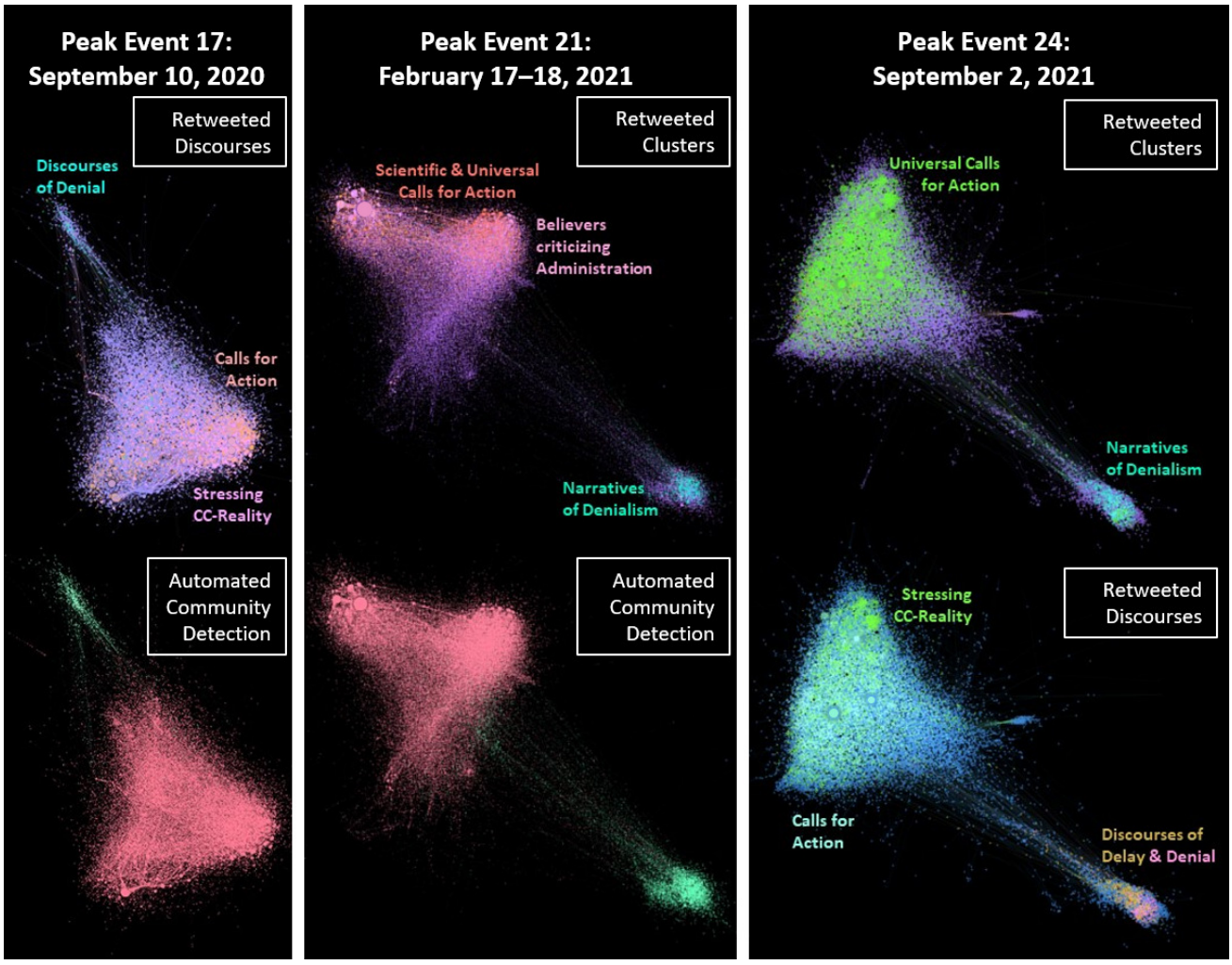

Figure 6. Comparative visualization of content amplification versus automated community detection (modularity classes) that is entirely based on retweet interaction. Notes: CC= Climate change; for two visualizations per year and additional material, see Section 3.1 of the Supplementary File.

actions during elections or stressing climate change reality during extreme weather events, see Figure 6). The application of more detailed community detection parameters, dissecting the network into more than two main communities, unveils that users within the mainstream community frequently share posts by users from other sub-communities, indicating diverse exchange (see Figure 3a in Section 3.1.3 of the Supplementary File). Denialism and hoax narratives, however, are continuously prevalent within oppositional networks—no matter the event type. Our network analysis thereby implies that attention rarely spills over to communities "from the other side." Highly contested debates, such as discussions on extreme weather events or debates about controversial actions and figures such as Donald Trump, may trigger attention to climate change. Nevertheless, this attention rarely surpasses community borders, resulting in publics talking about climate change but not necessarily with each other.

Attention to climate change does thus not mean the same for the Twittersphere as a whole—and does not indicate to what extent this attention can be translated into productive dialogue. Rather, amplified content and "crowdsourced elites" (Gallagher et al., 2021) appear only to trigger attention within ideologically aligned networked publics. This ideologically aligned attention, however, may cause backlashes from other communities. Throughout our data, we identified recurring patterns: mainstream sub-networks mainly communicated internally, while denialist counterpublics tried to engage to a much higher degree with the opposing communities through @mentions and replies (see Section 3.2 of the Supplementary File). Our analysis showed that mainstream communities preferentially self-refer (92%) rather than initiating conversation with the ideologically diverging outgroup community (8%). On the other hand, users belonging to counterpublics almost evenly address users from their own network (52%) and the mainstream (48%). They thereby reach out to (and potentially attack) their respective outgroup far more often, supporting earlier research regarding varying climate debates and media environments (e.g., Kaiser & Puschmann, 2017; Tyagi et al., 2020). From an event-specific perspective, releases of scientific reports tied to extreme weather

events as being the least polarizing types of focusing events. That is to say, the counterpublic represented the smallest proportion of the discourse relative to the other event types (see Section 3.2.2 of the Supplementary File). Interestingly, peaks associated with the releases of scientific reports are the only days on which the counterpublic preferentially communicates within itself rather than referring to the mainstream. This behavior may indicate a more pressing attempt to reaffirm skeptical beliefs, which could be more difficult to justify when presented with such incontrovertible evidence.

6. Conclusion: The Interplay of Climate Change Attention Triggers

We found that a majority of focusing events that were discussed on Twitter during attention peaks (RQ1) were related to politics, political actions, or protests. This illustrates a shift towards fewer peaks of attention associated with releases of scientific reports in comparison to research on older Twitter debates on climate change (Thorson & Wang, 2020). Simultaneously, our results support findings that more recent climate debates are more politicized with users increasingly calling for action during protests (Chen et al., 2022) and beyond.

Climate change attention may often be triggered in short-lived peaks. Nonetheless, we found re-occurring discursive patterns going beyond event types (RQ2), supporting initial findings. Highly amplified tweets were mostly politicized and connected to calls for action, stressing present or future threats, or feeling the urge to criticize those in charge or thinking differently. Accordingly, while releases of scientific reports still seem to be relevant focusing events, the climate change debate appears to be highly politicized, with politics being the most relevant domain and discussions on governmental actions and events being the most relevant event type and having mainly politicians' accounts being directly mentioned.

Here, journalistic content and debate about it often come together as journalistic and media accounts were, despite the highly politicized discussion, combining for more than 28% of the most relevant content, with political actors following closely. Therefore, journalistic contributions appear to ignite discussion on Twitter (Pearce et al., 2019). However, it then seems to matter how these journalistic contributions are discussed beyond the articles' content itself. Throughout our research, it became apparent that it was not just one topic or event that ignited the debate. Rather, it seems that topical hybridity, such as the combination of a climate summit with climate protests and reporting on that, could have resulted in actual attention triggers.

This high degree of politicization of climate change debates may also be a reason for the discursive tension discovered in a majority of the data. Here, both content and network analysis draw a similar picture.

Content-wise (RQ3), even though distributions in the online discourse are far from even, tweets referring to (imaginary) ideological opponents—either "hoaxers that deny climate change reality" or "globalist/socialist narratives based on climate scams"—appear to trigger both activity and amplification of posts. It is therefore not surprising that the cluster of believers criticizing (inactive) administrations, as well as the two clusters referring to highly polarized debates, are those with the highest rates of (re-)tweets, creating the image of attention being mainly drawn by negativity, controversy, and ultimately polarization, supporting Garimella et al. (2017) and Tyagi et al. (2020). However, both studies explicitly targeted conflicting debates through their research design, while we were able to show that high attention to climate change on Twitter is generally associated with politicization and conflict. Nevertheless, despite common conceptions of social media logics, negativity is not a successful driver of attention on its own. Negative future scenarios, exclusively focusing on decaying ecosystems without connecting their message with politics or calls for action, were rarely amplified.

What is more, highly-amplified climate change content does not evenly permeate the entire Twittersphere (RQ4) but produces structures of ideologically opposing (counter-)publics. The network analysis showed that the formation of climate change "ad-hoc publics" rarely results in ideological diversity within the discourse and thus does not seem to persuade those who think differently about these issues. Rather, "networked gatekeeping" (Gallagher et al., 2021) appears to produce a mainstream community and opposing "alliances of antagonism" (Kaiser & Puschmann, 2017). The counterpublics, however, appear to be much more engaged with the mainstream public, with nearly half of their mentions/replies addressing their respective outgroup. High levels of attention in the climate change debate can, therefore, not be understood as entirely positive. The question arises to what extent ideological homogeneity or discursive diversity can lead to dialogue between those with diverging views. We showed that different types of events seem to play a role here. Scientific report releases, for example, seem to initiate less inter-group contact than other events while at the same time generating a very homogeneous mainstream community of users who emphasize the reality of climate change. One can only speculate whether this effect results from the rarity and notoriety of such report releases or from epistemological isolation of dissenters with respect to scientific evidence. In any case, the question arises whether such ideologically homogeneous attention peaks are expedient or whether interaction among dissenters of the climate change debate is more desirable. Here, it will be vital to assess the nature of these cross-group interactions.

Thus, future research should focus on how attention to climate change is connected to either reasonable debate or incivility and how this may vary regarding topics, events, and communities. Thereby, one can evaluate which attributes of (affective) polarization can actually

be observed and which factors trigger (non-)polarized debates, thereby overcoming community boundaries and fostering inter-group deliberation. Here, the role of "narratives of delay" should be further evaluated, as at some moments they have transcended counterpublic boundaries and may implicitly promote skepticism towards climate change mitigation. Also, cross-media and cross-platform effects appeared to be essential to our investigation: We observed synergies between the publication of news and media posts that were then utilized as the basis for debates on political actions and the existence of climate change. Such cross-media flows should be further investigated.

This leads us to limitations in our research: We only investigated communication on one particular platform. While we hope that we made clear why it matters to study communication on Twitter in particular, it is crucial to consider where these insights are distorting the image of public discourses. This is particularly true as recent developments in Twitter's headquarters make it probable that the social media ecosystem will continue to evolve and cause users to migrate to other platforms. Also, it is important not to overestimate the public's engagement with climate change purely based on social media activity. Activism on social media has a relatively low cost to expressing oneself; thereby, participation may not result from deep commitment (Thorson & Wang, 2020). Also, our use of an English language search string neglected tweets in other languages, furthering a dominance (yet, by far not an entirety) of US-based discourses.

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Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the author (unedited).

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Article

The Multilingual Twitter Discourse on Vaccination in Germany During the Covid-19 Pandemic

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Abstract
There is evidence that specific segments of the population were hit particularly hard by the Covid-19 pandemic (e.g., people with a migration background). In this context, the impact and role played by online platforms in facilitating the integration or fragmentation of public debates and social groups is a recurring topic of discussion. This is where our study ties in, we ask: How is the topic of vaccination discussed and evaluated in different language communities in Germany on Twitter during the Covid-19 pandemic? We collected all tweets in German, Russian, Turkish, and Polish (i.e., the largest migrant groups in Germany) in March 2021 that included the most important keywords related to Covid-19 vaccination. All users were automatically geocoded. The data was limited to tweets from Germany. Our results show that the multilingual debate on Covid-19 vaccination in Germany does not have many structural connections. However, in terms of actors, arguments, and positions towards Covid-19 vaccination, the discussion in the different language communities is similar. This indicates that there is a parallelism of the debates but no social-discursive integration.

Keywords
content analysis; Covid-19; multilingual communities; Twitter; vaccination debate

Issue
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1. Introduction

There is evidence that the population with a migration background in Germany was hit particularly hard by the Covid-19 pandemic, and these groups were less willing to be vaccinated (Robert Koch-Institut, 2021). Various reasons were blamed for this, such as cramped living situations or unfavourable working conditions. Another problem was certainly the fact that, at least at the beginning of the crisis, a lot of information or counselling services were only available in German, which meant that not all population groups were reached.

Social media, especially Twitter, are widely used to engage and discuss the issue of vaccination (e.g., Keim-Malpass et al., 2017; Massey et al., 2016). Thus, social media can reach different societal groups with health-related information. But parallel to the great advantages that online media environments potentially offer for the dialogue between different groups in society, the possibilities of online communication may also lead to a fragmentation of public discourse, meaning that online conversations take place in different homogenous groups which are isolated from one another (Dahlberg, 2007). Also, regarding the process of integration, online

social networks can be used to maintain relationships with the heritage culture, as well as to bond to the new culture and build up social capital (e.g., Kim et al., 2011; Park & Gerrits, 2021). Additionally, a discursive fragmentation regarding most contemporary challenges (e.g., climate change or the Covid-19 pandemic) would be particularly severe; they affect society as a whole, and due to their complexity and possibly huge negative impact, they can only be solved if all societal groups are involved. Up to now, only a few studies have looked at online exchanges between different linguistic communities. The existing research does not provide a uniform picture: While some studies show a fragmentation, for example, between Farsi and English blogs (Kelly & Etling, 2008), others indicate that there is at least some degree of mutual reference and dialogue across language barriers in online social networks or that social media can help to overcome cultural differences (Eleta & Golbeck, 2012; Etling et al., 2014; Hale, 2012, 2014).

Against this background, the overall research question of our study is: How integrated or fragmented is the debate on Twitter across different multilingual communities located in Germany?

To answer our research question, we use the Twitter debate about Covid-19 vaccination as an example and include in our analysis tweets in German, Polish, Turkish, and Russian by Twitter users located in Germany in March 2021. We are particularly interested in how the debate on Twitter originated in Germany is structured, i.e., if the debate breaks into different language communities or concentrates on various positions concerning Covid-19 vaccination regardless of language.

By studying multilingual communication, we contribute to existing research in two main ways. First, our article theoretically combines and integrates research dealing with fragmentation and work regarding the role of media use in the process of social integration. Second, existing research regarding the analysis of public discourses mostly ignores modern societies' cultural and linguistic diversity and seldom analyses processes of fragmentation (or the potential of integration) across different language communities living in the same country. Thus, our study's results help provide deeper insights into how heterogeneous publics form and interact.

2. The Multilingual Discussion About Covid-19 Vaccination on Twitter

Online social networking sites offer new ways for different types of actors to relate to each other—a crucial characteristic of social networking sites like Twitter is their networked character, in which actors form the nodes of a network that can be connected through various types of relations (e.g., follower structures, retweets/forwards, hashtags, or mentions in distinct posts). Thus, each actor using social networking sites individually selects to whom or to which debate or argument they want to relate. The effects of these individual choices are a matter of an ongoing (scientific) debate in which the underlying question always refers to possible fragmentation or integration processes and, thus, the potential (or failure) of the public sphere to integrate different actors and viewpoints (Dahlberg, 2007).

Mostly, fragmentation is understood as a result of a sorting process in which people connect based on common homogeneous characteristics (e.g., ideological or political standpoints; Häussler, 2018), resulting in opposing groups that are segregated from each other.

With regard to our research question, two different drivers of fragmentation (or integration) could be identified: (a) the cultural background and the language in which Twitter users decide to write their tweets, as well as (b) the positions and arguments towards Covid-19 vaccination or regarding certain vaccines (independent from a specific language). Thus, different constellations are possible: First, discourses in the various languages may be detached from each other with varying degrees of internal conflict or consonance. This would point to segregation, i.e., actors have no relations to actors representing another culture but only connections to actors representing their own culture and tweet only in "their" language (Mittelstädt & Odag, 2015). Second, the different publics are connected by opinionative alliances that form around the positions towards the issue at stake with varying degrees of heterogeneity concerning the respective languages. Diverse communities in which actors are linked to each other across different languages could be interpreted as multiple inclusion and, thus, integration. Third, marginalisation would be indicated by isolates in the network, i.e., nodes that have no connections to any other part of the network (Mittelstädt & Odag, 2015).

Only a few studies have looked at the influence language or geographic region has on the structure of online networks. In general, digital media are particularly popular among people with a migration background (Gattringer et al., 2022). In a survey of young migrants (N = 475) from North Rhine-Westphalia (a federal state in Germany), WhatsApp and YouTube were the most used social networking sites; 21% indicated that they use Twitter regularly. But studies also show that language, as well as geography, play a large role in structuring hyperlink networks or follower relationships on Twitter (Hale, 2012, 2014; Herring et al., 2007; Kulshrestha et al., 2012; Takhteyev et al., 2012). Additionally, Hale (2014) found that multilingual users on Twitter were more active than those who tweeted in only one language. Thus, these multilingual users form important bridges between different language communities. Based on this, our first research question is:

> RQ1: How is the multilingual debate about Covid-19 vaccination in Germany on Twitter structured?

Regarding the discussion about vaccination on Twitter, studies show several interesting results. First, the majority of actors tweeting about Covid-19-related vaccination

consist of laypeople sharing their own experiences and opinions; (health or scientific) professionals only seem to play a minor role (Herrera-Peco et al., 2021; Lentzen et al., 2022). Second, the overall sentiment regarding Covid-19 vaccinations seems to be predominantly positive. However, the share of tweets with negative sentiments and mentioning vaccine opposition increased over the course of the pandemic (Bonnevie et al., 2021; Bustos et al., 2022; Hussain et al., 2021; Kwok et al., 2021). Third, regarding the discussed topics, people were particularly focused on vaccine development during the early stages of the pandemic. Pro-vaccine tweets shared their hopes for a timely introduction of a successful vaccine and later praised the relatively fast development, while vaccine-hesitant tweets expressed concern about a (perceived) lack of thorough clinical trials and therefore reduced vaccine safety (Jiang et al., 2021; Liew & Lee, 2021; Lyu et al., 2021; Thelwall et al., 2021). (Perceived) health effects were another widely discussed topic. Tweets with negative vaccine sentiment emphasised (potential) harmful side effects of the Covid-19 vaccines and tried to discourage people from getting vaccinated (Griffith et al., 2021; Liew & Lee, 2021; Muric et al., 2021; Thelwall et al., 2021). However, some people simply documented how they felt after being vaccinated (e.g., mentioning mild side effects) while still supporting and encouraging the uptake of Covid-19 vaccines (Lentzen et al., 2022). Fourth, since the beginning of the pandemic, a number of conspiracy theories have evolved that are disseminated through social networks such as Twitter, e.g. that vaccines will be used to control and monitor the public by implanting microchips into people while vaccinating them (Germani & Biller-Andorno, 2021; Muric et al., 2021). Fifth, specific vaccines were evaluated differently in the discussion on Twitter: BioNTech and Moderna were mostly mentioned in a positive context, whereas AstraZeneca was perceived quite negatively (Jemielniak & Krempovych, 2021; Lyu et al., 2021; Malagoli et al., 2021; Marcec & Likic, 2021).

Existing studies mostly focus on US or English tweets (see Jiang et al., 2021; Kwok et al., 2021; Liew & Lee, 2021; Lyu et al., 2021). However, a few studies focus on non-English discussions, for instance, by analysing tweets from a number of Spanish-speaking countries (e.g., Herrera-Peco et al., 2021). As far as we know, there are even fewer studies looking at different communities within individual countries; notable exceptions are a few works analysing the English Covid-19 vaccination discourse on Twitter (Guntuku et al., 2021; Thelwall et al., 2021). They found that different communities (primarily within the US) focus on varying aspects of the topic, e.g., Black communities debate issues of trust in the healthcare system. Following this, our second and third research questions are:

RQ2: What types of actors participate in the multilingual discourse about Covid-19 vaccination in Germany on Twitter, and which arguments do they use?

RQ3: How similar are the discussions in the different language communities?

3. Methods and Measurement

3.1. Time Frame and Collection of Tweets

We analyse the Twitter discourse on vaccination in Germany during the Covid-19 pandemic. Germany is a country in which a large share of inhabitants has a migration background (approximately 26.7% in 2020; Statistisches Bundesamt, 2022). The German Federal Statistical Office classifies a person as having a migration background if they or at least one parent does not have German citizenship by birth. In 2020, the largest share of people with a migration background (N = 21.9 million) had ties to Turkey at 12.6%, followed by Poland at 9.4% and Russia at 5.6% (Statistisches Bundesamt, 2022). Hence, we included German, Turkish, Polish, and Russian tweets in our sample.

We collected all German, Turkish, Polish, and Russian tweets between March 1st, 2021 and March 31st, 2021, that included one or more keywords related to Covid-19 vaccines. Our goal in defining the keywords was to ensure that our query would capture a wide range of tweets but would also be confined to the debate about vaccines and not Covid-19 in general. Based on the finding of DeVerna et al. (2021) that "covid19," in addition to the generic term "vaccine" as well as the names of certain vaccine developers, captured the most data for English tweets in early 2021, we decided on the following approach: Our list of keywords consisted of "covid19," which is universally applicable across languages, in addition to the generic terms "vaccine" and "vaccination" and the names of all marketing authorisation holders, developers, and specific vaccines that were approved for use or under rolling review in the EU at the time. A translated search query was used for each of the four languages (see Supplementary File). The data was collected by accessing the Twitter v2 API full archive search capability via the academic research program.

All users were then automatically geocoded based on the (non-mandatory) free-form "location" field in their user profile. For this purpose, we used the python library local-geocode (Müller, 2021), which matches (partial) strings against a database export of location names (such as countries, administrative areas, cities, and towns) from geonames.org. We used an extended database export to cover entries with at least 10,000 inhabitants (see Supplementary File for detailed information on matches/non-matches for each language). Relying on "location" fields to geolocate Twitter users is an established approach in social scientific research (for example, Bruns & Enli, 2018; Bruns et al., 2017; Rauchfleisch et al., 2021; Schweinberger et al., 2021; Vogler et al., 2019). However, some groups of users might be more inclined to disclose their location than others. For example, Baruh et al. (2017) find in their extensive

meta-analysis of research on social networking sites that users with greater concerns regarding their privacy are more reluctant to share personal information (see also Schmidt et al., 2022). Thus, users who disclose information about their location are probably less concerned about privacy issues than the general Twitter population. Nevertheless, we believe our geocoding approach is appropriate for this study because the reported differences do not seem to translate directly into differences between language communities. This expectation is supported by previous studies which do not find empirical evidence that a user's cultural background affects their online behaviour regarding private data (Baruh et al., 2017; Liang et al., 2017).

March 2021 was chosen as the investigation period because of the real-world developments that took place at the time, which indicate that it might have been a period when the Twittersphere in Germany was inclined to discuss the issue of vaccination: (a) The German immunisation campaign was making slow progress compared to other countries, (b) the German BioNtech vaccine was already in use, (c) rolling review for the Russian Sputnik V vaccine started in the EU on 4 March 2021, and (d) experts and citizens criticised the AstraZeneca vaccine due to reported severe side effects.

3.2. Sampling

We limited the sample to those 3,216 users who actively participated in the debate with at least two subject-related tweets. Users were considered multilingual if they used two or more of the four languages under study in the sampled tweets (see Table 1 for an overview).

We then built a network of message-sharing activities. This network is formed by considering the sampled users as nodes and their mentions (@user) and retweets of other nodes in the network as edges. Thus, each undirected edge (e_{ij}) represents the tweets authored by user i in which they mentioned or retweeted user j as well as the tweets authored by user j in which user i is retweeted or mentioned. By focusing on mentions and retweets, we capture dynamic interaction patterns between users as opposed to the more static follower structures. In sum, the network consists of 2,229 nodes connected by 4,150 undirected edges.

For the sampling of tweets which became part of the manual coding, a multistep procedure was used. First, all 3,216 active users were included in the sample. Second, we sampled tweets in different languages differently due to limited resources: All Russian (*n* = 420), Turkish (*n* = 88), and Polish (*n* = 39) tweets by active users were included in the sample. Regarding German tweets, we drew a proportionate stratified sample of 18% of all German tweets (*n* = 2658, see Supplementary File).

3.3. Measurement of Actor Types and Their Positions Regarding Covid-19 Vaccination

We conducted a manual quantitative content analysis. The developed codebook included variables on the level of single accounts (e.g., username, main language, actor type) as well as on the level of tweets (main topic, topic sentiment, mentioned vaccines, vaccine evaluation, sentiment towards Covid-19-related vaccination in general; see Supplementary File). Three trained coders worked on the account-related variables and were supported by two more trained coders for the tweet-related variables (see Supplementary File for details). Reliability scores were sufficient for all variables (see Supplementary File).

4. Results

Our first research question concerned how the multilingual debate about Covid-19 vaccination in Germany on Twitter is structured.

The majority of users tweeting in German were part of the network, while only about 30% were isolates (Table 2). However, the opposite was the case for all other languages: Users tweeting in Russian, Turkish, and Polish were mostly isolates and therefore disconnected from the vaccination-related Twittersphere in Germany. In contrast, however, most multilingual users were, via @mentions or retweets, connected to the discursive network that formed around the discussion of Covid-19 vaccination on Twitter.

Table 1. Languages used by Twitter users under study.

Language used	No. of users (perc.)	Mean no. of tweets (sd)
German	3,103 (96.5%)	4.7 (6.8)
Russian	42 (1.3%)	4.9 (4)
Turkish	20 (0.6%)	2.7 (1.3)
Polish	14 (0.4%)	2.6 (1.2)
Multilingual	37 (1.2%)	12.4 (25.1)
Total	3,216 (100%)	4.7 (7.2)

Notes: Based on active users authoring ≥ 2 tweets during the investigation period, *n* = 3,216; users who have published tweets in more than one of these languages were labelled multilingual and excluded from the "German," "Russian," "Turkish," and/or "Polish" categories.

Table 2. Networked and isolated users across all language communities.

Connectivity	German	Russian	Turkish	Polish	Multilingual
Networked users (perc.)	2,183 (70%)	13 (31%)	4 (20%)	0 (0%)	29 (78%)
Isolated users (perc.)	920 (30%)	29 (69%)	16 (80%)	14 (100%)	8 (22%)
Total	3,103 (100%)	42 (100%)	20 (100%)	14 (100%)	37 (100%)

Looking more closely at the multilingual users, almost all switched between two languages, the most frequent pairing being German and Russian (65%, *n* = 37). Interestingly, the only three verified accounts were official channels of Russian consulates and embassies in Germany, which mostly focussed on mentioning the Sputnik V vaccine in a positive way. Additionally, although only 1.2% of all active users were part of this subgroup, multilingual users were comparatively active, with 12.4 tweets per user on average (the average for the whole sample was 4.7 tweets per user, see Table 1). One individual user, in particular, seems responsible for the high mean number of tweets: "Karina Begun," who published 145 tweets in total. Many postings were retweets from accounts that mostly disseminated favourable statements about the Russian government. It is noteworthy that while "Karina Begun" is predominately tweeting in Russian and only occasionally in German, she is more heavily connected to a specific group of German-speaking users in our sample who focus on the negative aspects of vaccine-related policies in their discussions.

Our second research question dealt with the actors participating in the discourse about Covid-19-related vaccination on Twitter and the arguments used in those discussions. To answer this, we first looked at the actor type distribution across the different languages (Figure 1).

All language communities predominately consisted of private citizens, which we understood as individual actors directly translating their offline persona to Twitter and acting in a personal, unofficial capacity (Figure 1). While another large part of the Turkish language community was made up of journalistic actors, there were considerably fewer actors of this actor type in the other language communities. Furthermore, scientific, political, and healthcare actors only played a small role in our sample. Overall, no major differences can be identified regarding the actor type of active Twitter users in the different language communities.

Next, we looked at topics discussed in the different language communities (Figure 2). Across all language communities, vaccine-related policies dominated the discourse. Tweets were coded to contain this topic if they discussed policies directly or indirectly related to Covid-19 vaccines, including, for instance, the (political) vaccine authorisation process or the government's inoculation campaign. The rest of the German tweets were mostly concerned with vaccine-related (health) effects, i.e., discussing vaccine efficacy, health risks, or benefits. At the same time, vaccine availability (on a societal level in terms of production rate, distribution efficiency, and accessibility), vaccine development (in terms of research plans, clinical trials, development progress reports, or funding plans), and the vaccination process (the actual

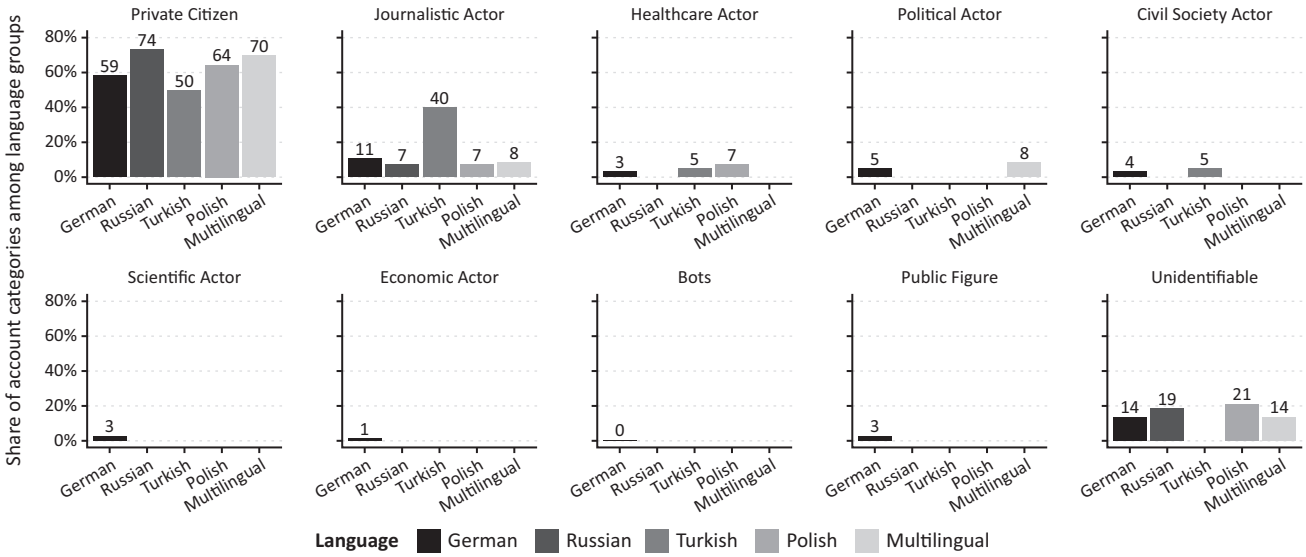

Figure 1. User categories among language groups for accounts with at least two tweets in the sample. Notes: German (*n* = 3,103), Russian (*n* = 42), Turkish (*n* = 20), Polish (*n* = 14), Multilingual (*n* = 37); no statistically significant association (*p* = 0.43).

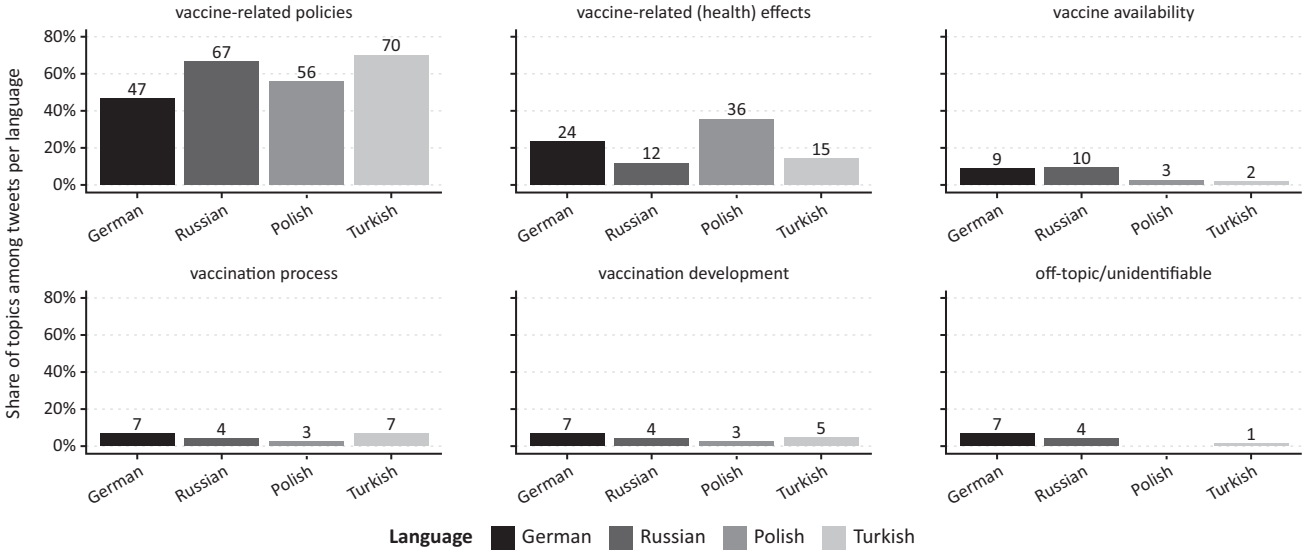

Figure 2. Topic distribution for all coded tweets. Notes: *n* = 3,205, German (*n* = 2,658), Russian (*n* = 420), Turkish (*n* = 88), Polish (*n* = 39); Cramer's *V* = 0.1; *p* < 0.01.

act of getting vaccinated or logistical aspects on an individual or local level) only played a minor role.

This hierarchy of topics was similar for the other languages as well. However, we found some slight differences, i.e., vaccine-related policies being especially important in the Russian and Turkish language communities (see example tweets no. 1–3 in the Supplementary File). In contrast, vaccine-related health effects took up a larger share in the German and Polish language communities in comparison (see example tweets no. 4 and 5 in the Supplementary File).

Regarding sentiments towards Covid-19-related vaccination, the results are similar across all four languages with only slight differences (Figure 3): Most tweets held no subjective opinions about vaccination and discussed the topic neutrally. Interestingly, a positive attitude towards vaccination was the second-most prevalent sentiment, especially in the German and Turkish tweets (see example tweets no. 6 and 7). For instance, users shared encouraging messages about vaccine uptake, demanded better vaccine availability, or discussed the efficacy of vaccination in general. Thus, overall, vaccination is viewed positively on Twitter. In contrast, tweets with negative sentiment contained disparaging messages about Covid-19-related vaccination, i.e., by criticising (perceived) health risks or doubting the efficacy of vaccination.

Sputnik V is the vaccine discussed most frequently in tweets across all four languages (Figure 4). The AstraZeneca vaccine was also discussed frequently, especially in the Polish and German tweets. All other vaccines were mentioned infrequently and did not play a major role in the Covid-19-related vaccination discourse.

Since the discourse seemed to focus on Sputnik V, we were interested in the users' sentiments towards the vaccine (Figure 5). Although the majority of tweets talked about Sputnik V neutrally, the tweets containing a sentiment towards the vaccine were predominately positive and contained supportive messages (see example tweets no. 8–13 in the Supplementary File).

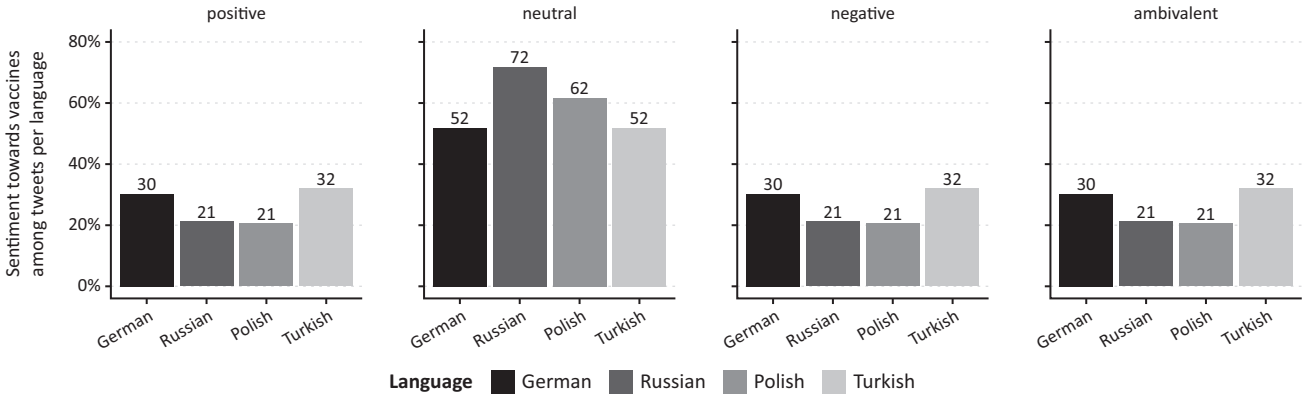

Figure 3. Sentiment distribution for all tweets coded with regard to sentiments about vaccination. Notes: *n* = 3,007, German (*n* = 2,476), Russian (*n* = 405), Turkish (*n* = 87), and Polish (*n* = 39); Cramer's *V* = 0.09; *p* < 0.01.

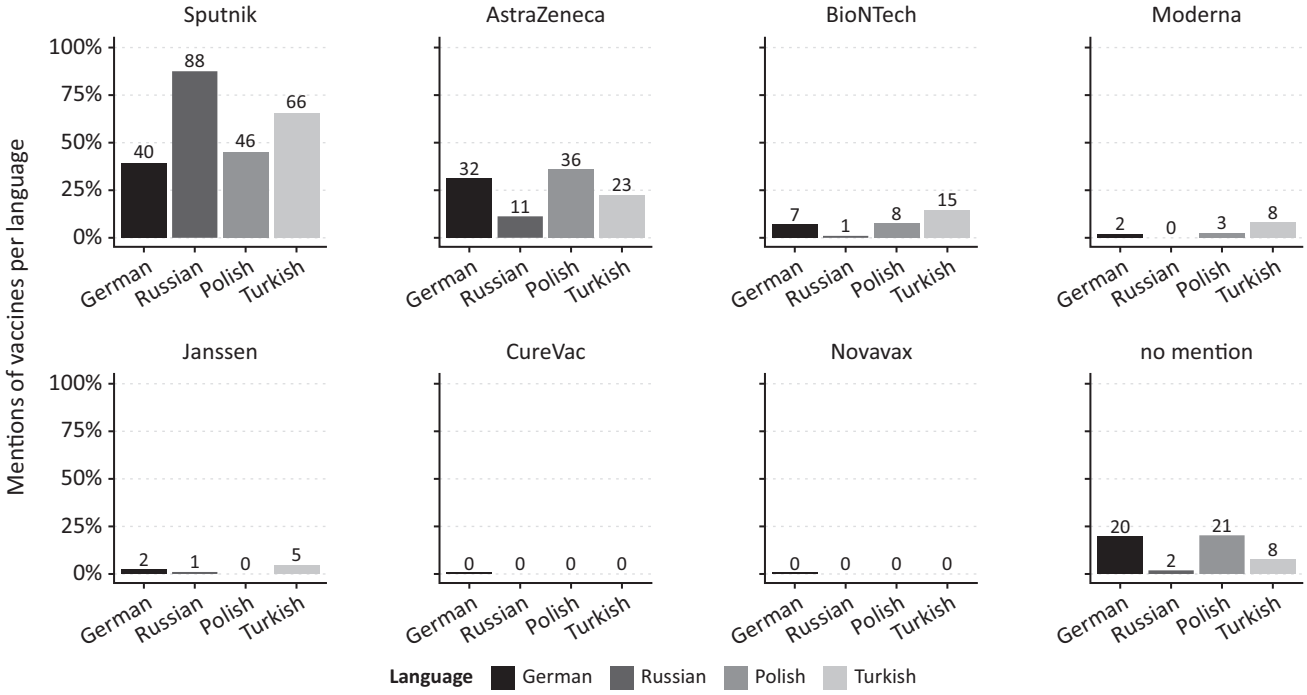

Figure 4. Mentions of specific vaccines in different languages. Notes: The base for each language are all manually coded tweets about Covid-19 vaccination; *n* = 3,205, German (*n* = 2,658), Russian (*n* = 420), Polish (*n* = 39), and Turkish (*n* = 88); Cramer's *V* = 0.19; $p < 0.01$.

Taking a closer look at this, we found that most users authoring those tweets were private individuals using Twitter to criticise the German federal government and the EU and share their personal opinions on various aspects of the Covid-19 pandemic. However, we could not discern a consistent pattern here; the accounts differed in political orientation and their attitude regarding the federal government's Covid-19 policies. The positions were especially divergent on the latter point; many people stated they had had their freedom taken away (see example tweets no. 8 and 9 in the Supplementary File). However, just as many accounts were in favour of containing the Covid-19 pandemic and consequently criticised the government for not going far enough with its measures (see example tweet no. 10 in the Supplementary File). In the next step, we analysed the context in which Sputnik was mentioned. Once again, we found a variety of different lines of argumentation. In most tweets, the users were dissatisfied with either the vaccine availability or the general Covid-19 management of the German federal government. Interestingly, to contextualise and explain those complaints, many users criticised an alleged bias of Germany/the EU against the Sputnik vaccine and Russia itself (see example tweets no. 11 and 12 in the Supplementary File).

In contrast, excluding tweets with a neutral sentiment, the AstraZeneca vaccine was predominately perceived negatively (see Figure 6 and example tweet

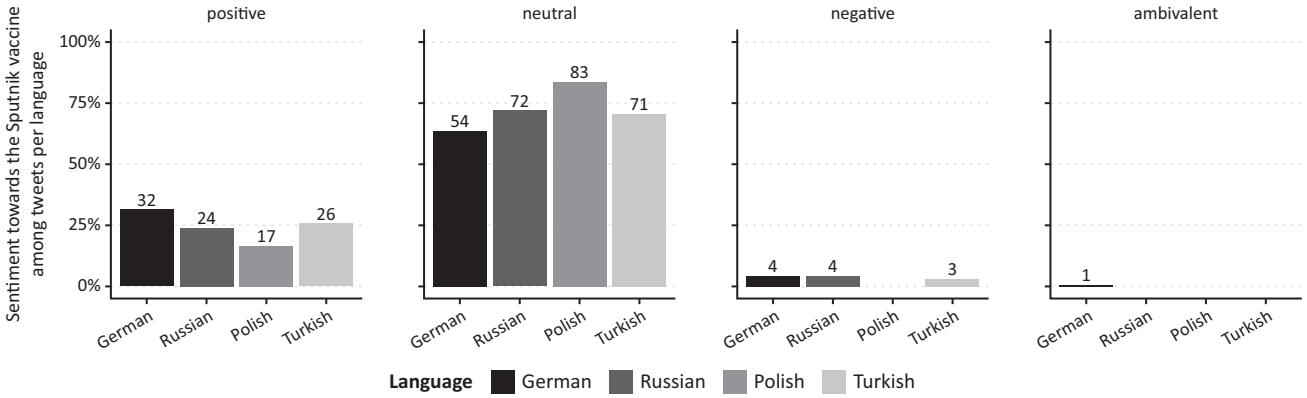

Figure 5. Sentiments towards the Sputnik vaccine. Notes: The base for each language is the number of tweets that mention the Sputnik vaccine; *n* = 1,504, German (*n* = 1,060), Russian (*n* = 368), Polish (*n* = 18), and Turkish (*n* = 58); no statistically significant association ($p = 0.1$).

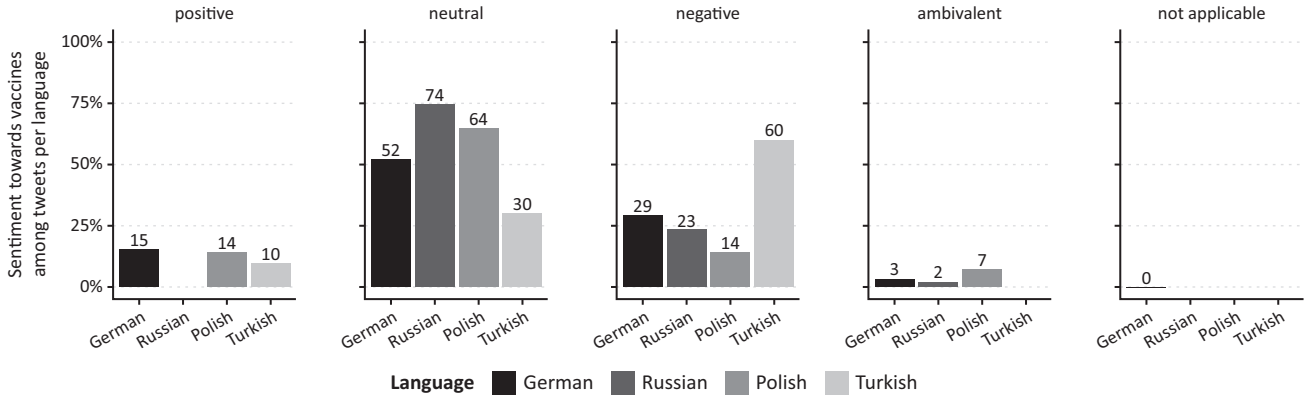

Figure 6. Sentiments towards the AstraZeneca vaccine. Notes: The base for each language is the number of tweets that mention the AstraZeneca vaccine; n = 920, German (n = 839), Russian (n = 47), Polish (n = 14), and Turkish (n = 20); Cramer's V = 0.09; p < 0.01.

no. 8 in the Supplementary File). Only the users tweeting in Polish were undecided since there was an equal number of tweets with positive and negative sentiments.

5. Discussion

In our study, we examined the question of how integrated or fragmented the Covid-19 vaccination debate is on Twitter in Germany.

Overall our results show that in March 2021, comparatively few Twitter users tweeted about Covid-19 vaccinations or revealed their location on Twitter, which were the two main conditions for the sampling of our study. Based on this result, one possible assumption could be that the discussions take place in other social networks, such as Facebook groups or Telegram (see, for example, Peter et al., 2022). In particular, there is little tweeting in other languages by people stating their location in Germany. This may point to the fact that for other cultural groups living in Germany, Twitter does not seem to be relevant for debates on Covid-19 vaccination—at least not for debates in Russian, Polish, or Turkish. Of course, the results could also indicate that people who live in Germany and tweet in other languages are less willing to disclose their location. However, previous research does not suggest that there are cultural differences in the disclosure of geo-location information on Twitter (Liang et al., 2017). Additionally, it is also possible for people with a migration background living in Germany to participate in the vaccination debate on Twitter in German or English.

Regarding our research question, we can state that there are few structural connections between the different language communities. This is especially true for the foreign-language communities, which hardly have any discursive connections via @mentions or retweets to one another or the German community. This is consistent with previous research (e.g., Hale, 2012, 2014)—our data also shows that the Twittersphere is structured along language boundaries. So, when Twitter debates occur in different languages but in the same country, they take place separately and are detached from each other. Multilingual Twitter users seem to act as important bridge actors and liaisons here, again consistent with previous studies (Hale, 2014).

However, regarding the discussed topics and positions towards Covid-19 vaccination and the actor types involved, the debates in the different languages are quite similar, with only a few differences. This means that the debates are not completely independent of each other (i.e., fragmented) in terms of the content discussed.

In all language communities, individuals from civil society dominate the debate—there are hardly any political or scientific actors or organisations from the health sector. Especially during a pandemic, such actors must be present on social networks and actively participate in the debate. Notably, the proportion of journalists is much higher among Turkish Twitter users. One possible (but, of course, speculative) reason could be the repression of media professionals in Turkey, which may have increasingly led Turkish journalists to work from exile. However, it remains unclear why this does not also apply to the Russian community.

Overall, this early Twitter debate shows a positive attitude toward Covid-19 vaccination in all language communities. However, even if most users were neutral or positive about vaccination, the political measures, in particular, were evaluated very negatively, which can be interpreted as criticism of the federal government's Covid-19 management.

The positive evaluation of vaccination in all language communities contradicts the finding that groups with a migration background are less willing to be vaccinated (Robert Koch-Institut, 2021), at least at the beginning of the immunisation campaign. This suggests that foreign-language Twitter users in Germany differ in certain characteristics from other members of the migrant community (e.g., formal education, age, and language skills).

Surprisingly, the discussion on Twitter was particularly positive about Sputnik. In this respect, the debate

on Twitter differs from the discussion of Covid-19 vaccines in other public arenas. Based on the data, it can be assumed that this positive evaluation was due to the fact that other vaccines were (still) in short supply, and thus a better vaccination strategy and a search for alternatives were demanded. Additionally, the positive evaluation of Sputnik was often accompanied by an "East nostalgia" (see example tweet no. 13 in the Supplementary File). Apart from that, the debate about Sputnik shows itself to be a conglomerate of many different attitudes: From the "left" side, a historical entanglement with Russia, which manifests itself in special consideration for Russian interests; from the "right," support for Putin and the strategy of populist elite criticism of German government officials. And last but not least, from the side of the Russian state, the spread of a narrative of Russophobia in the West.

Of course, our study has certain limitations. First, the geocoding approach comes with a few difficulties: In comparison to a random sample of Twitter accounts studied by Hecht et al. (2011), we were not able to locate as many accounts by analysing their location field (66% of users compared to 50.9%). And even if users specified their current location, we could not verify whether this information was correct. The existing research does not indicate any biases related to specific user groups that would substantially tarnish our study's goals (Baruh et al., 2017; Liang et al., 2017; Schmidt et al., 2022). However, digital trace data in general, and self-disclosed user location data in particular, is still afflicted with some uncertainties, such as inferring users' demographics from their social media usage or some users' maverick or even nefarious intentions (for an extensive discussion see Hultquist, 2020). Second, for the coding of the actors, we could only use the information published in their Twitter profiles and the languages of their tweets. This fact also limits our study's validity to some extent since users' migration backgrounds could not be confidently measured. Third, data collected from Twitter is, of course, not representative of the debate among the German population as a whole. Instead, our study considers the role of one platform in a heterogenous public sphere. Fourth, our sample size is rather small and only considers a very limited period of time and a limited number of users and tweets. This applies especially to the foreign language communities. Nevertheless, our data incorporates the entirety of the population tweeting in the non-German languages under study. This shows, as mentioned above, that the group of people tweeting in a foreign language and indicating their location as being in Germany is rather small. To our knowledge, there has not yet been a study that examines the different language communities or the discussion in different languages on Twitter in Germany. Our study could thus be seen as a first attempt to gain a better insight into what is happening on Twitter in this regard and is particularly relevant in light of the debate that various groups with a migration background were hit particularly hard by the pandemic. That said, and with the discussed limitations in mind, our study offers numerous starting points for future research projects: It could be interesting, for example, to combine a survey of Twitter users with a content analysis of their tweets. The survey could, for example, include various demographic variables, the migration background, and the information and usage behaviour of various (social) media. If the users were willing to donate their tweets for scientific purposes, the survey data could be combined with a content analysis of specific tweets, e.g., regarding the discussion about Covid-19 vaccination. This approach would avoid the difficulties of a specific geo-localisation procedure and provide further interesting insights into how people from different (cultural) backgrounds participate in debates on Twitter. Additionally, future research projects could use the manually coded data to establish a "ground truth" for further computational analysis that considers longer investigation periods, larger data sets, or different social networks (e.g., Facebook groups or Telegram). Fifth, we did not explicitly analyse the discussion of conspiracy theories, which would be an interesting line of enquiry concerning potential adverse effects on democracy.

Overall, it can be stated that there are only a few structural connections between Twitter users who tweet in different languages and who indicate in their profile that their location is in Germany. Regarding actors, arguments, and positions towards Covid-19 vaccination, the discussion in the different language communities is similar. This means there is a parallelism of the debates but no social-discursive integration. Thus, given that individuals with migration backgrounds were hit particularly hard by the Covid-19 pandemic, it can be stated that Twitter is not the appropriate channel to protect or engage with these individuals in health debates. Since the debates take place separately in the individual language communities, it seems all the more important to address the communities individually with precisely coordinated communication formats or with local on-site services. However, isolates in our data do not necessarily mean that someone is marginalised. Since we only collected connections to other users in Germany, isolates can also be segregated users who are strongly linked to the community of the country of origin. Additionally, it is important to keep in mind that there is a distinction between online and offline integration based on varying opportunities (Mittelstädt & Odag, 2015).

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Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

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Article

How Do Multiple Actors Conduct Science Communication About Omicron on Weibo: A Mixed-Method Study

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Abstract
This article explores science communication about Omicron on Weibo by eight actors from November 2021 to June 2022. Regarding the themes of vaccines, symptoms, and medicines, we examined the actors' communication with content analysis, presented the interactions of different actors using social network analysis, and assessed the impact of weibos on public sentiment using SnowNLP and descriptive statistics. The results showed that scientists are still the most important actors, focusing on science issues and using contrasting and contextual frames. Central-level media play an essential mediating role, relaying scientific knowledge. Science communication on Weibo had a positive impact on public sentiment.

Keywords
Covid-19; Omicron; public sentiment; science communication; social media; sentiment analysis; Weibo

Issue
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1. Introduction

Social media provides a channel for the public to "participate in science" (Schäfer et al., 2018), and scientists are no longer the only actors in science communication. As one of China's largest social media platforms, Weibo is an essential channel for obtaining information, communicating and interacting, and expressing ideas ("Weibo Q1 profit tops estimates," 2022). Although the state still sets boundaries for what may be criticized, and the censorship is very effective in some instances, Weibo communication fulfills some of the core criteria of a public sphere, such as it having open debates about issues of common concern, continuous debates, and a large number of participants (Rauchfleisch & Schäfer, 2015).

The Covid-19 pandemic has created a global health crisis. Omicron (B.1.1.529), the fifth-generation variant of Covid-19, was first detected in South Africa on November 9, 2021, and classified as having a "very high" risk level on November 29 (World Health Organization, 2021). Omicron challenges the public's understanding of existing vaccines, medicines, and reagents, and targeted science popularization work is needed. China's zero-Covid policy stands out internationally and has been noted by the scientific community (Mallapaty, 2022). Therefore, promoting the public's timely understanding, rational knowledge, and scientific treatment of information related to Omicron is an important task in scientific communication. During the outbreak of Omicron, Weibo provides the possibility for public discussion of scientific issues and participation in science communication between all kinds of actors (Yi et al., 2022).

This article examined the science communication of different actors under different themes, the content, the interaction, and the effects of communication. The results can present the state of communication about Omicron on Chinese social media and provide lessons for science communication on similar topics.

2. Literature Review

2.1. Multi-Theme Communication on Weibo During the Covid-19 Pandemic

The internet has freed the public's imagination (Papacharissi, 2010). In the social media environment, the public is even considered to be formed, re-formed, and coordinated through a dynamic network of communication and social connections organized primarily around issues or events (Bruns & Burgess, 2015). In terms of China, as a virtual online platform, Weibo can quickly and inexpensively generate networks of public online issues that transcend geographical boundaries (Huang & Sun, 2014). Therefore, Weibo provides a platform for participation in public affairs and offers a channel for the Chinese public to express their opinions (Jiang, 2014). Since the outbreak of the Covid-19 pandemic, many studies have been conducted using the content and data disseminated on Weibo.

One kind focused on the impact of health information dissemination on Weibo on users' attitudes and behaviors. Some explored public opinions and attitudes towards the Covid-19 vaccine and their emotional orientations, which could result in increased preventive behaviors via dialogues on Weibo (Gao et al., 2021; Liu, 2020). Some investigated how communicating uncertainty about preliminary evidence affects the spread of inferred misinformation in a Weibo case study (Lu et al., 2021). Chen et al. (2021) concluded that geographical proximity and level of expertise influenced users' commenting behavior on the Covid-19 super theme on Weibo. Others conducted a correlation analysis between public attention level and Covid-19-related case numbers, topic themes analysis, and sentiment analysis (Hou et al., 2021; Tsao et al., 2021). Li et al. (2020) explored the developmental course of online public opinion in terms of fine-grained emotions presented during the Covid-19 epidemic in China. These studies, which follow the traditional focus of health communication research and inspire us to use these perspectives and methods of health communication in science communication about Omicron on Chinese social media, indicate that public mental health, emotional expression, and position in public health crises deserve attention.

Another strand of the literature analyzed the content of Weibo during the Covid-19 pandemic, discussing how topics and themes changed as the epidemic progressed and the changes in framing they reflected. Researchers revealed that the main topics of scientific communication revolve around the domestic epidemic, including Covid-19 drug treatments, vaccines, medical resources, patients' calls for help, the resumption of work and production (Wang et al., 2020), as well as the echo chamber effect of Weibo regarding Covid-19 information dissemination in several dimensions, including topics, interaction mechanisms, and interaction levels (Wang & Qian, 2021). Emotion and social network analyses were used to examine the emotion flow by comparing them with the information flow (Yi et al., 2022). Liao et al. (2020) revealed that the common content patterns identified in personal and government posts included sharing epidemic situations, general knowledge of the new disease, policies, guidelines, and official actions. In this study, we selected three related hot themes based on previous research and platform observation (Tsao et al., 2021; Wang et al., 2020): vaccines (prevention before infection), symptoms (of Omicron), and medicines (treatment after infection). According to the communication contents, the issues of the weibos in this study are divided into progress, politics, science, international situation, and risk (Hu et al., 2021).

Furthermore, frame refers to continuous cognitive, interpretive, and presentation patterns, including selection, emphasis, and exclusion (Gitlin, 2003). The technique of frame analysis, as the way to organize and present information about social issues and controversy, allows us to understand the nature and dynamics of popular sentiments on China's internet (Wang, 2013). This study uses four science communication frames to describe the writing logic of weibos' text: the contextual frame, the contrasting frame, the emphatic frame, and the declarative frame (Gao et al., 2021; Khoury et al., 2021).

2.2. Changing Actors on Science Communication and Active Actors on Weibo

After more than 30 years of development, science communication has had a series of achievements. Scholars have proposed three interaction models for science communication that can coexist as policy instruments: the deficit model, the dialogue model, and the participation model (Bucchi, 2008; Hetland, 2014; Trench, 2008). Considering the impact of scientific information on public decision-making, some scholars argued that in science communication, it is essential to recognize that there is a high degree of scientific uncertainty in many policy contexts (Rowe et al., 2005).

Therefore, an essential mission of contemporary science communication is building trust and dialogue between different groups and reconciling values. Scientific input to the policy process requires an "extended peer community" of all who have a stake in the dialogue on the issue (Funtowicz & Ravetz, 1993), and the public is equally qualified to dialogue with scientists on scientific issues of interest to them (Irwin & Wynne, 1996). As dialogue and participation are increasingly emphasized, more research has focused on the growing diversity of actors involved in science communication. Participatory communication theory suggests that communication should be a two-way process between producers and consumers of information (Servaes & Malikhao, 2005; Tufte & Mefalopulos, 2009). Therefore, the actors involved can be classified based on their engagement level, ability to contribute to scientific

knowledge, and relationship with other actors in the scientific community (Marent et al., 2012). Social network theory suggests that social networks influence communication patterns and behavior (Burt, 1995). In this theory, researchers usually classify actors according to their position in the network, level of influence, and relationship with other actors (Haythornthwaite, 1996). Actor-network theory suggests that actors are connected through networks of relationships that are both human and non-human, and that these networks shape social action and behavior (Latour, 2007; Law, 1992). This theory inspires us to classify actors based on their roles in shaping scientific knowledge and their relationships with other actors in scientific networks. All these theoretical doctrines provide the bases for classifying actors in this study.

Nowadays, the frequent scientific controversies have made various forms of public participation in science an inevitable choice for science communication activities in China (Jia & Liu, 2014). Scholars are paying more attention to the diversity of actors in different issues of Weibo science communication. Some classified the numerous users on Weibo into four primary groups: celebrities, organizations/media accounts, grassroots stars, and ordinary individuals (Guo et al., 2014). Many actors, such as governments, PR experts, universities and research institutions, science journalists, and bloggers, have been captured in science communication on Weibo (Weingart & Guenther, 2016). Ordinary citizens on Weibo constitute the largest category of initiators of online public opinion in China, but they have to rely on media outlets to spread the news of the case (Nip & Fu, 2016). Meanwhile, the Chinese government is also an active user of Weibo, utilizing the microblogging sphere better to understand public attitudes, concerns, and needs (Sullivan, 2014; Zhu et al., 2020). Zeng and Li (2020) stated that Chinese Center for Disease Control and Prevention increasingly uses social media to popularize daily health information and improve communication between the government and the public. All these studies showed the active communication activities of different actors in science communication on Weibo.

Synthesizing the above literature, essential actors in science communication include scientists, organizations, media, and the public. In this study, the actors are further refined and categorized according to their profession, status, background, and specific involvement in disseminating weibos about Omicron to develop a more comprehensive understanding of the dynamics of Weibo science communication.

2.3. Effects and Strategies of Science Communication on Weibo

Social media platforms are media-oriented in Chinese science communication and are key in mediating information dissemination (Chen et al., 2020). As mentioned, Weibo plays a significant role in daily and interpersonal communication among Chinese people during times of uncertainty and crisis. Weibo allows citizens to receive timely, fact-checked, and up-to-date science communication information from the government, scientists, and doctors. (Zhu et al., 2020). Therefore, the importance of Weibo demands that its effects and role in science communication be investigated. We still need to evaluate the science communication strategies of different actors on Weibo and find ways to improve communication effects on the various users on Weibo.

Research on the effects on science communication users on Weibo involves establishing relevant dimensions and indicators of effects evaluation. The evaluation of the effects focused on the impact on public sentiment. The emotional contagion hypothesis can explain the spreading and diffusion of emotions and the formation of large-scale emotional and cognitive contagion (Hatfield et al., 1993). Previous studies of public emotions during public health crises have found that people usually have negative emotions such as fear, anger, anxiety, disgust, and sadness (Yang & Chu, 2018). Emotionally charged Twitter messages are retweeted more rapidly and often than neutral ones (Yang et al., 2019). In addition, some scholars measured the influence of Weibo content by the number of likes, reposts, and comments on the message content (Ma & Liu, 2020). Research showed that reposting behavior can reflect a position of viewpoint agreement and a willingness to assist in the diffusion of information (Shan et al., 2017). Some authors extracted engagement data (likes, comments, shares, and followers) from government agency accounts regarding Covid-19 posts to assess online public engagement with government posts (Liao et al., 2020). Using the number of reposts and the emotional classification of comments has been the regular way to analyze the effects of science communication on Weibo (Liu, 2020; Yang et al., 2019). These studies inspired us to examine weibos' comment sentiment and repost numbers, thus generalizing science communication's impact on public sentiment.

Choosing appropriate communication strategies in science communication, especially the narrative style, is a major initiative to promote public sharing of science communication content on social media platforms and to take preventive measures (Ngai et al., 2020). One study systematically investigated how Chinese central government agencies used social media to promote citizen engagement during the Covid-19 crisis (Chen et al., 2020). Official health organizations, scientists, and physicians tended to adopt a more flexible communication strategy on social media (Che et al., 2022). Some argued that the revelation of personal preferences in the form of individualized expressions of opposition was more common than mobilization and coordination. Such preferences were legitimized by the personal frames of risk and the distrust in government (Huang & Sun, 2016). Another framework analysis of Weibo health information found that gain-framed messages

and statistical expressions can successfully improve the influence of messages (Rao et al., 2020). Zhang and Skoric (2020) focused on Chinese environmental science communication on Weibo and found that government-organized and grassroots NGOs differ significantly in their strategies. A study found that health influencers in China use low-fear appeal and high-efficacy messages to communicate with their followers (Zou et al., 2021). Therefore, the scientific communication strategies of different actors about Omicron are also one of the concerns of this study.

3. Study Aim and Research Questions

Taking science communication about Omicron activities on Weibo in China as the research object, this article aims to present and analyze the actors (who provide scientific information), contents (the issues, topic, frame, and position contained in samples), interactions (communication among the actors), and impact on public sentiment. It focuses on the performances of different actors in Weibo science communication and the changes and innovations brought by Weibo to science communication. The research questions are:

RQ1: Who are the main actors in science communication about Omicron on Weibo?

RQ2: What are the contents of science communication about Omicron?

RQ3: How do the actors of science communication about Omicron interact with each other?

RQ4: What is the impact of science communication about Omicron on public sentiment?

4. Methodology

4.1. Method

Omicron has sparked an ongoing and complex debate on Chinese Weibo. Since various actors published many scattered Omicron-related weibos and highly diverse topics are not conducive to science communication analysis, we selected three related hot themes based on previous research (Tsao et al., 2021; Wang et al., 2020) and platform observation: Vaccines (prevention before infection), Symptoms (of Omicron), and Medicines (treatment after infection). According to these three themes, weibos, which initially spanned a vast period and had mixed contents, were divided into three relatively straightforward parts.

A weibo generally includes the text, the comment text, and the number of reposts. The text contains invisible information such as issues, topics, frames, interactions, and positions. We use content analysis to code and classify the text to examine the production and dissemination of scientific content by different actors. We also use social network analysis to evaluate whether the text is quoted, paraphrased, questioned, or communicated to characterize the interaction between the actors. The number of reposts is an important index to measure the degree of information diffusion: More reposts means greater communication power on Weibo (Lu et al., 2021). The number of reposts is a specific value and can be analyzed by simple statistics. Comments are direct feedback to the text, and more positive comments mean higher approval of the weibo (Hou et al., 2021). Since the number of comments is enormous compared to weibos, we use automated tools to analyze them.

4.2. Sampling

4.2.1. Classification of Actors

Actors in science communication can be divided into groups, including scientists, organizations, media, and the public (Masduki, 2021). However, due to their profession, status, and background, science communication actors on Weibo are more diverse and need to be further categorized. Based on previous literature and Weibo observation, scientists were further categorized into public health experts with positions in national health authorities and general doctors without official backgrounds (Nisbet, 2009). According to the scope of their functions, organizations are divided into health organizations and government organizations (Jin et al., 2022; Nisbet, 2009). Media are divided into central and local media according to the scope and level of the audience (Nip & Fu, 2016). The public, more active in science communication, is divided into journalists, who have experience in news production and information dissemination, and general individuals, who have little influence (Zeng & Li, 2020).

4.2.2. Selected Actors' Accounts

Based on their authentication information, Weibo officially classifies accounts into different industries, such as government, media, health, economy, sports, and personal. Moreover, it rated the top 100 most influential industrial Weibo accounts monthly according to four dimensions: dissemination intensity, service quality, interaction intensity, and identification degree (People's Daily Online & Sina Weibo, 2020). Based on the development of Omicron, we set the time range from November 9, 2021, to June 30, 2022. Using the keyword "Omicron," we checked the weibos of each account on the list and found that 40 had published weibos about Omicron (see Table A in the Supplementary File). These 40 accounts are "analyzable" and "representative" science communication actors, as they are among the most influential in their industry and have published weibos related to Omicron.

4.2.3. Sample Collection and Cleaning

We used a self-written Python program to download all weibos containing the keyword "Omicron" from the 40 Weibo accounts (Guo et al., 2021). Then, the collected weibos were manually checked individually, deleting repeated, vaguely expressed, and meaningless posts, leaving 752 valid sample weibos. We also collected comments under these weibos, yielding 3,247,136 valid comments once meaningless content, such as ads and those purely made of symbols or numbers, had been removed. Finally, according to the three themes classified by the method (Section 4.1), 752 valid samples (and their comments) were divided into three parts (see Table 1) and analyzed separately.

4.3. Content Analysis

4.3.1. Coding Rules

We analyzed the content and communication strategy of weibos from four aspects: issue, topic, frame, and position (see Table 2):

- Issue: According to the communication contents, the weibos are divided into progress, politics, science, international situation, and risk (Hu et al., 2021).
- Topic: Under the three themes of Vaccines, Symptoms, and Medicines, the core topics of communication contents are extracted respectively, and specific topics are obtained through classification (Hu et al., 2021; Khoury et al., 2021).
- Frame: Four science communication frames are used to describe the writing logic of Weibo text, namely the contextual frame, contrasting frame, emphatic frame, and declarative frame (Gao et al., 2021; Khoury et al., 2021).
- Position: Focusing on the inspirational words in weibos, the sample positions are classified into three categories—positive, neutral, and negative—based on grammar and sentence meaning (Gao et al., 2021; Xu et al., 2021).

Distilling issues enable us to find the domain to which weibos belong quickly. Then we identify the specific events and objects discussed in weibos by coding topics (Hu et al., 2021). The frame is widely used to describe communication strategies, which can reflect the intentions of science communicators (Zou et al., 2021). Clarifying the position also helps us better understand the scientists' communication intentions and strategies (Haythornthwaite, 1996).

4.3.2. Coding and Reliability

Two researchers screened and categorized samples according to the coding table. Two coders were trained before jointly coding the first 20% of the samples. Intercoder reliability scores were calculated using Scott's pi coefficient (π; Krippendorff, 2018). The scores all exceed 75%, indicating high coding reliability. When different opinions appeared, the coders chose a suitable one after discussion.

4.4. Social Network Analysis

Social network analysis can describe and measure the relationships between actors and analyze the information and resources behind the relationships (Wasserman & Faust, 1994). We used social network analysis to verify and describe the interaction behaviors (including reposting, quoting, exchange, question, @) between different actors. The number and direction of interactions between actors are counted and made into a 40 × 40 matrix. Moreover, the matrix plots into a directed interaction network diagram using the social network analysis software Gephi. The interaction network diagram consists of three components: actors (network nodes), connections (network links), and boundaries (Oliveira & Gama, 2012). The degree of centrality determines the size of the network nodes. The larger a node is (the more extensive the degree of centrality), the more it interacts with other nodes. The network link indicates the interaction between two nodes, and the color of the link corresponds to the information source node (e.g., if A quotes/forwards the content of B, the color of the link corresponds to the color of B node), and the more interactions are, the thicker the link is.

Table 1. Number of sample weibos.

	Scientists		Organizations		Media		The public		
Themes	Public health experts	Doctors	Health organizations	Government organizations	Central-level media	Local media	Journalists	Individuals	Total (%)
Vaccines	4	92	31	39	30	27	57	15	295
Symptoms	5	89	27	29	52	37	72	21	332
Medicines	2	48	8	7	10	19	22	9	125
Total	11	229	66	75	92	83	151	45	752

Table 2. The dimension and indicators of coding.

Dimension	Themes	Indicators	Description
Issue	Vaccines, Symptoms, and Medicines	Progress	Emphasizing the efforts made by human beings to cope with Omicron and its progress
		Politics	Describing the Omicron response policies introduced by the state, government, officials, and other authorities
		Science	Demonstrating scientific knowledge related to Omicron and the interpretation of scientific knowledge
		International situation	Evaluating international cooperation to respond to Omicron or compare medical conditions between countries.
		Risk	Emphasizing the adverse health effects of Omicron infection and the crisis that Omicron has brought to society and the economy
Topic	Vaccines	Prevention effects	Comparing the efficacy of various vaccines against Omicron
		Research development	Displaying progress in vaccine development, marketing, and use
		Side effects	Emphasizing side effects or risks of vaccination
		Usage suggestions	Suggesting vaccination tips and recommendations for different populations
		Vaccination work	Describing vaccination rates and doses
	Symptoms	Characteristics	Comparing and contrasting the similarities and differences between Omicron and other Covid-19 strains, such as gene sequence, variation, appearance, infectivity, etc.
		Infection symptoms	Demonstrating the health effects of Omicron infection, such as symptoms, rates of serious illness, mortality, hospitalization rates, etc.
		Social influence	Emphasizing the adverse social effects of Omicron, such as the functioning of the medical system, the functioning of the social system, social fear, etc.
		Preventative measures	Suggesting measures to prevent Omicron infection, such as wearing masks, disinfection, vaccination, hand washing, etc.
		Disease treatments	Describing the treatment modalities after Omicron infection, such as nucleic acid testing, medications, hospitalization, infusion, injection, etc.
	Medicines	Drug effects	Comparing the effect of different drugs in the treatment of Omicron
		Research development	Showing progress in medicine development, marketing, and use
		Side effects	Emphasizing side effects or risks of medicines
		Usage suggestions	Suggesting tips and recommendations for the use of different medicines
		Application situation	Describing the sales and use of medicines
Frame	Vaccines, Symptoms, Medicines	Contextual frame	Pointing out the context in which scientific knowledge is generated and the prior social experience or research process that enhances the credibility of scientific knowledge.
		Contrasting frame	Carrying out different viruses, vaccines, or medicines to highlight the main features of a particular vaccine or medicine
		Emphatic frame	Emphasizing the seriousness of virus infections, the importance of vaccines or medicines, and the presence of a specific tone of exclamation, command, or appeal
		Declarative frame	No excessive expression techniques are used, and the content is published straightforwardly

Table 2. (Cont.) The dimension and indicators of coding.

Dimension	Themes	Indicators	Description
Position	Vaccines, Symptoms, Medicines	Positive	Without fear of Omicron, support or praise vaccines and medicines
		Neutral	No apparent position
		Negative	Fear of Omicron, opposition or criticism of vaccines and medicines

4.5. Sentiment Analysis

For comment sentiment recognition, we used SnowNLP, a dictionary-based Python database for Chinese sentiment analysis (Chen et al., 2018). Sentiment analysis with big data usually includes sentiment dictionaries and machine learning. A sentiment dictionary is suitable for low-granularity texts (with shorter lengths), with the advantage of speedy procedures and high accuracy (Chen et al., 2018). We employed the Snow NLP (sample words shown in Table 3) for sentiment analysis because the sample comments were mostly short sentences or texts (Lan, 2013). In practice, we first split the 3,247,136 sample comments into words. By comparing the words in the text of the comments with the words in SnowNLP, we calculated the sentiment of the comments. The output range is [0, 1]: When the sentiment value is [0, 0.33], it indicates the comment is negative (e.g., you are hurting people); [0.33, 0.66) is neutral (e.g., 2022 is half over); [0.66, 1] is positive (e.g., the popular science articles are good).

5. Findings

5.1. Actors and Contents

5.1.1. Vaccines

Among the 295 sample weibos, scientists (*n* = 96) had the largest number of weibos, followed by the public (*n* = 72) and organizations (*n* = 70). The number of science issues (*n* = 169) was the highest, focusing on the preventive effects of different vaccines (such as BNT162b2 and mRNA-1273) or vaccination conditions (such as one to three shots and single or mixed vaccines). Public health experts, doctors, and health organizations are the more active actors discussing scientific issues. They have medical backgrounds and are good at presenting vaccine-related medical knowledge to the public. The number of progress issues (*n* = 63) was moderate. The content was mainly about the progress of vaccine development, which did not generate a lively discussion among different actors, only being published as news.

Vaccine efficacy was a concerning topic for most actors (*n* = 110), emphasizing that existing vaccines, although ineffective in preventing infection, provided some protection against severe illness, hospitalization, or death. Doctors are most concerned about vaccine efficacy and like to emphasize the efficacy of vaccines—for example, "vaccination will not save you from infection, but it will save your life after you get it." Weibos of usage suggestions (*n* = 85) and vaccination work (*n* = 36) were intrinsically linked to persuading the public to get the whole new vaccine from the perspective of doctors and the government, respectively. Most actors describe the efficacy and safety of the vaccine with solid trust.

The declarative frame (*n* = 128) was employed the most, consistent with the characteristics of Weibo as a short text. Except for public health experts, other actors are fond of using the declarative frame to post weibos, which may even have a specific "command" tone, such as "the safety of domestic vaccines is still good, so if you have elderly people at home who have not yet been vaccinated, do it quickly!" The contextual frame (*n* = 70) and contrasting frame (*n* = 69) were often used. The contextual frame was preferred by journalists, who tended to publish longer weibos with adequate background information about vaccines. Most journalists seem to voluntarily join in the mobilization for vaccination, actively presenting the beneficial nature of vaccines and inspiring users' trust in vaccines by citing social cases. Doctors prefer to use the contrasting frame to compare different vaccines with data.

Most samples (*n* = 233) held a positive attitude toward vaccines, and 56 were classified as neutral. Only six samples were negative toward specific vaccines instead of being anti-vaccination in general. Most doctors actively promote vaccines, trying to stimulate public willingness to vaccinate by demonstrating their efficacy and safety. Only a few doctors cite medical studies on vaccine side effects. The full coding results of vaccines are provided in Tale B of the Supplementary File.

Table 3. The example of emotion words with sentiments.

Sentiment dictionary	Sentiment	Sample words
SnowNLP	Positive	Happy, trust, safe, peace, clear, smooth, believable, reliable
	Neutral	Think, shyness, imagine, stop, wait, longing, precision, then
	Negative	Lying, cheating, stupid, fear, rumor, mess, scary, crazy

5.1.2. Symptoms

Among the 332 sample weibos, scientists (*n* = 94) posted the most, followed by the public (*n* = 93) and media (*n* = 89). More than half were science issues (*n* = 184), which dealt mainly with the mutation characteristics of Omicron. Doctors often discuss science issues, preferring to present and paraphrase medical papers related to Omicron and to comment on the results of the papers. When Omicron first appeared, doctors held widely diverse opinions. However, as the epidemic progressed, most doctors agreed that "Omicron is extremely contagious, but the lethality rate is low, and we still need to be cautious about it." Journalists often discussed risk and international situations to highlight the threat of Omicron, explaining that Omicron is causing much trouble abroad to convince the domestic public to be cautious.

Infection symptoms (*n* = 123), social influence (*n* = 105), and characteristics (*n* = 78) were the topics of most actors' weibos, describing Omicron's symptoms and highlighting its potential adverse social effects. There is an inherent consistency in topics between different actors. They were all very active in presenting the threat of Omicron, constantly informing the public about its symptoms, sequelae, and social threats. In the early transmission stages, all actors portrayed Omicron as the "most infectious Covid-19 variant." Although in the late stages of transmission, many studies have shown that Omicron has low rates of severe illness and mortality, all actors continued to emphasize that "Omicron should not be taken lightly."

Concerning expression, 105 sample weibos used a declarative frame. The weibos were similar to short news messages, mainly sharing the latest findings on Omicron's infectious features and genetic characteristics. Of the sample weibos, 98 used contextual frames. The context was mainly from medical research papers, which promoted public understanding of Omicron by reporting scientists' findings. Ninety-four samples used contrasting frames, most of which compared Omicron with Alpha and Delta. All these variants of Covid-19 were slightly different in infectivity, rates of severe illness, hospitalization, and lethality. These weibos comparing these mutant strains were often used to raise public awareness of the crisis by highlighting the infectious power of Omicron.

Most actors' weibos were neutral (*n* = 183), emphasizing the strong infectiousness of Omicron while also describing the low rate of severe illness and lethality. Doctors, in particular, were more objective and detailed in their presentation of Omicron, often citing research-validated ideas and hypotheses to convey relatively complex scientific information to the public. There were also weibos with negative positions (*n* = 56) bent on emphasizing the threat of Omicron, which may arouse public concern and cause unnecessary panic. The full coding results of Symptoms are provided in Table C of the Supplementary File.

5.1.3. Medicines

Among the 125 sample weibos, scientists (*n* = 50) posted the most, followed by the public (*n* = 31) and media (*n* = 29). The progress issues (*n* = 57) were the most, followed by the science issues (*n* = 33). Since there was no effective medicine for Omicron, mainly treated with antiviral medicines and antibiotics, the research and development of medicines, drug effects, and side effects were all actors' concerns. Scientists, organizations, and media were actively involved in presenting and discussing some medicines and related new development.

The most popular topic was research development (*n* = 48), covering medicine development, clinical trials, and marketing approvals. Doctors and media focused more on this topic. Doctors mainly relayed the clinical trial results of some Covid-19 medicines, such as Paxlovid by Pfizer and Molnupiravir by Mercer. Drug effects (*n* = 31) focused on the effects of medicines on hospitalization, severe illness, and mortality, which raised the concern of many individuals. For the average individual, the efficacy and safety of the medicine are of primary concern.

The contextual frame (*n* = 44) was the most frequent expression to promote public understanding of various medicines by providing background. Most people do not understand the process of Covid-19 medicine development and how it works, only having a vague impression that "effective medicines for viruses are hard to develop." The main actors of medicine science communication using context were not individuals but doctors with professional backgrounds and some journalists who focus on related topics. A contrasting frame (*n* = 35) was used to compare the research and development progress, curative effects, and prices of different medicines.

Positive (*n* = 55) and negative positions (*n* = 58) were very close, and the neutral position (*n* = 12) was limited. Because some medicines were still immature, actors' attitudes were greatly divided. Actors with a negative stance believed that "it is impossible to develop an effective medicine for Omicron in a short period" or "there is no need to develop an effective medicine for Omicron." Positive actors believed that "existing medicines have achieved some results in treating severe illnesses, and we should support them." The full coding results of medicines are provided in Table D of the Supplementary File.

5.2. Interactions

5.2.1. Vaccines

Figure 1 shows the network diagram of the interactions of different actors under the Vaccine theme. Most of the connected lines are gray, which means doctors are the most dominant information source, and the vaccine science weibos posted by doctors triggered massive

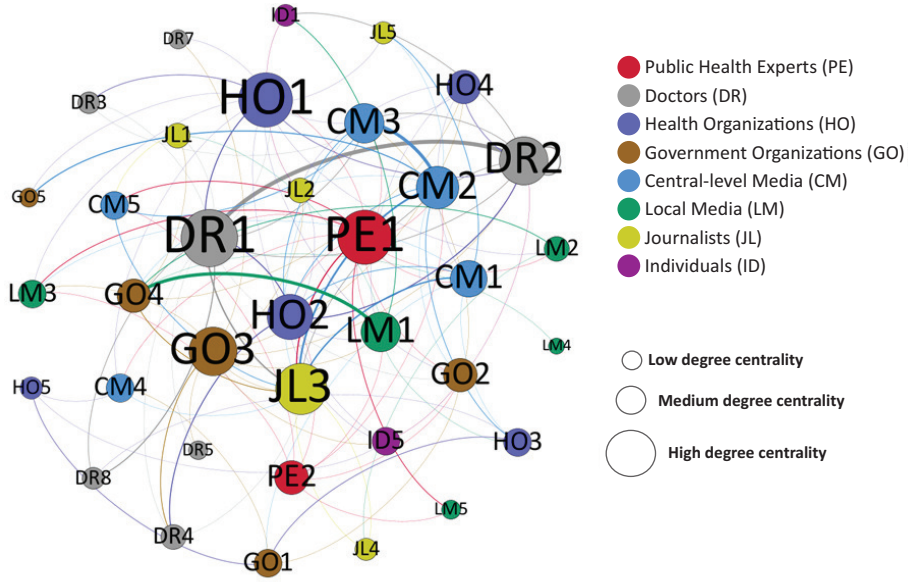

Figure 1. Interaction of the actors (Vaccines).

citations and discussion. In particular, DR1 and DR2 have a high degree of centrality and frequently interact with each other. Public health experts have a prominent degree of centrality, and their published weibos are more widely cited, but they are less likely to cite content published by others. Health organizations and central-level media produced content that generated more positive interactions, had some official stances and provided some original vaccine news. In addition, government organizations and journalists with large nodes (e.g., GO3, GO4, JL3, etc.) interact with other actors by quoting and asking questions. In terms of vaccine information distribution, they are more like intermediaries, paraphrasing original content published by other actors.

5.2.2. Symptoms

Figure 2 shows a network diagram of the interactions of the different actors under the Symptoms theme. Weibos posted by public health experts were likely to be processed and cited by central-level media. Government organizations and health organizations often reposted weibos published by central-level media. To some extent, the central-level media acted as a communication intermediary between public health experts and organizations (e.g., PE1–CM2–HO4, PE1–CM4–CM1–HO2, etc.). The content published by doctors often triggered extensive and direct interactions; for example, DR1, DR2, and DR5 were more centralized, and there were

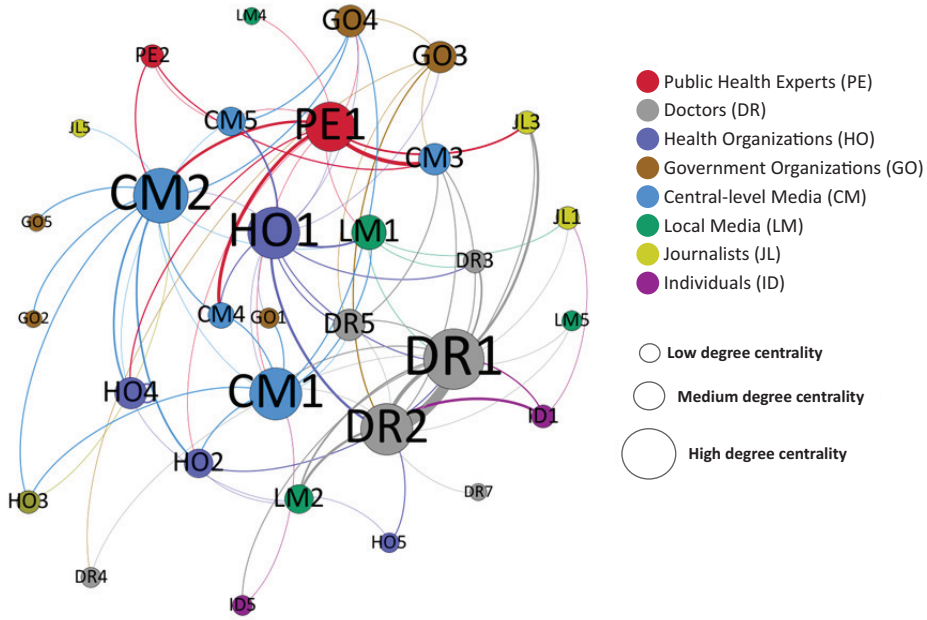

Figure 2. Interaction of the actors (Symptoms).

frequent interactions not only among them but also with other actors.

5.2.3. Medicines

Figure 3 shows the network diagram of the interactions of different actors under the Medicines theme. Weibos posted by central-level media generated the most interaction, followed by health organizations, public health experts, and government organizations. The scientific knowledge about medicines was more specialized than vaccines and diseases. These actors, with official backgrounds, were responsible for the science communication of medicines, and the content they delivered was more accessible so that they could generate a broader range of interactions. Weibos published by nodes such as DR1 and DR2 contained too much medical knowledge and academic research. Although they had a significant centrality, the interactions were limited to doctors.

5.3. Impacts

5.3.1. Vaccines

An average number of reposts refers to the ratio between the number of forwarded weibos and the total number of weibos. The attitude proportion of comments refers to the ratio of positive, neutral, and negative comments to total comments. Figure 4 shows that public health experts had the best science communication, with an average of 35,479 reposts per weibo, and the positive comments were 47.81%, while the negative comments were 14.57%. Weibo posts by central-level and local media were more recognized by the audience, with more than half of their comments being positive. Central-level media and doctors were also influential, with an average of over 200 reposts. Vaccine science communication has a practical impact on public sentiment, which received many positive comments and feedback.

5.3.2. Symptoms

As shown in the right of Figure 5, Symptoms' science communication moderately impacted public sentiment, with many reposts and more positive comments than negative ones. Public health experts had the most potent communication power. Their weibos had a relatively high percentage of positive comments (47.81%), and the average number of reposts exceeded the sum of the other seven actors. Central-level media and doctors' communication power were the second and the third. Local media was ineffective, with fewer reposts and more neutral comments than positive ones.

5.3.3. Medicines

As shown in Figure 6, Medicines' science communication had a moderate impact on public sentiment, with many reposts, but the attitude of the comments was polarized. The average number of public health experts and central-level media reposts exceeded 4,000. Public health experts, doctors, health organizations, local media, journalists, and individuals had more negative comments than positive ones. Government organizations and central-level media had more positive comments than negative ones. Government organizations and central-level media published mainly authorized medicines already approved for marketing. Doctors were

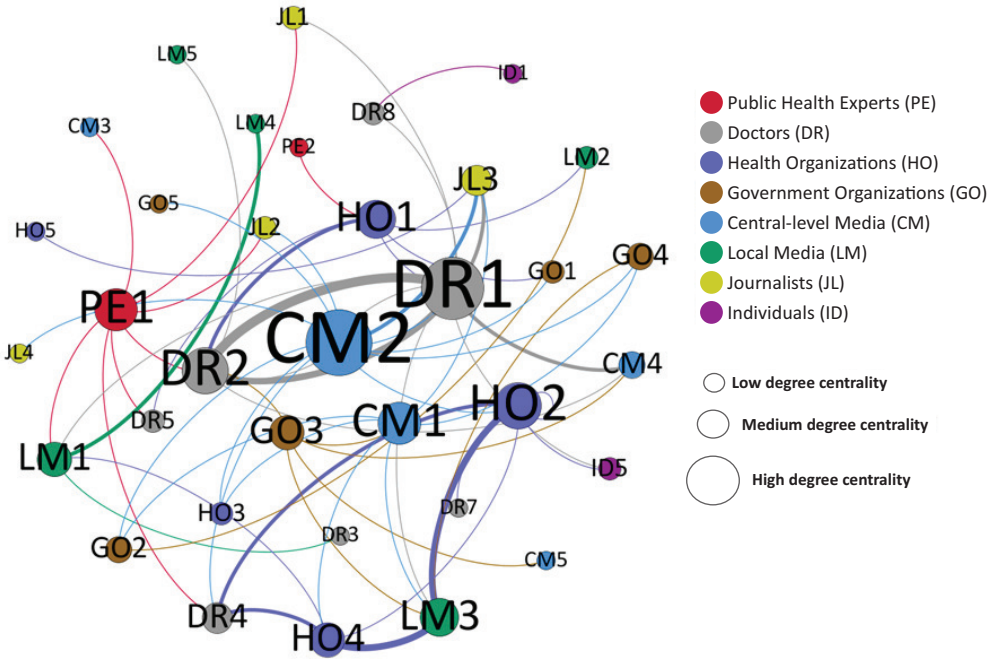

Figure 3. Interaction of the actors (Medicines).

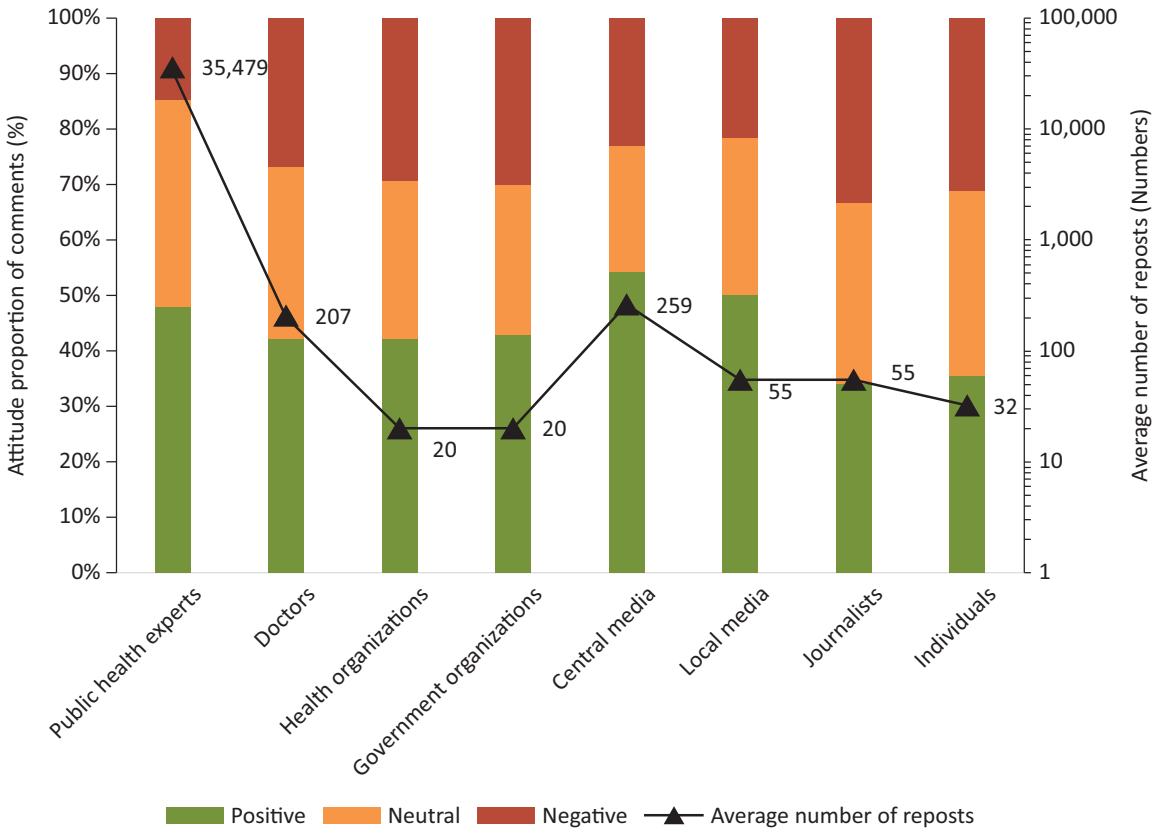

Figure 4. Impact of weibos on public sentiment (Vaccines).

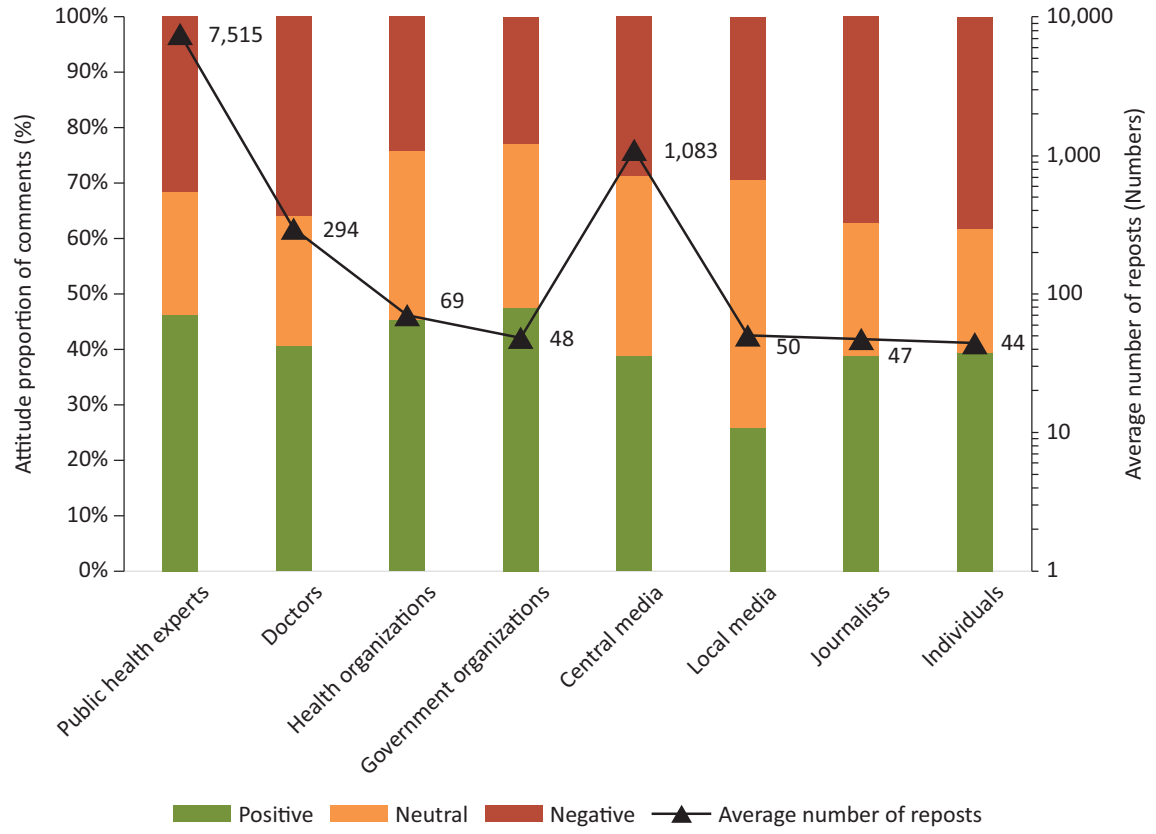

Figure 5. Impact of weibos on public sentiment (Symptoms).

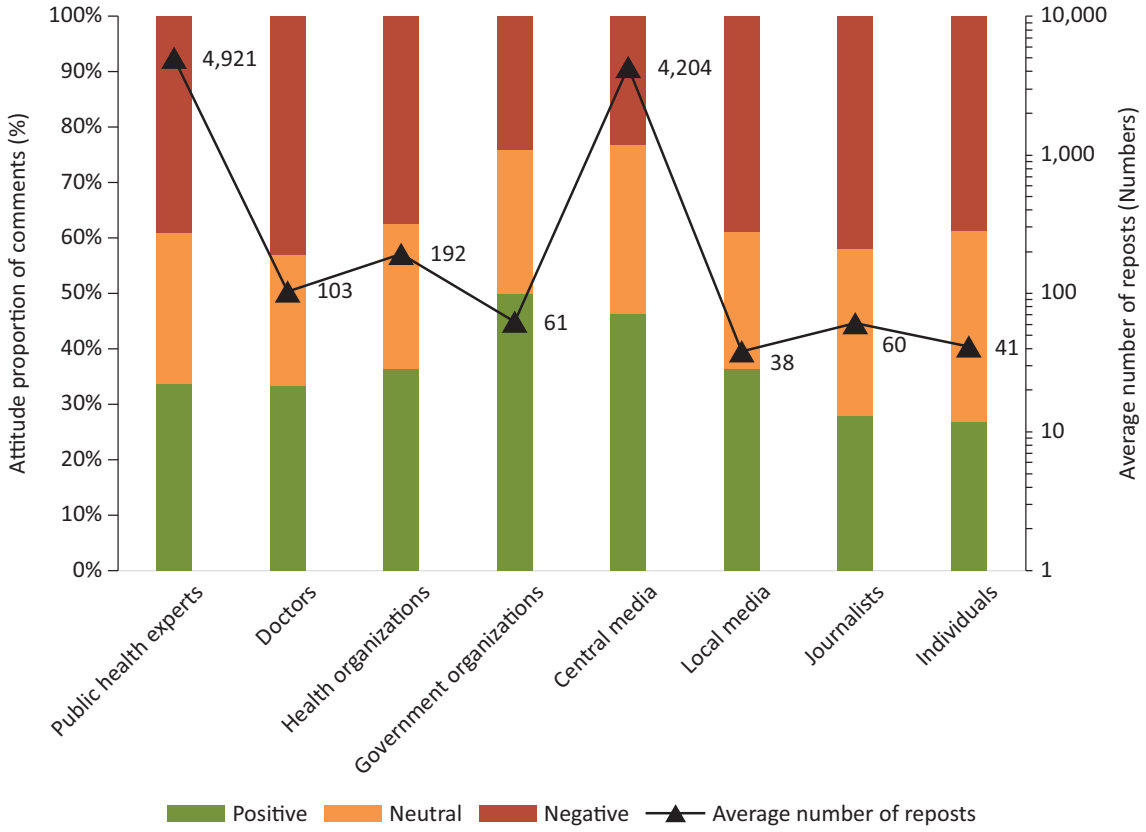

Figure 6. Impact of weibos on public sentiment (Medicines).

concerned about a much more comprehensive range of medicines, many of which were clinical trials of drugs. The academic content also limited the efficacy of doctors' communication.

6. Discussion and Conclusion

We selected 40 representative actors and 752 valid sample weibos to explore the scientific communication of Omicron on Weibo. Based on previous studies and sample characteristics, we divided the actors into eight categories. Under the themes of Vaccines, Symptoms, and Medicines, we examined the content of the actors' communication with content analysis, presented the interactions of different actors using social network analysis, and assessed the impact of weibos on public sentiment using SnowNLP and descriptive statistics.

Research has shown that scientists are the primary science communication actors within traditional media (Burns et al., 2003). Our research confirmed that scientists (public health experts and doctors) remain the most critical actors on Weibo, generating and disseminating a more objective and comprehensive knowledge of Omicron and bringing the public closer to science. Although these scientists also faced official guidance and scrutiny, they presented scientific knowledge about Omicron to the public by paraphrasing research papers. Doctors were among the actors with the highest number of weibos under all three themes, actively participating in the production and transmission of Omicron knowledge. Public health experts focused on science issues and surpassed at using contrasting and contextual frames to paraphrase esoteric medical research results related to Omicron into a form that ordinary people may easily understand and inspire public thinking.

The public's understanding of scientific information depends on how actors introduce, interpret, and evaluate scientific facts (Decieux, 2016). In this study, the specific topics focused on by actors with different identities, backgrounds, and jobs differed. However, the content posted by different actors was internally consistent. This suggests that scientific communication between different actors on Weibo is not entirely free and unregulated. Weibo is a "relatively" free space, and communication activities are still subject to national policies and related regulations. Certain information that is officially emphasized and promoted often generates more discussion, and official assertions about Omicron influence the perceptions of other actors. First, under the Vaccines theme, most actors strongly emphasized the safety and efficacy of the Covid-19 vaccine. There was almost no anti-vaccine rhetoric, consistent with the Chinese government's strategy to promote universal vaccination against Covid-19 (Xu et al., 2021). Second, under the Symptoms theme, there was unanimous consensus among all actors on the perception of Omicron as a "highly infectious, mildly symptomatic, but still noteworthy variant of Covid-19." Since the outbreak of

Covid-19, China has maintained a "zero-Covid" disposal policy, isolating and treating infected cases at the earliest opportunity. The actors' statements followed the national policy that Omicron still requires the continued use of the "zero-Covid'' disposal method. Third, under the Medicines theme, although different actors had different perceptions of the various Covid-19 medicines, they essentially held a positive position on domestic medicines.

Brossard and Nisbet (2007) stated that in science communication, the scientific information presented by news media plays a vital role in general cognition and emotion. From interactions between different actors, we found that central-level media was a crucial intermediary for communication or interaction between different actors. Many actors reproduced the information published by central-level media, acting as disseminators rather than producers. With regards to the themes of Vaccines, Symptoms, and Medicines, weibos published by public health experts, played the role of policy guidance, and those published by doctors had more widespread scientific knowledge. Central-level media interpreted public health policies and Omicron knowledge published by scientists, behaving as a channel for relaying and diffusing science. It serves as a link between the public and scientists, promoting public understanding of medical knowledge (Wintterlin et al., 2022).

Science communication on Weibo influenced public sentiment to a certain degree. Overall, the sum of positive and neutral comments was much higher than negative comments under the three themes, suggesting that the public tended to have a positive attitude toward weibos' content. The number of reposts also showed that Weibo is gaining public acceptance. Specifically, scientists usually generate mass reposts and have more positive comments than other actors. In the age of social media, scientists still strongly influence the transmission of scientific communication about Omicron. Central-level media had many followers, and their weibos triggered many reposts and received sound diffusion effects. It also inspires us to take advantage of media and organizations with a solid fan base when disseminating scientific information on social media platforms (Liao et al., 2020).

The findings and conclusions of this article can bring at least two contributions. At the theoretical level, the study confirms the ability and status of scientists and central-level media in science communication on Weibo, contributing to actor innovation in science communication theory in the age of social media. At the methodological level, this article uses a mixed research approach that helps to inspire the integration and innovation of content analysis, social network analysis, sentiment analysis, statistical analysis, and other methods in science communication.

This article also has some shortcomings. We selected 40 of the most influential Weibo accounts as the sample, inevitably ignoring some less influential accounts. Such a sampling method will make the results biased regarding the number of weibos and reposts. We divided the actors of science communication into eight types according to previous research and sample characteristics, which can cover the samples and apply them to health issues. Nevertheless, there is still room for further expansion and refinement of the classification. We examined the number of weibo reposts and commented sentiments to evaluate the impact on public sentiment. However, other indicators, such as the number of likes, were not included.

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Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the author (unedited).

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Article

Covid-19 Research in Alternative News Media: Evidencing and Counterevidencing Practices

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Abstract
The Covid-19 pandemic has been accompanied by an excess of accurate and inaccurate information (infodemic) that has prevented people from finding reliable guidance in decision-making. Non-professional but popular science communicators—some with a political agenda—supply the public with scientific knowledge regarding Covid-19. This kind of communication represents a worrisome force in societal discourses on science-related political issues. This article explores online content (*N* = 108 articles) of two popular German "alternative news" media (*NachDenkSeiten* and *PI News*) that present and evaluate biomedical research concerning Covid-19. Using thematic analysis, we investigated how scientific evidence was presented and questioned. Regarding the theoretical background, we drew on the concept of "evidencing practices" and ideas from argumentation theory. More specifically, we studied the use of the following three evidencing and counterevidencing practices: references to Data/Methods, references to Experts/Authorities, and Narratives. The results indicate that the studied alternative news media generally purport to report on science using the same argumentation mechanisms as those employed in science journalism in legacy media. However, a deeper analysis reveals that argumentation directions mostly follow preexisting ideologies and political agendas against Covid-19 policies, which leads to science coverage that contradicts common epistemic authorities and evidence. Finally, we discuss the possible implications of our findings for audience views and consider strategies for countering the rejection of scientific evidence.

Keywords
alternative news media; argumentation theory; counterevidencing practice; Covid-19; science communication

Issue
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1. Introduction

The Covid-19 pandemic represents a historically almost unprecedented period of economic, political, and sanitary disruptions (Strydhorst & Landrum, 2022, p. 534). To date, there have been approximately 633 million cases of Covid-19 and 6.6 million related deaths (World Health Organization, 2023). Moreover, the Covid-19 pandemic, instead of being a purely medical topic, has been accompanied by an "infodemic." This term refers to an excess of (online) information—accurate as well as inaccurate—that prevents people from finding reliable guidance in decision-making (World Health Organization, 2020).

Even though pandemics have always functioned as breeding grounds for incorrect information and conspiracy theories (Schade et al., 2021, p. 140), the Covid-19 pandemic is the first "to hit a digitized and networked society" (Frischlich & Humprecht, 2021, p. 9). Every online user can share scientific information with a broad audience, while expertise becomes hyperaccessible (Brubaker, 2021). As a result, the number, diversity, and quality of communicators and sources beyond established media that supply the public with the latest

scientific knowledge regarding Covid-19 has expanded in an alarming fashion. Considering that even well-trained science journalists struggle to create scientifically sound reports about Covid-19 evidence (Schäfer, 2020), non-professional voices found in online media may present a worrisome force in Covid-19 discourses.

In Germany, Boberg et al. (2020) identified the so-called alternative news media as a major force fueling the infodemic. Research on the new mediators of public knowledge mostly agrees that these actors mainly spread information and interpretations that contradict established media, politics, and science (Holt et al., 2019). By doing so, they clash with established science journalism, which mostly follows the scientific and governmental Covid-19 assessments and recommendations (Maurer et al., 2021, p. 28), and contribute to the public's increasing distrust of pandemic-related authorities (e.g., politicians and virologists). Considering the remarkable role that alternative news media play in people's Covid-19-related media repertoires (Viehmann et al., 2020), to better understand the discourse on the pandemic, it is necessary to examine alternative news media as scientific information sources and Covid-19 science communicators in detail. In the science news of legacy media, scientific evidence is used to support research-based findings and conclusions (Kinnebrock et al., 2019). During the pandemic, information has been permeated with references to scientific evidence. When alternative news media attempt to refute this kind of evidence, they need to refer to it and undermine it to make their point. However, little is known about the ways in which alternative communicators treat scientific evidence and what (alternative) discursive evaluation strategies they adopt (Neuberger et al., 2019, pp. 179–180).

The present study addresses this research gap by focusing on Covid-19 science news coverage and argumentation strategies of alternative news media. In terms of theoretical background, we build on the concept of "evidencing practices" (Kinnebrock et al., 2019) and ideas from argumentation theory (Barnes et al., 2018, 2020). Evidencing practices are an evaluation mechanism employed by science communicators and can be defined as "textual (or visual) strategies to support a claim as 'true' or 'valid' " (Kinnebrock et al., 2019). Regarding print media journalism, three common evidencing practices have been identified: Data/Methods, Experts/Authorities, and Narratives (Kinnebrock et al., 2019). When exploring evidencing practices in the online content of alternative news media, we also examined argumentation strategies for countering or criticizing scientific Covid-19 evidence. Therefore, we combined ideas from argumentation theory regarding attacks on scientific claims (Barnes et al., 2018, 2020) with the concept of evidencing practices, arguing that common evidencing practices can also be applied as *counterevidencing* practices by alternative news media—for instance, by using the Data/Methods of a study to criticize it and classify its claims as "untrue" or "invalid." In terms of our empirical investigation, we concentrated on the application and use patterns of evidencing *and*/*or* counterevidencing practices—in short, (counter)evidencing practices—in the online content of two popular German alternative news media, *NachDenkSeiten* and *PI News*, focusing on their presentations and evaluations of biomedical studies concerning Covid-19. We investigated the extent to which alternative news media apply argumentation strategies from science journalism and argumentation theory and explored what themes and functions characterize alternative news media's uses of those strategies. Regarding methodology, we employed deductive main categories to identify the text parts in which (counter)evidencing practices were applied and inductive approaches to thematically categorize the themes and functions of these (counter)evidencing practices.

In the following, we first address theoretical questions related to alternative news media as science communicators as well as (counter)evidencing practices and argumentation theory (Sections 2 and 3). Then, we discuss our study goals and methodological approach (Sections 4 and 5). Finally, we present our findings according to our research questions (Section 6) and examine their implications for audience views as well as consider strategies for countering the rejection of scientific evidence (Section 7).

2. Alternative News Media as Science Communicators

In light of rising online media consumption, Ehlers and Zachmann (2019, p. 19) identified actors that used to be marginalized but now participate online in societal debates on what scientific knowledge counts as true or false, thus becoming part of scientific evidence production. As the new possibilities of online participation and news production have provoked a kind of "hyperaccessibility of expertise" (Brubaker, 2021, p. 75), scientific knowledge is no longer accepted automatically, and researchers' authority is no longer unquestionable (Ehlers & Zachmann, 2019, p. 9; Marres, 2018, p. 423). Moreover, scientific knowledge must compete with "alternative facts," which question the credibility and persuasiveness of scientific arguments and epistemic authorities (Gierth & Bromme, 2020; Neuberger et al., 2019, p. 167). Furthermore, science communication in legacy media needs to handle the new rhetorical strategies of science deniers, such as singling out highly specific data points out of all available data while ignoring others ("cherry-picking" evidence) or inventing "fake experts" (see Betsch et al., 2019; Lewandowsky et al., 2022; Schmid & Betsch, 2019). According to Kienhues et al. (2020) and Neuberger et al. (2019), these trends have led to an erosion of common knowledge bases and challenged established hierarchies of knowledge providers, paving the way for an era of post-truthism and alternative access to reality. In this context, previous studies have identified various dangers stemming from different forms of epistemological

fragmentation, such as counter-knowledge, pseudoscience, anti-intellectualism, and ideological negotiations of expertise (see Eslen-Ziya, 2022; Marres, 2018; Marwick & Partin, 2022; Merkley, 2020). We assume that alternative news media represent an important jigsaw piece in this process of changing societal knowledge systems (Ylä-Anttila, 2018).

However, some "conceptual confusion" remains regarding the definitions and key features of alternative news media (see Holt, 2020; Schwarzenegger, 2021, pp. 100–101). In our study, following the relational understanding of Holt et al. (2019), we expected alternative news media to tendentiously contradict established politics and media. Alternative news media "represent a proclaimed and/or (self-)perceived corrective," pretend to take up the news disregarded by "mainstream" institutions (Holt et al., 2019, p. 862), and/or offer "re-narrations'' of news and events (see Doerr & Gardner, 2022). Regarding the Covid-19 pandemic in the German context, Boberg et al. (2020) found that alternative news media steadily reported popular conspiracy theories and rumors concerning Covid-19 (see Boberg et al., 2020, p. 15). Moreover, the content included a constant negative tone toward the establishment, public institutions, and the handling of the pandemic and its political and scientific consequences (Boberg et al., 2020, p. 17). Boberg et al. (2020, pp. 17–20) summarized the situation by saying that alternative news media "contribute to public confusion" by "constructing a contradictory, menacing, and distrusting worldview, which calls any official statement into question."

3. (Counter)Evidencing Practices and Argumentation Theory

From a science communication perspective, we still do not know much about the spread of Covid-19 information in and through alternative news media or what specific criteria are applied to evaluate scientific information (Neuberger et al., 2019, pp. 179–180). We assume that science communicators generally do not apply established scientific evaluation and evidence production criteria (Merton, 1942), using, instead, other mechanisms to rate facts and claims as true or trustful (Post, 2013). Kinnebrock et al. (2019) referred to more or less scientific evaluation mechanisms performed by science communicators as "evidencing practices" and defined them as "textual (or visual) strategies to support a claim as 'true' or 'valid.'" Investigating print media journalism, Kinnebrock et al. (2019) identified the following three common evidencing practices: Data/Methods, Experts/Authorities, and Narratives.

First, references to Data/Methods support findings by describing methodological parameters, study designs, and/or statistical procedures and numbers. This evidencing practice is closest to scientific logic, which builds on state-of-the-art methods, procedures, and conventions to support the validity and veracity of findings (Merton, 1973) and plays an indispensable role in scientific evaluation and peer regulation. References to Experts/Authorities represent an evidencing practice that is more easily usable in journalism. This practice includes (a) naming, describing, or attributing the source of the claim that implies authority (e.g., prestigious journals, research institutions, or highly regarded researchers) and (b) referencing external scientific and nonscientific experts (e.g., representatives of media, economy, or politics) to support reported research. Finally, Narratives constitute a journalistic evidencing practice whereby abstract scientific findings are transformed into representations of events and characters (e.g., patients and scientists) to convey scientific facts in the familiar shape of everyday communication (see Kinnebrock et al., 2019). Kinnebrock et al. (2019) described the use of Narratives as a highly persuasive strategy for science communicators that has the unique potential to contextualize and transform scientific knowledge into a language appropriate for both professional *and* mass audiences.

These evidencing practices are similar to the argumentation heuristics from argumentation theory (Barnes et al., 2018, 2020). References to Data/Methods and Experts/Authorities correspond to the argumentation heuristics that Barnes et al. (2018, 2020) called direct and indirect evaluations of scientific claims. As a theoretical background, Barnes et al. (2018, 2020) use the heuristic-systematic model (Chaiken, 1987). The use of Data/Methods and Experts/Authorities as evidencing practices is considered heuristics because it is not the strength of the arguments that facilitates persuasion but the heuristic cues that indicate (but do not prove) the legitimacy of the findings. For example, stating that a study was published in the journal *Nature* does not prove the truthfulness of the study; rather, it references the journal's good reputation to project the image of solid science onto the findings. Likewise, interviewing the director of a research institute relies on the anticipated trust that people have toward science and scientists to validate scientific findings. In the heuristic-systematic model, such cues are considered message or source characteristics. In this context, Barnes et al. (2018) studied the user effects of direct and indirect attacks on scientific claims. They defined direct evaluations as references to the empirical foundations of claims and indirect evaluations as references to the credibility of those who generate the data and support the scientific claims. Barnes et al. (2018, 2020) also described indirect evaluations as arguments "ad hominem" or "second-hand evaluations" because they represent a type of argumentation that allows people to avoid the complexity inherent in most science claims (Bondy, 2015; Yap, 2013, p. 99). Ad hominem attacks can refer to (alleged) conflicts of interest, past misconducts, or missing competence or education (Barnes et al., 2018), thus touching on the expertise, morality, or personal characteristics of participating actors. The evidencing practice of

Experts/Authorities also includes references to external experts (Kinnebrock et al., 2019). In argumentation theory, this practice is mirrored in arguments "ad verecundiam" (see Woods & Walton, 1974). According to Barnes et al. (2020), such arguments include appeals to source quantity, an argument for or against a scientific claim based on the number of people agreeing or disagreeing with it.

4. Present Study

In our study, we combined insights from argumentation theory with the concept of evidencing practices in legacy media to investigate the argumentation strategies that alternative news media use to evaluate Covid-19 research and affirm or reject the science behind it. We assumed that such strategies are not necessarily employed by all science communicators—Science communicators differ not only from scientists but also from one another in terms of their specific contexts and strategies for explaining, accepting, and rejecting scientific knowledge and arguments (Ehlers & Zachmann, 2019, p. 19). Therefore, we expected science communicators in alternative news media to use a specific set of evaluation mechanisms and to apply the evaluation mechanisms of legacy media differently when reporting and evaluating research. More specifically, we first considered whether and to what extent argumentation strategies known from science journalism and argumentation theory are applied in alternative news media (RQ1a). Then, we explored what themes and evaluation dimensions characterize the use of these argumentation strategies in alternative news media (RQ1b) and what functions they fulfill (RQ2).

Based on argumentation theory and the concept of evidencing practices, we developed a new taxonomy of (counter)evidencing practices that serve as heuristic categories for analyzing alternative news media discourse on Covid-19 research. We kept the category of Data/Methods because it represents the main connection between evidencing in science and in the media. Moreover, this category is consistent with both the concept of evidencing practices and argumentation theory ("direct evaluations of scientific claims"). We also retained Narratives, a common practice of mediating reality (Kinnebrock et al., 2019). However, we split the category of Experts/Authorities into two parts. First, we considered references to the original source of a scientific claim or finding, such as the researchers that conducted the study, the institutions in which the study was conducted, or the journals in which it was published ("source of the claim"). Second, we examined references to authorities and external experts inside and outside the scientific field ("external experts"), such as scientists commenting on other scientists' studies, representatives of society, or media representatives. We argue that common evidencing practices can also be used as *counterevidencing* practices by alternative news media—for instance, by using Data/Methods of a study to criticize it and classify its claims as "untrue" or "invalid." Therefore, we considered evidencing (supporting a scientific claim) and counterevidencing (refuting a scientific claim) practices—in short, (counter)evidencing practices—to identify situations in which alternative news media turn against the consensus of the scientific community regarding specific aspects of Covid-19 and to analyze the tools for doing so. In our analysis, we included reports about studies cited in scientific outlets and studies cited only in other media. In summary, we developed a taxonomy of the following three (counter)evidencing practices to analyze how alternative news media cover Covid-19 research:

1. References to Data/Methods;
2. References to Experts/Authorities, including (a) references to the source of the claim and (b) references to external experts;
3. Narratives.

We assumed that several (counter)evidencing practices can be combined in a single overarching argument for or against a research claim. For instance, cited external experts can use Data/Methods in their argumentation or the source of the claim can be evaluated by Narratives.

5. Methods

To answer our research questions, we conducted a thematic analysis (Braun & Clarke, 2006) of online content of German alternative news media (*NachDenkSeiten* and *PI News*). The alternative news media we selected represent divergent political views from different sides of the political spectrum and rank among the most popular sites (Doerr & Gardner, 2022; Similarweb, 2023a, 2023b). Both alternative news media represent some kind of "proclaimed and/or (self-)perceived corrective" (Holt et al., 2019, p. 862), describing themselves as either an information source for those distrusting the mainstream opinion makers and the agenda of mainstream media as well as a contact point for citizens who think about societal problems on their own (https://www.nachdenkseiten.de) or as a mainstream-corrective institution that sheds light on ignored or falsely framed topics and fights against the human rights violations of German citizens (https://www.pi-news.net).

Using the search functions available on the websites of the alternative news media, we selected articles (a) published between February 2020 and December 2021 and (b) focused on the presentation and evaluation of biomedical studies concerning Covid-19. The chosen timeframe ensured the inclusion of different phases of the Covid-19 pandemic (see Schilling et al., 2022). The focus on biomedical Covid-19 studies included, for instance, research from virology, biotechnology, and epidemiology on Covid-19 vaccination, medication, and virus mutations but excluded research on the social

and economic consequences of the pandemic. We used keywords related to science journalism (German words for "science," "scientist," "research," "researcher," and "study") in combination with keywords related to the pandemic ("corona" and "covid") and scanned the results for relevant articles. The final sample comprised 108 articles.

During the analysis, we coded the text parts of the 108 studied articles dealing with biomedical studies (coding units, n = 294). In a pretest with 13 articles, two trained coders achieved perfect agreement (Cohen's κ = 1.000; p < 0.001) by identifying 30 coding units, which represented approximately 10% of our full sample (Neuendorf, 2002). In the first step, to answer RQ1a, we used the three (counter)evidencing practices as deductive main categories to initially code the material and identify text parts containing one or more of the three (counter)evidencing practices (see coding scheme in the Supplementary Material). During this essential step, Cohen's κ coefficients (Cohen, 1960; Feng, 2015) were calculated to compute inter-rater reliability. Processing 30 coding units, two trained coders reached excellent (Landis & Koch, 1977) agreements (between κ = 0.895 and κ = 0.911) across all (counter)evidencing practices. Table 1 demonstrates that all coefficients were highly significant, which indicates that the subsample of the reliability test was large enough to form a reliable basis for statistical comparison (see Früh, 2017, p. 180). To answer RQ1b, the text coded according to the three main categories was differentiated into subcategories, with specific themes further refining the categories (see Section 6 and the coding scheme in the Supplementary Material). Finally, we inductively pinpointed the functions of the identified argumentation strategies by analyzing the contexts of the referenced study presentations and evaluations, as well as the ways in which the data in general employed (counter)evidencing practices (RQ2).

6. Results

6.1. (Counter)Evidencing Practices

First, we identified the regular use of all (counter)evidencing practices. Throughout the coding process, we remained vigilant of other (counter)evidencing practices. However, the deductive categories proved to be sufficient to classify all instances that served to support or reject research as (in)valid based on the three existing practices. The 294 study presentations that we coded were most commonly characterized by references to Data/Methods (74.15%) and Experts/Authorities (81.97%). Narratives were identified in 32.31% of the study presentations (see Table 2).

6.1.1. References to Data/Methods

We identified references to Data/Methods as a highly common (counter)evidencing practice in the material.

Table 1. Inter-rater reliability in identifying (counter)evidencing practices (Cohen's κ).

(Counter)evidencing practices	Inter-rater reliability (n = 30 coding units)	
	κ	p
1. References to Data/Methods	0.902	<0.001
2. References to Experts/Authorities	0.895	<0.001
2a. References to the source of the claim	0.927	<0.001
2b. References to external experts	0.862	<0.001
3. Narratives	0.911	<0.001

Notes: We used dichotomous coding for (counter)evidencing practices (0 = *practice absent*, 1 = *practice present*); all numbers for κ have been quadratically weighted.

Table 2. Frequencies of (counter)evidencing practices.

(Counter)evidencing Practices	Coding frequencies (n = 294 studies)	
	n	%
1. References to Data/Methods	218	74.15%
2. References to Experts/Authorities	241	81.97%
2a. References to the source of the claim	127	43.20%
2b. References to external experts	114	38.78%
3. Narratives	95	32.31%

Notes: We used dichotomous coding (0 = *practice absent*, 1 = *practice present*) regardless of the direction of the references (evidencing or counterevidencing practice); multiple coding at the level of different (counter)evidencing practices was possible; all figures were rounded to two decimal places.

Parts of the examined articles were highly professional by entirely focusing on discussions of Data/Methods related parameters (e.g., in articles P36 and N27; see Supplementary Material; "P[number]" represents an article in *PI News*, while "N[number]" represents an article in *NachDenkSeiten*) or using scientific citation standards and comparatively analyzing great amounts of divergent Covid-19 study results based on Data/Methods (e.g., N58 and N66). Regarding the themes and concrete content of Data/Methods, we found that such references were often related to findings, theories, and/or methods. Findings were often described in terms of general quality, usefulness, plausibility, correctness, consistency, and traceability of interpretations (e.g., P1, P30, N22, N44, N45, and N51). Sometimes, findings were also discussed in terms of the informative value and significance of the discovered statistical intersections (e.g., P15, N35, and N49). Theories could be evaluated according to the quality of their hypotheses (e.g., P7 and N5) or their scientific terminology (e.g., N58). Regarding references to methods, the articles discussed sample sizes and representativeness (e.g., P38, N14, and N49), the appropriateness and limitations of the methods used, analysis strategies, method-related statistical numbers (e.g., P6, P18, N33, N58, and N59), the study design and reliability (e.g., P26, N28, and N68), and the adherence to research standards and rules of clean academic working (e.g., P23, N11, and N16). Of course, in many cases, the three themes overlapped. For instance, reported statistical information was often difficult to categorize because it could be related to findings (e.g., reporting on statistical relationships) and methods (e.g., reporting on the reliability measures of survey instruments).

6.1.2. References to Experts/Authorities

Regarding the first part of this (counter)evidencing practice—references to the source of the claim (2a)—we identified references to expertise, morality, and/or the characteristics of actors, institutions, and journals directly associated with the reported research. Expertise could be conveyed implicitly or explicitly: implicitly by naming and briefly describing the involved research institutions, academic journals, or the academic status and professional functions (PhD, professor, director, etc.) of researchers (e.g., P12, P22, N29, and N49) and explicitly by directly evaluating the experience, competence, and relevant expert knowledge of the actors involved (e.g., P35 and N47). The morality of the involved actors was evaluated in terms of research ethics (e.g., N21 and N37), commitment to public welfare (e.g., N59), past misconduct or good deeds (e.g., N12 and N21), the secrecy of information and research (e.g., P6 and N65), and the existence of potential conflicts of interest. The latter could involve, for example, discussions of the political susceptibility of the researchers (e.g., P10) or of potentially competing financial, political, or prestige-related motives (e.g., N2, N27, N45, and N67), a theme that was highly prominent within the data. Finally, the involved actors were sometimes described in terms of their characteristics by rating personality traits that were rather irrelevant to the claim, such as the actors' open-mindedness, popularity, or willingness to cooperate with media representatives (e.g., P12, P35, and N15).

The analysis of the second part of this (counter)evidencing practice—references to external experts (2b)—revealed that, in many cases, the investigated alternative news media cited or relied on external experts to evaluate the reported research. This role was fulfilled by, among others, scientists or scientific collectives (e.g., P3, N40, and N66), scientific journals (e.g., N22 and N24), a broad range of more or less established media organizations or journalists (e.g., P10, N18, and N29), online blogs and portals (e.g., P18 and P36), representatives of medical institutions or public health authorities (e.g., N6 and N36), politicians or political institutions (e.g., P17 and N48), economic experts (e.g., N24 and N44), or individual citizens (e.g., N50). We also identified appeals to source quantity and references to common collective knowledge and experiences to (de-)value reported research (e.g., P20, P29, and N66). As for references to Data/Methods, the themes of references to Experts/Authorities also overlapped (e.g., references that involved expertise and morality at the same time or references to external experts having affiliations with several societal fields at the same time).

6.1.3. Narratives

In our analysis, we found that Narratives were often combined with one of the other two (counter)evidencing practices—in many cases, to emphasize the direction of evaluation. For instance, Narratives were used to portray and explain study procedures (e.g., N31), to describe the personal careers of research actors (e.g., N68), to highlight people influenced by study results (e.g., P7 and N10), to analyze research actors' motives for conducting a study (e.g., N5 and N7), or to exemplify the misconducts and scandals of the involved research actors (e.g., N21 and N24). Moreover, these functions of Narratives overlapped as well (see Sections 6.1.1 and 6.1.2). However, in accordance with previous research (see Sections 3 and 4), we assumed that Narratives mostly functioned as bridges between the abstractness of the scientific claims and findings on the one hand and the fates, experiences, and attitudes of the people and institutions associated with specific research on the other.

6.2. Functions of (Counter)Evidencing Practices

The fact that similar mechanisms can also be found in traditional science journalism led us to focus on the specifics of (counter)evidencing practices in alternative news media and to investigate how specific (counter)evidencing practices fit into the presumed

anti-mainstream agenda of alternative news media. Consequently, we analyzed the functions of the related argumentation strategies by examining how the studied articles embedded (counter)evidencing practices and expressed evaluations along with ideologies, prototypical stories, and similar motives for reporting on Covid-19 science. To be more precise, we identified a relationship between the use of either evidencing or counterevidencing practices and their respective functions, which we will discuss for each practice by considering typical cases.

6.2.1. References to Data/Methods

In the following example, a recently published study was presented as valid (evidencing practice) by referring to sample size and statistical results as well as describing its experimental arrangement as "large-scale" and the practical implementation of the study as "meticulously monitored'':

> We indicate a study recently published in the *New England Medical Journal* investigating the case of corona "control strategies" under military supervision. First, 3,000 recruits from the US marines had to undergo two weeks of strict quarantine as part of a large-scale experimental arrangement. Then, the recruits were kept in military barracks for 14 days and had to follow strict hygiene regulations, distance control, face-mask duties, and regulations to minimize social contact. They were meticulously monitored. The result after one month: Both soldiers who initially tested negative and soldiers who were not tested beforehand showed, in the end, positive rates of approximately 2%. (N28; all direct citations translated from German)

The use of this evidencing practice in the context of the article's overall argumentation shows that the Data/Methods of the presented study may be evaluated positively because it is supposedly excellent research ignored by the mainstream. In this article, the so-called mainstream media, science, and politicians are criticized for downplaying and not using this highly important knowledge. It also highlights the alleged low efficacy of the anti-Covid-19 measures implemented by so-called mainstream politicians and scientists. To compare, the following example involves a study that is invalidated by referring to its Data/Methods (counterevidencing practice):

> Regarding the development of their vaccine candidate, Pfizer, together with the German biotech company BioNTech, want to conduct an intermediate examination after only 32—also mild—Covid-19 infections among study participants. Then, if six cases of illness are assigned to vaccinated participants and the rest are assigned to the control group that received a placebo, this should, according to Pfizer, prove the effectiveness of the vaccine and justify an emergency admission. (N22)

In this paragraph, a BioNTech–Pfizer study on the efficiency of their vaccine candidate is criticized in terms of its study design and statistical procedures. The article claims that the companies formulated claims that were too strong and far-reaching regarding the effectiveness of their vaccine in relation to their actually rather poor and hasty methodological approach. Clearly, negative evaluations of methodological procedures serve the function of devaluing one of the government's great hopes in fighting the Covid-19 pandemic. In addition, it is a starting point for sowing doubts about government-endorsed vaccination.

6.2.2. References to Experts/Authorities

New research was also commonly validated (evidencing practice) by referring to the source of the claim (2a)—for instance, by describing the involved researcher as "internationally acknowledged" and the journal in which the work was published as "highly regarded": "Already on January 4th, an article of the internationally acknowledged expert in the effectiveness and safety of drug substance, Assistant Professor Peter Doshi from Baltimore (USA), appeared in the highly regarded *British Medical Journal*" (P26). When investigating why this study and the referenced actors were evaluated positively, we identified connections with Covid-19-related political motives. According to the article, Peter Doshi's work sheds light on common vaccines not being as effective as proclaimed. To the writer's surprise, his work was supposedly ignored by the mainstream because the results would not fit the mainstream's narrative of crises and the importance of mass vaccination.

At the same time, references to the source of the claim could also serve to invalidate a study (counterevidencing practice): "This operetta-like causality seems to be an expression of political wishful thinking. Christoph Richter has no scientific competence at all regarding medical or even epidemiological questions" (P35). In this case, the article criticizes a study that proposed a connection between a region's infection numbers and its proportion of right-wing party Alternative for Germany voters. The study authors assumed that Alternative for Germany supporters might be less willing to follow official anti-Covid-19 measures and thus face a higher risk of becoming infected, while people strictly following anti-Covid-19 measures might face lower risks of infection. A confirmation of this hypothesis would have underlined the usefulness of the government's anti-Covid-19 measures at the time. In the article, the study's assumption was completely rejected, not only by arguing about misguided causality but also by claiming that its author, Christoph Richter, showed a complete lack of "scientific competence" concerning "medical or even epidemiological questions." Questioning the study author's expertise

fulfils the function of diminishing the government's competence to adequately handle the pandemic.

In the context of this (counter)evidencing practice of Experts/Authorities, below is an example of referring to external experts (2b) to validate a biomedical Covid-19 study (evidencing practice):

> It can be assumed that nowadays, the Spanish flu would cause way fewer deaths. Considering that no one still contests the existence of a high number corona-infected people with no or very mild symptoms as well as the fact that many Covid-19 victims died *with*, not *because of*, the virus, Streeck should know the truth, not the Johns Hopkins University. (P2, emphasis in the original)

This article reports on a case study conducted by virologist Hendrik Streeck in the German region of Heinsberg, known for having suffered diverse superspreading events at the very beginning of the crisis. Streeck and his team investigated how many people had antibodies against SARS-CoV-2. They found that there was a high number of unrecorded cases in the region of Heinsberg, which was five to 10 times higher than the assumed infection numbers. This result was employed to relativize and reduce the claimed mortality rate of Covid-19 as well as to question the extant anti-Covid-19 measures. In the cited excerpt, the robustness of Streeck's findings is strengthened by appealing to source quantity and claiming that *everyone* already knows that these findings must be true and "yet *no one* contests" (P2, emphasis added) them. Thus, this reference to external experts and source quantity supports the presented study and is used to question the official guidelines for fighting Covid-19. At the same time, references to external experts can also serve to devalue reported Covid-19 research (counterevidencing practice):

> First of all, there was criticism of the mathematical model underlying Report 9. The *Daily Mail* presented this headline on May 17, 2020: "Computer code for Prof. Lockdown's (Neil Ferguson) model, which predicted 500,000 would die from Covid-19 [in Great Britain] and inspired Britain's Stay Home plan, is a 'mess which would get you fired in private industry,' say data experts." (N24)

External experts (in this case, the tabloid *Daily Mail* in relation to data experts) are cited to evaluate the computer model of scientist Neil Ferguson as "a mess which would get you fired in private industry." An examination of the context revealed that the use of this counterevidencing practice served to delegitimize a scientist who consulted the government and inspired Britain's stay-at-home plan. By using the label "Prof. Lockdown" to refer to Neil Ferguson, this example also contains a reference to the source of the claim (2a).

6.2.3. Narratives

In the following example, the last argumentation strategy, Narratives, is used to support the reported research (evidencing practice):

> Dr. Stefan Tasler has a PhD in organic chemistry and has been working in the biotech sector with a focus on active pharmaceutical ingredient research and development for 20 years. During this time, he has intensively studied the functioning of the immune system in the context of autoimmune diseases. Later, he became a research director. Between 2016 and 2019, he was part of the dual leadership of a subsidiary of BioNTech before going into research on Alzheimer's disease as vice president of Drug Discovery & Development. (N68)

The article discusses some of Tasler's research and gives him space to make highly critical comments on extant vaccine projects. The authors use a narrative to describe the personal career of this researcher. They point out different areas in which Tasler has scientific experience as well as his academic degree (PhD), responsible positions (director), and lengthy experience regarding the relevant topics (more than 20 years). The narrative element underscores the researcher's experience and expertise, fulfilling the function of supporting a scientist who criticizes established vaccine projects that are important for the German government's long-term strategy of controlling Covid-19. At the same time, Narratives can also be used to invalidate research (counterevidencing practice):

> But Pfizer has a globally bad reputation. In the mid-1990s, this US company carried out illegal and fraudulent meningitis (brain fever) tests on children in African Nigeria. During the tests with the experimental medicine Trovan, 11 children died, and dozens suffered lifetime disabilities….The company succeeded in designing a clinical study for the experimental Trovan compound in six weeks, although the risks and complications associated with such tests usually require one year to make an appropriate assessment. (N21)

This article tells a story of Pfizer's past misconduct from the mid-1990s: The US company is said to have carried out illegal and fraudulent meningitis tests on children in African Nigeria. The article reports that 11 children died. This narrative functions as a strong devaluation of Pfizer by questioning the company's professional and moral qualities. The implication is that if Pfizer has done morally reprehensible things in the past, it cannot be more conscientious in its research on Covid-19 vaccines.

7. Discussion and Conclusions

To summarize, the examined alternative news media used the same argumentation strategies as those found

in traditional science journalism. However, the evaluations offered in the articles were transfused with ideological evaluations, prototypical stories, and a contrarian agenda regarding Covid-19 policies. On the surface, the articles reported on science. After a deeper analysis, it became clear that the content was used to undermine scientific claims confirming a (preliminary) consensus of the scientific community regarding certain aspects of Covid-19. Similarly, in both alternative news media, evidencing practices were typically used in connection with research supposedly ignored by the so-called mainstream and research to call for a renegotiation of Covid-19 politics. The content often emphasized research that supposedly had not received the public interest it deserved and that would have paved the way for the easing of anti-Covid-19 measures. The emphasis fell on the studies and claims that rejected the consensus of the scientific community and that were often conducted by researchers who had been expelled from their scientific communities and deemed unreliable by their peers; alternative news media judged them to be geniuses who had been ostracized and downplayed. Counterevidencing practices were often employed in connection with research supporting extant Covid-19 policies as well as research conducted by public health institutions and well-established scientists—for example, the German Robert Koch Institute, the American Johns Hopkins University, and scientists serving as government consultants.

Furthermore, the examined alternative news media were not skeptical of science in general, as is sometimes assumed. In some cases, their science news coverage contained calls for a stronger reliance on science—that is, for *other*, *alternative* science resisting the consensus of the scientific community regarding specific aspects of Covid-19. However, by generally rejecting *common* epistemic authorities and evidence, the alternative news media accelerated the processes of gradually destabilizing well-established expertise and evidence. Therefore, the identified argumentation schemes are, to some degree, similar to the typical strategies of strict science deniers, such as cherry-picking evidence or inventing fake experts (see Section 2). In any case, our investigation indicates an enormous bias within alternative news media when dealing with scientific knowledge regarding Covid-19. As re-narrators (Doerr & Gardner, 2022) and re-evaluators of science news, these organizations constitute a quite worrisome force in societal Covid-19 discourses.

Our research is limited to the German case, specifically two alternative news media. In future research, some of the themes and functions of (counter)evidencing practices identified here should be examined in broader samples and in other countries as well as comparatively applied to other science communicators. Moreover, although our study provides in-depth analyses of the exact techniques in (counter)evidencing practices, we did not perform a quantitative analysis of the categories. Therefore, we cannot infer the frequencies or co-occurrences of the (counter)evidencing practices. Quantitative research on (counter)evidencing practices and their co-occurrence would be an important step in this domain.

Our findings also have implications for audience views. The counter-mainstream science news coverage may increase public uncertainty and confusion regarding Covid-19, casting doubts on the effectiveness of related political measures. The constant stream of "science reporting" in alternative news media may undermine professional accounts in legacy media. For example, audiences may be exposed to both sources and get the impression of deep discord in science. Finally, competing forms of reporting may produce the sensation of not understanding or being incapable of understanding science—a negative predictor of overall trust in science (Bromme et al., 2022). Audiences of alternative news media are confronted with science news that is primarily guided by ideological motives and evaluated in terms of its usefulness for ideological or political aims, which mostly involve arguing for a change in Covid-19 politics and questioning well-evidenced research. Thus, the consumption of anti-mainstream media can result in a lack of trust in science, which can impact Covid-19-related health decisions. Previous research has already hinted at strong correlations between the consumption of alternative news media and distrust in the establishment as well as support for radical anti-vaccination movements or the violation of official Covid-19 guidelines (Frischlich & Humprecht, 2021; Lange & Monscheuer, 2021; Soveri et al., 2021).

Given that neither Covid-19 nor dubious nonprofessional science communicators are likely to disappear any time soon, potential strategies for countering the rejection of scientific evidence are urgently needed. To make audiences more resilient and critical in their consumption of science news, it may be fruitful to investigate techniques for correcting inaccurate information online (Schade et al., 2021), means of strengthening established science journalism (Wormer, 2020, p. 467), strategies to argumentatively counter science denialism (Lewandowsky et al., 2022; Schmid & Betsch, 2019), and ways of increasing audience members' media and science literacy (Kienhues et al., 2020; Wolling et al., 2021, p. 16).

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Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

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Article

Scientific Information Literacy: Adaption of Concepts and an Investigation Into the Chinese Public

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Abstract
Many studies have developed the concepts and measurements of scientific and information literacy. However, the changes in the media environment, the complexity of scientific information, and low entry barriers have brought new challenges to scientific information communication. A single scientific or information literacy concept cannot provide a clear overview of the competencies and literacy required for individuals to access scientific information in new media contexts. This study aims to adapt the existing concepts and measurement frameworks related to information literacy in science communication and to investigate scientific information literacy and the demographic differences among the Chinese public through a cross-sectional survey (*N* = 2,983). The results showed that compared to self-directed information acquisition, accurate information filtering, and information sharing and dissemination, the Chinese public has relatively lower levels of information credibility assessment and opinion expression. Besides, the scientific literacy levels among the Chinese public had significant differences according to gender, age, and education. This study argues that adapting current information literacy concepts into science communication can promote public understanding of scientific information. The concept of scientific information literacy should be considered as a means of understanding the impact of new media on scientific information communication. The contribution of this study is that it adapts existing concepts into a novel context, further enriching the empirical research on scientific literacy and the research perspective on science communication.

Keywords
information literacy; literacy investigation; new media; science communication; scientific literacy

Issue
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1. Introduction

As Tsabari and Schejter (2019) stated, new media is a double-edged sword in its support of public engagement with science. The characteristics of new media, such as rich content, interactivity, mobility, and multimedia, provide higher affordance than traditional media while making it more difficult for non-expert audiences to access informed messages and science-related decisions.

Flew (2007) demonstrated that new media are forms of media content that integrate diverse kinds of data, text, sound, and images—and unlike previous media, it is interactive. New media provide convenience and opportunities but also bring great challenges for scientific information communication. First, new media allow users to reach information instantly and make it easier for science communicators to address audiences directly through new dissemination channels and forms (Peters

et al., 2014). However, corrupting influences that could cause the de-professionalization of science might also be generated in this context (Rödder et al., 2012). Second, although new media have the advantage of massive scientific information resources, empirical evidence shows that inaccurate descriptions of scientific phenomena are present in the online world, and that new media can facilitate the rapid spread of potential misconceptions about scientific discoveries among large audiences (Liang et al., 2014). Third, new media bring great interactivity to science communication, but studies have shown that increased interactivity and engagement do not automatically improve public discourse. Uncivil social media comments left by audiences about scientific information might cause polarized views of technology-related risks (Anderson et al., 2014).

Science communication faces many challenges in an information environment with incorrect, confusing, and rapidly changing messages. Multidimensional literacies can help people deal with complicated and dynamic challenges. The literacies involved in the context of science communication and the new media environment are complex, and literacy-related terms have commonalities and differences in their concepts. For example, media literacy emphasizes the acquisition, analysis, evaluation, and dissemination of information (Potter, 2004). Scientific literacy emphasizes the understanding of the nature of science, the concepts behind key terms, and the impact of science and technology on society (Miller, 1983). Scientific information literacy highlights the ability to access and critically analyze scientific information (Welborn & Kanar, 2000). Over the past few decades, it has been recognized that there is a need to increase the proportion of citizens who are sufficiently scientifically literate to understand public policy controversies involving scientific or technical issues (Miller, 1998). Scholars have also debated and generated new insights into the definition and scope of literacy-related terms. However, from the science communication practices in the new media environment, the single concept of scientific literacy or media literacy cannot summarize the competencies and literacies required for individuals to access scientific information (Gu & Feng, 2022). Furthermore, many countries have investigated scientific literacy and information literacy, but their surveys did not measure public scientific information literacy in the new media environment. Thus, this study aims to adapt the previous concepts and measures of literacy to the context of new media science communication and further explore and examine it among the Chinese public.

The implications of the contributions of this study are conceptual, theoretical, and empirical. First, this study adapted previous concepts and measurements of scientific information literacy into the context of science communication. Traditional scientific literacy education neglects the skill of searching and understanding scientific information sources in the media, resulting in people lacking the ability to read scientific information (Majetic & Pellegrino, 2014). Previous scientific information literacy emphasizes "the ability to access and critically analyze information with a scientific nature" or "identifying misinformation related to science" (Gu & Feng, 2022). However, literacies, such as scientific information dissemination, are also significant in practical scientific communication (Abhijit, 2012). Thus, adapting the existing and relatively well-developed literacy framework to the science communication context is necessary. Second, as Miller (1998) pointed out, despite the increasing attention, there has been a marked decline in the debate and a lack of consensus on measuring scientific literacy. Moreover, the debates are primarily about the conceptual level, with little to no empirical testing of these conceptualizations. This study reviews the concepts and measurement framework of scientific information literacy, then empirically examines the updated concept of scientific information literacy through a cross-sectional survey. Third, the data in this study enriches the research perspective in scientific communication. Studies on scientific literacy and media literacy are originated and well-developed in Europe and the US (Miller, 1998), but the relevant studies in China are somewhat lacking. The findings from this study provide a diverse perspective for scientific communication research.

2. Literature Review

2.1. Literacy: Scientific, Media, Information, and Digital Competencies

The term "literacy" is usually interpreted as the ability to read and write. The expansion of the term, such as cultural, scientific, and media literacy, suggests the semantic importance of the term (Kintgen, 1988). Different literacy concepts have been developed based on the emphases in specific domains. Concepts related to scientific information communication practices, such as scientific literacy, media literacy, information literacy, and digital literacy, have driven increased attention in recent years.

Scientific literacy is widely referred to in science communication and has become an internationally recognized contemporary educational goal (Laugksch, 2000). Miller (1983) conceptualizes scientific literacy as three dimensions: (a) an understanding of scientific norms and methods (i.e., the nature of science), (b) an understanding of key scientific terms and concepts, and (c) perception and understanding of the impact of science and technology on society. In recent years, increased activities have been designed to improve scientific literacy due to growing concerns about spreading misinformation and conspiracy theories that contradict established scientific findings (Howell & Brossard, 2021). Previous scientific literacy education has often neglected the skills of finding and understanding scientific information sources in the media, leading to a lack of ability to read scientific information. Thus, scholars suggested that the combination

of information and scientific literacies education can narrow the gap and increase people's ability to identify and access sources of news and information (Majetic & Pellegrino, 2014). Klucevsek (2017) pointed out that scientific literacy requires information literacy, which is a fundamental, continuous, and integral part of the scientific process. Howell and Brossard (2021) conceptualized scientific literacy into three dimensions: civil scientific literacy, digital media scientific literacy, and cognitive scientific literacy. They argued that digital media scientific literacy, as a sub-dimension of scientific literacy, has to include the ability to navigate and evaluate scientific media information, which is further required in the next stage of the lifecycle of science information. Cognitive scientific literacy refers to the process of personal thinking through information and the perception of how the thinking process shapes the conclusion (Israel et al., 2006), which can facilitate searches for scientific information and improve critical thinking and reading skills (Bannister-Tyrrell, 2017).

Media perception has become critical with the rise of digital technology (Koltay, 2011); thus, scholars have turned their attention toward literacy related to media. Bawden (2001) identified terms related to information literacy, including information literacy, media literacy, and digital literacy, which focus on a critical approach to media messages (Koltay, 2011). From the scope of the definitions, the concept of media literacy covers the narrowest scope, usually described as facilitating critical engagement with media information (Bulger & Davison, 2018). According to the basic definition, media literacy refers to active inquiry and critical thinking about the received and created information, and its connection to critical thinking is recognized (Hobbs & Jensen, 2009). The National Association for Media Literacy Education (2007) defines media literacy as the ability to access, analyze, evaluate, create, and act through various communication forms, emphasizing the ability of analysis. Information literacy is broader than media literacy, which refers to the skills required to identify sources, access information, evaluate information, and use information effectively, efficiently, and ethically. Information literacy education emphasizes the use of meta-cognitive, critical thinking, and procedural knowledge to locate information in specific domains, fields, and contexts (Koltay, 2011). Furthermore, much attention has been paid to recognizing information quality, authenticity, and credibility (Hobbs, 2006). Compared to the two literacies mentioned above, the concept of digital literacy is the broadest. Digital literacy is considered a multidisciplinary concept that includes information literacy, computer literacy, media literacy, communication literacy, and technological literacy. In addition, digital literacy emphasizes the ability to communicate through media and apply technologies to specific life contexts (Chetty et al., 2018).

2.2. Adapting Information-Literacy-Related Concepts Into Science Communication: Attempts, Limitations, and Frameworks

As Bawden (2008) stated, no single individual or group can rely on one single literacy without it being updated with new concepts and abilities in response to the changing information environment. The practice of scientific information communication faces many challenges in the new media environment, and the scientific process requires information-related literacy. Thus, the concepts and requirements of literacy have to evolve with the times. Some academic attempts have adapted concepts related to information literacy into the science communication context. In addition to including digital media scientific literacy and cognitive scientific literacy as subdimensions of scientific literacy mentioned above, some scholars have proposed the concept of scientific information literacy. Welborn and Kanar (2000) illustrated that scientific information literacy should emphasize the ability to access and critically evaluate scientific information. Gu and Feng (2022) argued that neither information nor scientific literacy captures the public perception of scientific information. They defined scientific information literacy as "the ability to think critically based on scientific evidence, sound analysis, and consensus within the scientific community to identify misinformation related to science."

The review of literacy-related concepts reveals the previous attempts to expand the concept of scientific literacy in the new media context, such as the concepts of scientific literacy and scientific information literacy, but improvements are still needed. The current definition of scientific information literacy only emphasizes the personal ability to access, identify, critically analyze, and evaluate scientific information but ignores the ability to disseminate information in the media (emphasized in digital literacy; Chetty et al., 2018) and the ability to express opinions (emphasized in new media literacy; Lin et al., 2013). The blurring of the boundaries between media consumers and producers demands attention in academic research (Koltay, 2011). Traditional media technologies did not allow users to share or negotiate their views (Berger & McDougall, 2011), but new media's interactive and participatory nature allows opinion expression. In the current practice of science communication, the public is not only the receiver but also a disseminator of scientific information and an exponent of scientific opinions. Thus, the ability of information dissemination and opinion expression proposed in the concept of media literacy should be included in scientific information communication. Besides, compared to the formulation and improvement of the concept, a framework for measurement is still lacking. This study followed the concept of scientific information literacy to show the ability and literacy required in science communication practices.

This study attempted to adapt previous concepts and measurement frameworks in the context of science

communication, defining scientific information literacy as a multidimensional construct that enhances people's ability to use media to acquire, select, evaluate, and disseminate scientific information. Specifically, there are five basic dimensions of scientific information literacy framing. First, the ability to acquire scientific information, which refers to using different media skillfully and appropriately to obtain different scientific information and further meet individual needs for information. The ability to access information is fundamental for information literacy and the same for scientific information. Breivik (1987) also suggested that information literacy needs to contain the element of access to information when defining information literacy. Information access is integral to the information literacy skill level. Second, the ability to filter scientific information. The ability to recognize useful scientific information and to access information that meets personal needs from masses of information is significant in the new media environment. Besides, filtering information is in line with the concept of "understanding" in the theoretical framework of new media literacy (i.e., the ability of individuals to grasp the meaning of media content). It includes the ability of individuals to understand the ideas expressed by others on different new media platforms (Lin et al., 2013). Third, the ability to evaluate the credibility of scientific information. This indicator includes the ability to analyze and judge whether scientific information is correct, especially the ability to question, which aligns with the existing concept of scientific information literacy (Gu & Feng, 2022). This indicator also echoes the concept of critical thinking, a mental activity that emphasizes the evaluation of information (Hollis, 2019). Fourth, the ability to disseminate scientific information. This indicator refers to the ability to spread scientific information that is found. Buckingham (2009) stated that the most important development in recent years had been related to distribution rather than production technology. This indicator shares the concept of information literacy discussed by Jenkins (2006), which focuses on the ability to search, synthesize, and disseminate information. For example, people express their feelings about scientific information (e.g., like/dislike) and share media information. Lastly, the ability to express opinions. This indicator refers specifically to the ability to engage in discussion about scientific information, actively criticize and refute misinformation in science communication, and express opinions via new media. The indicator is similar to the "engagement" proposed by Lin et al. (2013), which indicates the ability to participate interactively and critically in the new media environment.

2.3. Demographic Information and Scientific Information Literacy: Importance and Relationship

In addition to the concept, empirical studies in literacy competencies are also important in literacy research. Literacy statistics, including literacy levels and demographic information, are often used as indicators of social inequality and as a basis for policies to improve rights and educational attainment (Street, 2011). Specifically, regarding the literacy competencies required in science communication, literacy gaps reflect the disadvantage and cultural oppression experienced by minority groups and people with low economic and social status (Allum et al., 2018). Also, the literacy gap might be an important indicator for evaluating groups that participate/do not-participate in science communication. In scientific literacy research, most studies focused on the temporal changes in scientific literacy and its relationship with attitudes and beliefs, but few cared about the differences in scientific literacy across groups (National Academies of Sciences, Engineering, and Medicine, 2016). Thus, the relationship between scientific information literacy and demographics is important in terms of literacy inequality and research scarcity.

Although no studies directly show an association between scientific information literacy and demographic information, some findings have suggested a relationship between literacy competencies, such as scientific literacy and information literacy, and demographic information. Bacanak and Gökdere (2009) investigated the relationship between gender and scientific literacy levels. They found that men's scientific literacy is not higher than women's, except within the life sciences field. Another study involving Nebraskan adults found that while gender and age did not significantly affect scientific literacy levels, education was positively correlated with high scientific literacy (Swendener, 2017). In terms of information literacy, a growing number of studies have shown individual differences in digital skills across different age and gender groups (Michalak et al., 2017). Therefore, gender, age, and education are important demographic indicators related to scientific and information literacy, providing a literature basis for further validation of demographic differences in scientific information literacy.

3. Study Aim and Research Question

According to the previous research on scientific literacy, media literacy, information literacy, and digital literacy, this study pointed out the limitation of current literacy-related concepts. Then, this study proposed the need to introduce information literacy into the science communication context and to develop a measurement framework and empirical studies. This study aims to adapt previous conceptual and measurement frameworks into the science communication context. In addition, this study conducted a cross-sectional survey (N = 2,983) to investigate scientific information literacy among the Chinese public. The research question addressed in this study, therefore, is:

> RQ: Are there any significant differences in the level of scientific information literacy among the Chinese public in terms of demographics, such as gender, age, and education?

4. Methods

4.1. Research Sample

This study conducted a cross-sectional survey from September to October 2021. We commissioned the professional data research company wjx to carry out the survey by distributing paid questionnaires online (around 19,334 CNY). The company wjx has a sample base of 2.6 million potential respondents reasonably distributed by gender, age, occupation, and region. The company distributed 3,000 copies nationwide by means of a convenience sample and finally collected 2,983 valid samples for this study, with a valid return rate of 99.43%. The company is responsible for the quality and validity of the data during the completion process. After distribution and data collection, the company provides the final valid data to the researcher, but the detailed recruitment process and response rate are not open to the researcher. This study adopted all valid samples offered by the company without additional censoring. The sample of this study covers all provincial administrative regions of China, and the population distribution (Figure 1 of the Supplementary File) is also basically consistent with the demographic characteristic reported by the seventh national census of China (National Bureau of Statistics, 2021; Figure 2 of the Supplementary File), which is that Southeast China has a larger population than Northwest China.

4.2. Measures

The items used for measuring variables in the questionnaire are partly original and partly adapted from previous studies (Dijkstra et al., 2012; Gu & Feng, 2022; Miller, 1998). Besides investigating the channels the public uses to access and obtain scientific information, we asked respondents how frequently they accessed scientific information through new media for descriptive analysis. The questions were: (a) What channels do you use to access and obtain scientific information (multiple choice)? (b) How often do you access scientific information through new media? The options and results are shown in Table 4. Two bilingual researchers translated the original English surveys into Chinese and then translated them back into this study.

4.2.1. Self-Directed Information Acquisition

This study used a five-point Likert scale (1 = *strongly disagree*, 5 = *strongly agree*) to measure respondents' ability to access scientific information (*M* = 3.90, *SD* = 0.67). Here are the example statements:

- Q1: I try to obtain scientific information and knowledge from different media sources to ensure that I get a comprehensive understanding.
- Q2: I compare and synthesize scientific information from different media sources to ensure reliable information.
- Q3: I go further to search for information when I am exposed to scientific information in the media that lacks evidence and support.

4.2.2. Accurate Information Filtering

This study used a five-point Likert scale (1 = *strongly disagree*, 5 = *strongly agree*) to measure respondents' ability to filter and select scientific information (*M* = 3.94, *SD* = 0.61). For example:

- Q4: I am good at using different media sources and platforms to obtain scientific information.
- Q5: I usually know which media sources to use when I want to learn about a certain topic of scientific information.
- Q6: I can use the media to gain enough useful scientific information and knowledge for life, work, and study.

4.2.3. Information Credibility Assessment

This study used a five-point Likert scale (1 = *strongly disagree*, 5 = *strongly agree*) to measure respondents' ability to assess the reliability of scientific information (*M* = 3.78, *SD* = 0.74). For example:

- Q7: I would evaluate the credibility of information by assessing the authority of the source platform.
- Q8: I would evaluate the credibility of information by assessing the identity of information providers.

4.2.4. Information Sharing and Dissemination

This study used a five-point Likert Scale (1 = *strongly disagree*, 5 = *strongly agree*) to measure the ability to share and disseminate scientific information (*M* = 3.87, *SD* = 0.70). For example:

- Q9: For scientific information from the internet, I give likes to the scientific information that attracts me.
- Q10: I like to share and spread scientific information I come across through the media to people around me.
- Q11: I retweet the scientific information that interests me on my own social media.

4.2.5. Opinion Expression

This study used a five-point Likert scale (1 = *strongly disagree*, 5 = *strongly agree*) to measure the ability to express opinions on science-related topics (*M* = 3.42, *SD* = 0.81). For example:

- Q12: I am happy to participate in discussions on topics related to scientific information.
- Q13: I will refute rumor articles about scientific information.
- Q14: I will express opinions on the scientific information that interests me through my own social media.
- Q15: I will release and disseminate the scientific information reviewed and created by myself through various media platforms.

4.2.6. Socio-Demographic Information

Socio-demographic measures include various socio-demographic information, such as gender, age, educational background, and place of residence. This questionnaire set the socio-demographic response as the following: gender (male and female), age (18–29, 30–39, 40–49, 50–59, and 60 and above), education background (0 = *below primary school or none*, 1 = *primary school*, 2 = *middle school*, 3 = *high school/technical secondary school*, 4 = *junior college*, 5 = *bachelor's degree*, 6 = *master's degree*, 7 = *PhD*).

4.3. Data Analysis

We reviewed the psychometric properties of the items adapted from previous studies before proceeding to the main analysis.

4.3.1. McDonald's *ω* Reliability Test

Despite the widespread use of Cronbach's alpha, some scholars have argued that it is not the best measure of reliability, nor should it be preferred as it has been for many years (Hayes & Coutts, 2020). Cronbach's alpha is not as accurate as McDonald's *ω* in reliability tests since Cronbach's alpha underestimates reliability and requires tau equivalence. Compared to Cronbach's alpha, McDonald's *ω* has performed well in previous studies, does not make as strict assumptions as Cronbach's alpha, and is conceptually easy to understand. Thus, McDonald's *ω* has been one of the recommended alternatives for reliability tests (McNeish, 2018). Table 1 shows the McDonald's *ω* coefficient for the total scale and each subscale. The McDonald's *ω* coefficients for both the total scale and the subscales were greater than 0.7, indicating good reliability of the science information literacy scale.

4.3.2. Validity Test (Exploratory Factor Analysis)

Table 2 shows that the KMO value is over 0.6, meeting the requirements for factor analysis. Also, the data passed Bartlett's test of sphericity ($p < 0.05$), indicating that the study data were suitable for factor analysis.

This study used varimax to rotate and explore the correspondence between the factors and the items. Table 3 presents the results of extracted factors, and five factors were extracted from the factor analysis. The percentages of explained variance of the five factors after rotation were 14.704%, 12.670%, 10.672%, 10.070%, and 7.873%, with a cumulative explained variance after rotation of 55.989%. All research items corresponded to a communality value above 0.4, implying a strong correlation between the research items and the factors, and that the factors were able to extract information effectively. Then, this study explored the correspondence between the factors and the research items (an absolute value of the factor loading greater than 0.4 indicates a correspondence between the item and the factor). Table 3 shows that Factor 1 corresponds to opinion expression; Factor 2, to information sharing and dissemination; Factor 3, to self-directed information acquisition; Factor 4, to accurate information filtering; and Factor 5, to information reliability assessment.

Table 1. McDonald's *ω* coefficients for scientific information literacy scale.

Scale	McDonald's *ω*
Total scale	0.843
Subscale—Self-directed information acquisition	0.769
Subscale—Accurate information filtering	0.754
Subscale—Information credibility assessment	0.756
Subscale—Information sharing and dissemination	0.773
Subscale—Opinion expression	0.832

Table 2. KMO and Bartlett's test.

KMO		0.884
Bartlett's test of sphericity	Approx. chi-square	7,577.481
	df	105
	p-value	<0.05

Table 3. Factor loading (rotated).

	Factor loading					
Name	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
1			0.669			0.524
2			0.773			0.625
3			0.621			0.546
4				0.733		0.574
5				0.59		0.537
6				0.698		0.572
7					0.807	0.742
8					0.658	0.615
9		0.678				0.491
10		0.537				0.429
11		0.668				0.541
12	0.567					0.535
13	0.696					0.54
14	0.562					0.584
15	0.675					0.543

Note: Factor loadings below 0.5 are not listed in this table.

5. Findings

5.1. Scientific Information Literacy Among the Chinese Public

Table 4 shows the socio-demographic information for the 2,983 respondents. Table 2 in the Supplementary File provides details on the demographic information for evaluating biases.

Combined with skewness and kurtosis values, we used the Kolmogorov–Smirnov test to examine whether the data conformed to a normal distribution. The absolute kurtosis values were less than 10, and the absolute skewness values were less than 3 (seen in Table 1 of the Supplementary File), indicating that the data in this study were normally distributed (Kline, 2015). Then, this study tested the differences between the level of scientific information literacy and the intermediate response items through a one-sample t-test (seen in Table 5). The results indicated that the mean value of each literacy dimension level was significantly higher than the middle response option (three; $p < 0.001$).

Table 4. Socio-demographic Information of the respondents (N = 2,983).

Items	*n* (%)
Gender	
Male	1,352 (45.32)
Female	1,631 (54.68)
Age (year)	
18–29	1,679 (56.29)
30–39	992 (33.26)
40–49	240 (8.05)
50–59	58 (0.47)
60 and above	14 (0.44)
Education level	
Middle school	13 (0.44)
High school/technical secondary school	130 (4.36)
Junior college	402 (13.48)
Bachelor's degree	2,178 (73.01)
Master's degree	244 (8.18)
PhD	16 (0.54)

Table 4. (Cont.) Socio-demographic Information of the respondents (*N* = 2,983).

Items	*n* (%)
Exposure and access to scientific information	
New media	2,983 (100)
Books	2,219 (74.31)
Academic articles	1,386 (46.42)
Newspaper	1,254 (42)
TV	2,016 (67.52)
Radio	499 (16.71)
Interpersonal communication	1,266 (42.4)
Expert lectures	1,573 (52.68)
Science venues and facilities	1,275 (42.7)
Science activities	1,231 (41.23)
Others	5 (0.17)
Frequency of access to scientific information through new media	
Every day	1,084 (36.34)
More than three times a week	1,206 (40.43)
One to three times a week	614 (20.58)
Once a week or less	719 (2.65)

Note: Respondents with no education and primary school were zero and are not listed here.

We conducted repeated ANOVA with pairwise contrasts to compare the levels of different literacy dimensions. The Greenhouse–Geisser test showed significant differences between the dimensions of scientific information literacy ($p < 0.05$). As shown in Table 6, we also conducted pairwise comparisons. Combined with the means of the dimensions of scientific information literacy shown in Table 5, the results indicated that the level of opinion expression is the lowest sub-dimension ($M = 3.42$), and information credibility assessment is the second lowest sub-dimension ($M = 3.78$).

5.2. Differences in Socio-Demographics

The ANOVA results showed significant differences between males and females in self-directed information acquisition, accurate information filtering, and opinion expression ($p < 0.05$). Table 7 presents the results of ANOVA for gender and other variables. Men tended to report higher levels of self-directed information acquisition, accurate information filtering, and opinion expression than women.

The ANOVA results also revealed significant differences in the levels of self-directed information acquisition, accurate information filtering, information sharing and dissemination, and opinion expression among groups of different ages ($p < 0.05$). Table 8 shows the results of ANOVA for ages and other variables. The group aged 30–39 tended to report the highest levels of accurate information filtering, information credibility assessment, information sharing and dissemination, and opinion expression. The group aged 50–59 tended to report

Table 5. Results of one-sample t-test.

			Test value = 3					
	Mean	Standard deviation	*t*	*df*	*p* (two-tailed)	Mean difference	95% confidence interval of the difference	
							Lower	Upper
Self-directed information acquisition	3.90	0.67	74.14	2,982	$p < 0.001$	0.90	0.88	0.93
Accurate information filtering	3.94	0.61	83.95	2,982	$p < 0.001$	0.94	0.91	0.96
Information credibility assessment	3.78	0.74	57.41	2,982	$p < 0.001$	0.78	0.75	0.81
Information sharing and dissemination	3.87	0.70	67.68	2,982	$p < 0.001$	0.87	0.84	0.89
Opinion expression	3.42	0.81	28.73	2,982	$p < 0.001$	0.42	0.40	0.45

Table 6. Results of pairwise comparisons.

Dimensions (I)	Dimensions (J)	Mean Difference (I−J)	Standard error	p^1	95% confidence interval for difference	
					Lower Bound	Upper Bound
(1) Self-directed information acquisition	(2) Accurate information filtering	−0.03	0.014	0.168	−0.071	0.006
	(3) Information credibility assessment	0.12*	0.015	<0.001	0.079	0.164
	(4) Information sharing and dissemination	0.04	0.015	0.155	−0.006	0.077
	(5) Opinion expression	0.48*	0.015	<0.001	0.436	0.521
2	1	0.03	0.014	0.168	−0.006	0.071
	3	0.15*	0.015	<0.001	0.113	0.196
	4	0.07*	0.014	<0.001	0.029	0.108
	5	0.51*	0.015	<0.001	0.469	0.553
3	1	−0.12*	0.015	<0.001	−0.164	−0.079
	2	−0.15*	0.015	<0.001	−0.196	−0.113
	4	−0.09*	0.016	<0.001	−0.132	−0.04
	5	0.36*	0.017	<0.001	0.309	0.404
4	1	−0.04	0.015	0.155	−0.077	0.006
	2	−0.07*	0.014	<0.001	−0.108	−0.029
	3	0.09*	0.016	<0.001	0.04	0.132
	5	0.44*	0.013	<0.001	0.405	0.48
5	1	−0.48*	0.015	<0.001	−0.521	−0.436
	2	−0.51*	0.015	<0.001	−0.553	−0.469
	3	−0.36*	0.017	<0.001	−0.404	−0.309
	4	−0.44*	0.013	<0.001	−0.48	−0.405

Notes: Based on estimated marginal means; * the mean difference is significant at the 0.05 level; [1] adjustment for multiple comparisons—Bonferroni.

the highest levels of self-directed information acquisition, and those over 60 tended to report the lowest level of scientific information literacy (all sub-dimensions).

Results showed differences in the level of self-directed information acquisition, accurate information filtering, information credibility assessment, information sharing and dissemination, and opinion expression among people with different educational backgrounds ($p < 0.05$). Table 9 presents the results of ANOVA for education background and other variables. People with doctoral education tended to report the highest level of scientific information literacy (all sub-dimensions). People with middle school education tended to report the lowest levels of self-directed information acquisition, information credibility assessment, and information sharing and dissemination. People with high school and junior college education tended to report the lowest levels of accurate information filtering and opinion expression.

Table 7. Gender differences in levels of information literacy.

	Gender (Mean ± *SD*)			
	Female (n = 1,631)	Male (n = 1,352)	F	p
Self-directed information acquisition	3.88 ± 0.68	3.93 ± 0.65	5.13	0.024*
Accurate information filtering	3.91 ± 0.60	3.96 ± 0.61	4.437	0.035*
Information credibility assessment	3.77 ± 0.75	3.79 ± 0.74	0.624	0.43
Information sharing and dissemination	3.88 ± 0.69	3.85 ± 0.72	2.276	0.131
Opinion expression	3.36 ± 0.81	3.50 ± 0.80	24.407	0.000**

Notes: * $p < 0.05$, ** $p < 0.01$.

Table 8. Differences in information literacy levels by age group.

	Age (Mean ± *SD*)						
	18–29 (*n* = 1,679)	30–39 (*n* = 992)	40–49 (*n* = 240)	50–59 (*n* = 58)	60 and above (*n* = 14)	*F*	*p*
Self-directed information acquisition	3.84 ± 0.68^{b}	3.98 ± 0.64^{a}	3.98 ± 0.67^{a}	4.05 ± 0.58^{a}	3.79 ± 0.38^{b}	8.167	0.000**
Accurate information filtering	3.87 ± 0.63^{b}	4.03 ± 0.56^{a}	3.98 ± 0.57^{a}	3.98 ± 0.55^{ab}	3.76 ± 0.61^{b}	10.683	0.000**
Information credibility assessment	3.78 ± 0.75^{a}	3.80 ± 0.73^{a}	3.76 ± 0.71^{a}	3.68 ± 0.84^{a}	3.46 ± 0.66^{a}	1.071	0.369
Information sharing and dissemination	3.82 ± 0.70^{b}	3.97 ± 0.68^{a}	3.86 ± 0.70^{b}	3.78 ± 0.83^{b}	3.26 ± 1.02^{c}	10.088	0.000**
Opinion expression	3.36 ± 0.81^{b}	3.56 ± 0.76^{a}	3.41 ± 0.84^{b}	3.23 ± 0.80^{b}	2.71 ± 0.95^{c}	14.116	0.000**

Notes: ** $p < 0.01$; different letters indicate significant differences ($p < 0.05$) in mean values (one-way ANOVA); mean values with the same superscript letters (a, b, and c) were similar, and no statistical differences were observed for these samples.

Table 9. Differences in information literacy levels across the educational background.

	Educational background (Mean ± *SD*)							
	Middle school (*n* = 13)	High school/ technical secondary school (*n* = 130)	Junior college (*n* = 402)	Bachelor's degree (*n* = 2,178)	Master's degree (*n* = 244)	PhD (*n* = 16)	*F*	*p*
Self-directed information acquisition	3.67 ± 0.56^{b}	3.77 ± 0.70^{b}	3.82 ± 0.67^{ab}	3.92 ± 0.66^{a}	3.99 ± 0.65^{a}	4.13 ± 0.58^{a}	4.187	0.001**
Accurate information filtering	3.77 ± 0.37^{b}	3.74 ± 0.70^{b}	3.83 ± 0.60^{b}	3.96 ± 0.60^{a}	3.97 ± 0.60^{a}	4.21 ± 0.50^{a}	7.214	0.000**
Information credibility assessment	3.38 ± 0.46^{a}	3.67 ± 0.76^{a}	3.66 ± 0.76^{a}	3.81 ± 0.73^{a}	3.81 ± 0.80^{a}	3.84 ± 0.79^{a}	4.276	0.001**
Information sharing and dissemination	3.54 ± 0.62^{a}	3.77 ± 0.69^{a}	3.77 ± 0.73^{a}	3.88 ± 0.70^{a}	3.93 ± 0.64^{a}	3.96 ± 0.61^{a}	3.431	0.004**
Opinion expression	3.60 ± 0.77^{ab}	3.24 ± 0.81^{b}	3.31 ± 0.80^{b}	3.44 ± 0.81^{ab}	3.53 ± 0.78^{ab}	3.75 ± 0.76^{a}	4.731	0.000**

Notes: ** $p < 0.01$; different letters indicate significant differences ($p < 0.05$) in mean values (one-way ANOVA); mean values with the same superscript letters (a, b) were similar, and no statistical differences were observed for these samples.

6. Conclusion and Discussion

This study adapted existing conceptual and measurement frameworks in science communication contexts, investigated the level of scientific information literacy among the Chinese public, and analyzed the demographic differences in scientific information literacy.

This study investigated the levels of each subdimension of scientific information literacy among the Chinese public. First, the results reflected two key sub-dimensions of scientific information literacy relatively lacking among the Chinese respondents: information credibility assessment and opinion expression. Information assessment and opinion expression represent much higher-order criticality than other subdimensions (Lin et al., 2013). In science communication, access to reliable scientific information sources does not equal a critical evaluation in an accurate or relatively

unbiased manner (Howell et al., 2019), so information credibility assessment is important. Compared to information dissemination, opinion expression demands higher individual competency, representing the ability to participate in science communication interactively and critically in the new media environment. Second, the results indicated that the science communication environment in the new media context is also related to low information credibility assessment and opinion expression. On the one hand, the lack of control mechanisms is considered the most significant difference between content assessment in online and print environments. This leads to a massive "misinformation epidemic" when users select information resources that challenge their ability to evaluate information credibility (Metzger, 2007). On the other hand, although the internet can facilitate scientific discussion, audiences are less likely to engage with issues that are not important to them (Rosenthal, 2020). Another study has also argued that the internet is primarily used to search for general, factual, and specific information and ephemeral content (Voorbij, 1999). Thus, individuals have limited opportunities to express their opinions about scientific information through the internet, which might explain their lower scores in opinion expression than other abilities. Finally, the findings provided a reference for future priorities in building a science communication environment and the main focus of science information literacy education. Large-scale scientific information dissemination challenges people's ability to assess its credibility, a topic worth exploring both in the early days of the internet and the current new media environment (Keshavarz et al., 2020). On this occasion, adapting information literacy concepts into science communication contexts is important, and constructing a participatory science communication environment is essential to enhance people's ability to express their opinions. Many studies also suggested that participatory culture forms, such as online communities, Wikipedia, and social media, can provide opportunities for peer-to-peer learning, develop skills, and promote more authoritative citizenship (Jenkins, 2009).

The research question examined whether there are significant differences in the level of scientific information literacy among the respondents in terms of demographic information, such as gender, age, and education. The results indicated that men report higher levels of self-directed information acquisition, accurate information filtering, and opinion expression than women. The group aged over 60 tended to report the lowest level of scientific information literacy (all sub-dimensions), and the highly educated group tended to report the highest scientific information literacy. Regarding gender differences in scientific information literacy, men have more positive attitudes toward technology and tend to perceive themselves as more competent than women (Cai et al., 2017), leading to differences in self-reported results. The age and education differences in scientific information literacy found in this study also echo previous scientific and information literacy studies (Wang et al., 2022). In addition, the findings might reflect the characteristics of marginalized groups in scientific information dissemination. Previous research focused more on the deficit model but ignored structural inequalities and social issues of gender, race, and social status (Sturgis & Allum, 2004). Sections of the public excluded from science communication and not involved in science communication have been considered unexamined and negative in previous studies (Dawson, 2018). The Public Attitudes Towards Science survey in the UK reported that people from disadvantaged socio-economical backgrounds and women were described as people who knew little about science, distrusted science, or rarely participated in science communication (Castell et al., 2014). Research from the US suggested that people who are more likely to participate in science communication have higher education and household status (Klucevsek, 2017). In short, socially dominant groups are key participants in science communication (Dawson, 2018) and have higher levels of scientific information literacy. This study indicated that women, low educated, and older groups might have lower scientific information literacy levels and are likely to participate least in scientific information communication.

Back to the literacy needed in science communication in the new media environment, this study attempted to adapt the concepts and measurement frameworks related to information literacy into science communication contexts. The concepts of scientific literacy have evolved from the initial simple definition of knowledge to a better understanding of the complexity and difficulty of achieving scientific literacy (Klucevsek, 2017). Scientific literacy has also faced competition with many other types of literacy that the public should have and understand (Paisley, 1998). In the expanding digital world, this competition is directly reflected in the intersection of scientific and information literacy concepts. The intersection is manifested as the fact that information literacy is a prerequisite for audiences to understand scientific information, which is one of the most fundamental and continuous parts of the scientific process. For example, the ability to read and understand scientific articles and participate in scientific conversations requires locating and identifying articles through information literacy (Klucevsek, 2017). Although the public does not often read or need to understand scientific articles, they have become used to accessing scientific information on the internet. In China, 74% of respondents access scientific information through the internet and mobile internet, with 49.7% using the internet and mobile internet as their preferred channel (China Association for Science and Technology, 2021). Thus, information literacy-related concepts are important to promote the public understanding of science. In other words, information literacy can improve scientific literacy and help audiences become critical in thinking and communication. Scholars have argued that competencies and literacies

required for individuals to be exposed to scientific information are also required for the next stage of the lifecycle of scientific information (Howell & Brossard, 2021). To build a more scientifically literate population, we have to consider applying different literacy concepts in scientific information communication. The intersection and combination of existing concepts of information and science literacy can help the public understand scientific information. Scientific information literacy should be a more meaningful means of understanding the impact of new media on scientific information communication.

7. Limitations and Future Research

There are several limitations of this study. First, we used self-reported measures to examine the level of scientific information literacy, which predicted the performance to a certain extent, but only provided a rough indicator of the effect (Honicke & Broadbent, 2016). Future research will consider other forms, such as open and closed questions, to measure scientific information literacy. Second, we aimed to adapt existing concepts and measurements related to scientific information literacy into science communication contexts, which still require more improvements in the future. Third, the gender differences in this study are slight, which is of little practical significance. Fourth, the convenience sample used in this study might cause the results to be limited in terms of general descriptions. In this study, there were more male respondents than female, which is contrary to the seventh Chinese population census results and might affect the findings in gender differences. Besides, the research sample has a higher level of education than the general Chinese population, which potentially impacts the measurement of literacy levels. Finally, the online survey conducted in this study cannot cover the groups who cannot use the internet but are exposed to scientific information. Future research will adopt a combination of online and offline surveys to investigate scientific information literacy more specifically.

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Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the author (unedited).

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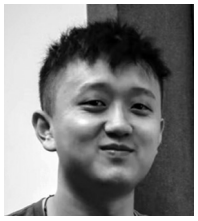

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Article

Meet Bob and Offset Your Flight: Optimising Explainer Videos to Promote Voluntary Carbon Offsetting

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Abstract
In Germany, over 60% of people use YouTube as a search engine and watch explainer videos or tutorials at least occasionally. Two studies were conducted to determine how explainer videos can be optimised to promote sustainable minority behaviour such as voluntary carbon offsetting. A typical way to present information in explainer videos is by using exemplars (the "meet Bob" trope), which can change recipients' judgements of the frequency of events. When an exemplar is included, the frequency of occurrence can be estimated to be higher, even if the actual base-rate information is given. Therefore, study one (N = 482) tested whether an exemplar could enhance the positive effects of a dynamic descriptive social norm appeal (DSNA), prevent the backfire effects of a static minority DSNA, and examine whether there were any differences depending on the narrative perspective. In study one, we conducted a 2 (narrative perspective: first vs. third person) × 2 (DSNA: static vs. dynamic) × 2 (travel destination: Europe vs. overseas; control factor) between-subjects experiment using six self-produced explainer videos about voluntary carbon offsetting (N = 270). The results show that the narrative perspective, different DSNAs, and the destination had no effect on persuasive outcomes. Study two (N = 270) focused on social norm appeals and supplemented minority DSNAs (DSNA: static vs. dynamic vs. absent) with an injunctive social norm appeal (ISNA: present vs. absent). The results show that a majority injunctive social norm appeal can improve attitudes towards voluntary carbon offsetting and perceived effectiveness.

Keywords
exemplar; experiment; explainer video; narrative perspective; nudging; social influence; social norm appeals; sustainable behaviour; voluntary carbon offsetting

Issue
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1. Introduction

Anthropogenic climate change is progressing, and the proportion of greenhouse gases in the atmosphere continues to rise (Intergovernmental Panel on Climate Change, 2021; H. Ritchie et al., 2020). As individuals and households may be responsible for up to 72% of global emissions (Eurostat, n.d.; Hertwich & Peters, 2009), changing individual consumption behaviour is a critical and contemporary ambition (Fell & Traber, 2020). Consumers drive several carbon-intensive sectors due to travel but are not directly affected by international agreements (Intergovernmental Panel on Climate Change, 2015). Thus, voluntary mitigation initiatives such as voluntary carbon offsetting (VCO) are a good way to bridge this gap until full carbon neutrality is achieved (Kobiela et al., 2020). However, while the majority approve of VCO, less than 10% of people actually engage in it (e.g., Gössling et al., 2009; Umweltbundesamt, 2022; Wulfsberg et al., 2016). This situation is typical of many sustainable behaviours; there are prevalent positive attitudes, but only a minority acts accordingly. One reason for this is that sustainable behaviour often presents a social dilemma, and people often do not benefit

directly from acting in an environmentally friendly manner (Thøgersen, 2008). At the same time, studies on VCO have shown that many people do not know what carbon offsets are, but when they are provided with relevant information, their willingness to engage increases (Babakhani et al., 2017; Denton et al., 2020; Gössling et al., 2009; Lu & Wang, 2018; Ritchie et al., 2021).

This study aimed to determine how such information could be designed to be highly persuasive. We focused on explainer videos because, on the one hand, they are increasingly being used as an information tool on YouTube for scientific topics and are frequently utilised by scientists, journalists, and activists to raise awareness of different science topics. On the other hand, they might be particularly persuasive because of their features and thus, are well suited to promote environmentally friendly behaviour (Schorn, 2022). Therefore, we conducted two studies concentrating on explainer videos applying the "meet Bob" trope, in which a fictional character serves as a behavioural model, addressing a certain problem and demonstrating a solution. Such exemplars can offer broad potential for identification and inspire behavioural change by illustrating positive results in their life evoked by call-to-action (Alam, 2021; Peter & Zerback, 2020). Stylistic devices and social norm appeals (SNAs) related to the use of such exemplars were investigated in the VCO context. SNAs have proven to be efficient in promoting sustainable majority behaviour (e.g., Rhodes et al., 2020); however, it is still not clear how they can be best applied to promote minority behaviour. Nevertheless, research indicates that they might be particularly effective in combination with exemplars such as those used in "meet Bob" explainer videos.

2. Explainer Videos

Explainer videos are short films in which abstract concepts are explained using visualisation techniques, animations, and storytelling elements, typically combined with informal, humorous voiceovers (Schorn, 2022). Explainer videos on science topics, news, and climate change represent important information tools that are increasingly being used by a broad audience (Allgaier, 2019; Frees et al., 2019; Galan et al., 2019). In Germany, 62% of the population indicate that they use YouTube at least occasionally as a search engine for finding answers to specific questions, and almost 70% watch videos on knowledge topics, explainer videos, or tutorials; these percentages are higher among young people (Koch & Bleisch, 2020). However, such videos do not just have the aim of transferring knowledge, but also often have the goal of persuading (Schorn, 2022). According to a study by Davis and León (2018), a considerable proportion of science (explainer) videos follows an agenda, particularly with regard to controversial topics such as climate change. In this case, explainer videos aim to do more than present relevant information; they attempt to persuade by raising awareness of a certain position or promoting environmentally friendly behaviour (De Lara et al., 2017).

3. The "Meet Bob" Trope

One reason why explainer videos might be particularly persuasive is the use of storytelling elements: Storytelling and informal communication style can lead to ease in processing, which in turn might enhance persuasive outcomes (Bullock et al., 2021). A typical way to present complex information in explainer videos is to tell a story using an exemplar, similar to the audience, who solves a problem. Explainer videos applying the "meet Bob" trope use fictional characters similar to the target audience to introduce a problem and then provide a solution (Findeisen et al., 2019; Najeeb, 2020). Such exemplars offer broad potential for identification and serve as behavioural models, showing positive results in the character's life from responding to a call to action (Alam, 2021). The use of exemplars has been shown to be successful in several fields in terms of influencing people's attitudes and behaviours (e.g., Bigsby et al., 2019; Rhodes et al., 2020).

Exemplars are ordinary citizens representing the general population (Peter & Zerback, 2020). They have no special expertise (e.g., carbon offset) and are unknown to the general public. Therefore, they are illustrative examples of the average in society (Beckers et al., 2018; Bigsby et al., 2019; Peter & Zerback, 2020). The advantage of applying an interchangeable, ordinary person as an exemplar is that it maximises the possibility of identification (Cohen, 2001) and generalisation (Zillmann, 1999) because the perceived social distance between most members of the general population and this exemplar is small (Hofer et al., 2021). They require little cognitive processing in comparison with abstract generalities because they represent specific cases (Rosenthal & Dahlstrom, 2019). Therefore, an exemplar is well suited for illustrating vicarious experiences for the largest possible group of people. However, in the context of explainer videos promoting sustainable behaviour, to the best of our knowledge, there have been no studies on "meet Bob" explainer videos, despite their frequent use and the potentially strong persuasive effect.

4. Narrative Perspective

In "meet Bob" explainer videos, generally, the voice-over narrator first informs the audience about the character's problem and then offers a solution, including an explanation of why this works (Alam, 2021; Najeeb, 2020; Oentoro, 2018). Typically, these exemplars do not themselves talk about their experiences, but the narrator does ("This is Bob…"). However, first-person narration could increase recipients' identification with the character, which could strengthen the persuasive impact (e.g., Cohen, 2001; Kim et al., 2020; Winterbottom et al., 2008). A recent meta-analysis concluded that a

first-person perspective could lead to better persuasive outcomes than a third-person narrative (Chen & Bell, 2021). In general, most scientific YouTube videos use the first-person perspective; however, almost one-third apply third-person narration, specifically in animated videos, including explainer videos (Munoz Morcillo et al., 2016). Therefore, we investigated whether the narrative perspective could impact persuasive outcomes of a "meet Bob" explainer video, leading to the first hypothesis:

> H1: First-person narration leads to better persuasive outcomes than third-person narration.

5. Exemplars and Social Norms

One benefit of using exemplars is that they can change recipients' judgement of the frequency of events; when an exemplar is included, the frequency of occurrence may be overestimated, even when the actual base-rate information is given (e.g., Gibson & Zillmann, 1994; Zillmann, 2006). Therefore, exemplars can play an important role in belief formation, even when contrasting statistical information is present in the same message (Rosenthal & Dahlstrom, 2019). One reason for this is that scientific consensus and probabilistic statements can be described as well as experienced; low probabilities tend to be overweighted when described as statistics but underweighted when experienced as probability information (cf. Harris et al., 2019). Thus, an experiential format such as that of a "meet Bob" video might be particularly effective at promoting VCO because an overestimation of sustainable (minority) behaviour could increase social pressure and encourage compliance (cf. Cialdini & Goldstein, 2004).

In the social norm context as well, Rhodes et al. (2020) concluded that presenting a model of behaviour or an exemplar is more effective than merely quoting statistics. Typically, when SNAs are applied, individuals are informed about the proportion of those engaging in the target behaviour (descriptive SNA, from now on DSNA) or those who approve of the target behaviour (injunctive SNA, from now on ISNA), both within a reference group (Cialdini et al., 1990, 1991). Overall, such SNAs are promising because they are subtle, low-cost, and effective in encouraging compliance (Rhodes et al., 2020; Yamin et al., 2019). Nevertheless, in the specific context of sustainable behaviour, there are very few studies combining the use of exemplars and SNAs, which do not use videos but printed information (Elgaaied-Gambier et al., 2018; He et al., 2019; Huber et al., 2018). However, Rhodes et al. (2020) concluded that SNAs might be more effective in promoting sustainable behaviour when embedded in audio-visual material than in text-based stimuli. Therefore, we explore in more detail how minority SNAs work when embedded in a "meet Bob" explainer video.

5.1. Descriptive Social Norm Appeals

According to the focus theory of normative conduct (Cialdini et al., 1991), descriptive norms refer to perceptions regarding the prevalence of a behaviour among group members (what people do). Such norms can be activated or made salient, which can increase the likelihood that individuals will behave in a norm-consistent manner. However, when the target behaviour is not prevalent (descriptive minority), SNAs run the risk of undesirable backfire effects when people learn that their (unsustainable) behaviour is actually the norm (e.g., Elgaaied-Gambier et al., 2018; Loschelder et al., 2019; Richter et al., 2018; Schultz et al., 2007; Smith et al., 2012). However, the backfire effects of minority DSNAs can be prevented not only by highlighting the minority group performing the target behaviour (static DSNA) but by presenting the behaviour as a growing trend (dynamic DSNA) that an increasing number of people are following (Mortensen et al., 2019; Sparkman & Walton, 2017). Studies examining the use of dynamic DSNAs to promote sustainable behaviour have shown positive effects overall in comparison with static DSNAs (Loschelder et al., 2019; Mortensen et al., 2019; Sparkman & Walton, 2017). However, there are a limited number of studies on this, and the lowest prevalence of sustainable behaviour addressed in the experiments is 25%, which is well above the 10% reported for offsetting air travel. Such studies usually work with simple and less complex appeals that are not embedded in media contributions or narrations.

Studies on exemplars have shown that exemplars can increase the positive effects of majority SNAs (Elgaaied-Gambier et al., 2018; He et al., 2019). More specifically, when promoting environmentally friendly behaviour, Elgaaied-Gambier et al. (2018) showed that the presence of an exemplar in a message including a majority DSNA has a direct positive influence on the intention to purchase non-overpackaged products. Huber et al. (2018) examined the combination of DSNAs and a narrative told by an exemplar in the context of VCO. Although this was minority behaviour, it was presented as common behaviour within the reference group (friends of the exemplar). As the authors themselves note, this may have led to difficulties in conveying a social group norm convincingly; it may not appear to be common that within a typical friend group, many compensate for their car driving and that even more think about doing so. Nevertheless, this group norm intervention had little (negative) effect on behavioural outcomes.

However, to date, there have been no studies that employ SNAs and an exemplar to directly address minority behaviour. For this reason, we investigated, within the context of a "meet Bob" explainer video, whether a dynamic minority DSNA could lead to better persuasive outcomes than a static minority DSNA. We assumed that a dynamic minority DSNA improves persuasive outcomes in comparison with a static minority DSNA or a message without any DSNA, which leads to the following hypotheses:

H2: An explainer video with a dynamic minority DSNA leads to better persuasive outcomes than an explainer video with a static minority DSNA.

H3: An explainer video that includes a dynamic minority DSNA leads to better persuasive outcomes than an explainer video without a DSNA.

5.2. Injunctive Social Norm Appeals

In addition to the use of dynamic DSNA, another strategy to promote minority behaviour is the activation of injunctive majority norms instead of describing the minority of people performing the target behaviour (Schultz et al., 2007). Injunctive norms reflect perceptions of group members' approval of the behaviour (Cialdini et al., 1991). Accordingly, ISNAs state the proportion of people who approve of the behaviour. Majority ISNAs can have a positive impact on attitude, behaviour, and behavioural intentions (Rhodes et al., 2020). For example, they can be used to increase public support for climate policies (Nolan, 2021). Therefore, we assume that a majority ISNA has a positive effect overall:

H4: An explainer video including a majority ISNA will improve persuasive outcomes compared with an explainer video without a majority ISNA.

However, this effect can be weakened or even reversed when it is evident that the target behaviour is only performed by a minority. Research on social norm conflict indicates that SNAs can be ineffective when (majority) ISNAs do not match salient descriptive (minority) norms (e.g., Smith et al., 2012).

5.3. Norm Alignment

Incongruent or conflicting social norms exist simultaneously as long as they are not prominent in consciousness at the same time (Cialdini et al., 1991). Overall, majority ISNAs might be relatively fragile because people have an idea about the prevalence of a behaviour, even if the descriptive minority norm is not made salient in the appeal. They infer social norms through their observation of others, personal and media communication, and self-knowledge (e.g., Cialdini et al., 1991; Miller & Prentice, 1996; Witzling et al., 2019). Survey studies have shown that even when the injunctive norm was perceived as strong, which could be reinforced through majority ISNA, it was still problematic when it did not align with the perceived descriptive norm because the impact of an ISNA can be moderated through perceived descriptive norms (cf. Jacobson et al., 2020; Thøgersen, 2008; Witzling et al., 2019).

A counterstrategy could be the combination of majority ISNAs with dynamic DSNAs: The majority have a positive attitude, and an increasing number of people start acting accordingly. In this manner, social norm conflict could be mitigated when individuals perceive that there are increasing efforts to behave according to their attitudes, or rather according to injunctive norms. However, to the best of our knowledge, to date, no study has examined this combination explicitly by using a majority ISNA in combination with a dynamic minority DSNA. Studies using dynamic SNAs have not addressed social norm conflict (e.g., Mortensen et al., 2019; Sparkman & Walton, 2017), while studies focusing on social norm conflict have not included dynamic SNAs (e.g., Smith et al., 2012). Therefore, it is still a novel line of research, without any study investigating the combination of dynamic DSNAs and ISNAs using a factorial design. Based on previous research, we assume that the positive effect of majority ISNAs might be weakened when combined with a static minority DSNA, instead of a dynamic minority DSNA or no DSNA, leading to the following hypotheses:

H5: An explainer video including a majority ISNA in combination with a static minority DSNA will weaken persuasive outcomes compared with an explainer video that includes only a majority ISNA (social norm conflict).

H6: An explainer video including a majority ISNA in combination with a dynamic minority DSNA will improve persuasive outcomes compared with an explainer video with a combination of majority ISNA and static minority DSNA.

Furthermore, He et al. (2019) suggested that showing ordinary consumer endorsers, such as "Bob," leads to stronger persuasive outcomes when using dynamic DSNAs than when using ISNAs. However, they operationalised their ISNA via a direct behavioural appeal ("every student should save energy") and not by specifying a proportion of people. Thus, their results could stem from the fact that direct behavioural appeals are more likely to be accepted by celebrities than by ordinary consumers. Therefore, we examined within the context of a "meet Bob" explainer video whether a traditional majority ISNA can be more effective than a dynamic DSNA, leading to the following research question:

RQ1: Does an explainer video including a majority ISNA lead to better persuasive outcomes than an explainer video including a dynamic minority DSNA?

6. Study One

6.1. Method

The hypotheses were tested in two studies for economic reasons. The first study focuses on the narrative perspective and minority DSNAs to test H1 and H2. We conducted a 2 (narrative perspective: first- vs. third-person) × 2 (DSNA: static vs. dynamic) × 2 (destination: Europe

vs. overseas) between-subjects experiment (N = 482, M_{age} = 44.93, SD_{age} = 14.58, 50% female; representative of Germany). In addition to the narrative perspective and DSNA, we added the destination as a control factor because, in the context of a VCO for aviation, there is a well-known counterargument that flying should be avoided completely. Although there are several ways to travel within mainland Europe, it is nearly impossible to travel to distant countries or overseas without flying. In addition, the willingness to offset can depend on price (e.g., Wulfsberg et al., 2016), which might be estimated based on the destination of the exemplar.

6.1.1. Stimulus Material

Six explainer videos with professional speakers were produced as stimulus material (see Supplementary Material). All videos consisted of a frame story (animated with Animaker) around the fictional character, Christian. He is 46 years old, which is approximately the mean and median age of the German population. Around 46 years ago, Christian was the most popular name for boys in Germany. In a recent empirical study by Nett et al. (2020), the name Christian was perceived as ageless, and to belong to a person with average intelligence, attractiveness, education, and religiosity. Christian works in an office because this is the most common characteristic of job descriptions in Germany, and approximately 38% (increasing) of all German employees work in an office (Hammermann & Voigtländer, 2020). His experiences were either conveyed by himself (first-person perspective) or by a voice-over narrator (third-person perspective) using the same speaker. Christian was planning a vacation trip to Spain (Europe) or California (overseas) and was contemplating about VCO to reduce his impact on the environment. He learnt about the topic via an explainer video (whiteboard video animated with the Simpleshow video maker). The second explainer video contained general information about offsets and different DSNAs. Participants were informed that, at present, only a minority of people voluntarily offset their flights (static DSNA) or were further informed that this proportion has increased recently and is expected to continue increasing (dynamic DSNA). At the end of the video, Christian states that he offsets his flight and repeats the DSNA.

In addition to the experimental conditions, different control groups were included in the study. A video without an exemplar (whiteboard explainer video without a frame story) was used to test whether the exemplar had an effect. A video without any DSNA was used to test the possible backfire effects of the static DSNA. Another control group served to test the effects of video as a medium, and a written script was presented without visualisation. In addition, we conducted a small parallel study without stimulus (N = 44), in which we measured dependent variables as a baseline measurement.

6.1.2. Procedure

Participants were recruited and compensated by a market research institute (aiming for representativeness of the German population). They were told that this study was about VCO and that they would view a video. Individuals who generally avoid flying for private reasons were excluded. After answering demographic questions, each participant was randomly assigned to one of the conditions. Several persuasive outcomes were measured after the participants watched the videos. The questionnaire contained quality checks to ensure data quality. Participants who failed the quality checks were immediately excluded. This study was approved by the ethics committee of our university.

6.1.3. Measures

Persuasive outcomes were operationalised using four dependent variables (see Supplementary Material). The intention to offset (five items; M = 2.77, SD = 1.03, α = .98) and attitude towards VCO (three items; M = 3.91, SD = 1, α = .91) were measured following Denton et al. (2020). The intention to obtain further information about VCO was measured using six self-developed items (M = 3.23, SD = 1.16, α = .92), and perceived effectiveness of VCO was measured with three items (M = 3, SD = 1.24, α = .95). All constructs were measured on a 5-point scale (1 = *do not agree at all*, 5 = *agree completely*).

6.2. Pre-Study

We tested the measures and the stimulus material in a pre-study (N = 181). The results of the manipulation check showed that participants in the first-person condition perceived a stronger sense of being addressed personally (M = 2.57, SD = .90) than those in the third-person condition (M = 3.68, SD = .91, $F(1, 156) = 54.83$, $p < .001$, $\eta^2 = .26$). Moreover, an increasing trend was practically more likely to be perceived in the dynamic DSNA condition (M = 3.27, SD = .96) than in the static DSNA condition (M = 3, SD = .93, $F(1, 156) = 3.33$, $p = .07$, $\eta^2 = .02$). Participants in the European condition perceived the destination as closer, while participants in the overseas condition perceived the destination as farther away ($F(2, 155) = 94.10$, $p < .001$, $\Lambda = .45$, $\eta^2 = .55$). Perceived quality (M = 4.14, SD = .97) and credibility (M = 4.10, SD = 1) did not differ between the conditions and were significantly higher than the centre of the scales ($p < .05$).

6.3. Results

To test the hypotheses, we conducted several analyses of covariance, controlling for age and gender. Neither the narrative perspective, DSNAs, nor the destination had any effect on any dependent variable (see Supplementary Material). Therefore, H1 and H2 were rejected.

Next, we examined the control groups to determine whether the videos were perceived as equally effective or ineffective. Contrast analysis showed almost no differences between the experimental and control groups for all dependent variables. Regarding baseline measurement, we found that some of the videos, at least marginally, strengthened the intention to obtain further information about VCO (see Supplementary Material).

6.4. Discussion

There were no differences between the experimental groups for any of the dependent variables. Regarding the narrative perspective, our results reflect those of Chen and Bell's (2021) recent meta-analysis, showing that a first-person narrative perspective cannot directly strengthen attitude and behavioural intentions compared to a third-person perspective in the health context. However, their results indicated that first-person effects might be stronger when the narration uses past tense because this could reinforce the impression that the experience is already complete. An alternative explanation might be that it was due to the reception habit because third-person narration is conventionally used in "meet Bob" explainer videos. However, we did not ask whether the participants watched such videos regularly.

Furthermore, we considered why the DSNAs did not lead to significant differences. From a theoretical perspective, dynamic DSNAs can lead to pre-conformity (a future descriptive norm) and compliance when individuals anticipate ongoing change and a future world in which minority behaviour is the norm (Sparkman & Walton, 2017). However, the lowest proportion of sustainable behaviour addressed was 25%. The proportion of 10% in the case of VCO might be too small to evoke pre-conformity because it is far from the threshold of majority behaviour (50%). In addition, we did not refer to an explicit reference group, which may have weakened the effects (cf. Yamin et al., 2019).

7. Study Two

7.1. Method

In the second study, we focused on the combination of minority DSNAs and majority ISNAs to test H2–H6 and RQ1. We conducted a 3 (DSNA: static vs. dynamic vs. absent) × 2 (ISNA: present vs. absent) between-subjects experiment (N = 270, M_{age} = 44.56, SD_{age} = 14.05, 50% female; representative of Germany). This study followed the same procedure as that used in the first study. The same explainer videos were used (narrative perspective: first-person; destination: Europe), but the DSNAs were slightly revised by explicitly including the German population as a reference group and adapted to the new design: the static DSNA, the dynamic DSNA, and the video without a DSNA were either supplemented with a majority ISNA or not (see Supplementary Material). Again, all SNAs were repeated verbally by the exemplar at the end of the video.

In addition to the measures from the first study, manipulation checks for the DSNAs and ISNA were carried out (DNSA: What do you think—By how much will the proportion of people who offset their air travel increase by 2025?; and ISNA: What percentage of Germans do you think are in favour of voluntary CO2 offsetting of flights?).

7.2. Results

7.2.1. Manipulation Check

Analyses of covariance, controlling for age and gender, were assessed. With respect to DSNAs, there were differences in the perception of a future trend (F(2, 262) = 8.52, p < .001, η^2 = .06); Tukey's post-hoc analysis showed that participants who viewed a dynamic DSNA perceived a stronger trend (M = 3.39, SD = .94) than those who viewed a static DSNA (−.55, p < .001) or no DSNA (−.32, p = .03). There were no differences between those who viewed static DSNA and those who did not view DSNA. Results for ISNA showed that the percentage of people who approved of VCO was estimated to be significantly higher when watching a video with ISNA (M = 58.38, SD = 24.71) than without (M = 40.39, SD = 24.82, F(1, 262) = 35.08, p < .001, η^2 = .12).

7.2.2. Hypothesis Testing

Again, several analyses of covariance controlling for age and gender were conducted for the dependent variables (see Supplementary Material). Regarding the DSNAs, there were only differences in the attitude towards VCO (F(1, 262) = 6.09, p = .003, η^2 = .04). Tukey's post-hoc analysis showed that a dynamic DSNA could improve attitude compared to the group without a DSNA (95% CI [.09, .42], p = .002), partially confirming H3. Furthermore, the results show that a majority ISNA can at least marginally strengthen the intention to offset (F(1, 262) = 3.36, p = .07, η^2 = .01), attitude towards VCO (F(1, 262) = 4.19, p = .04, η^2 = .02), perceived effectiveness (F(1, 262) = 6.23, p = .01, η^2 = .02), and intention to obtain further information about VCO (F(1, 262) = 2.91, p = .09, η^2 = .01), partially confirming H4. ISNA led to an increase in the mean values in all DSNA conditions. Other effects of ISNA, DSNA, and their interaction were not significant, leading to the rejection of H2, H5, and H6. There was no descriptive evidence of social norm conflict.

7.2.3. Baseline Measurement

To assess the general effectiveness of the stimuli, they were again compared with the baseline measurements. Contrast analysis shows that watching any of the explainer videos including an SNA strengthened the intention to offset and to obtain further

information about VCO compared to the baseline (see Supplementary Material). However, there were no differences in the attitude towards VCO.

7.2.4. Additional Analysis

In studies on dynamic DSNAs, pre-conformity or projected commonness of future behaviour is often used as a mediator (e.g., Loschelder et al., 2019; Mortensen et al., 2019; Sparkman & Walton, 2017). For this reason, we conducted a mediation analysis with 5,000 bootstrap samples using our manipulation checks as mediators (Lavaan Package; Rosseel, 2012). Pre-conformity (*ab* = .28, 95% CI [.12, .45]) and perceived injunctive norms (*ab* =.20, 95% CI [.05,.35]) mediated the effect of SNAs on the intention to offset (see Figure 1). There were no direct effects of SNAs on the intention to offset, and SNAs only had the expected effect on the respective manipulation check (see Supplementary Material).

7.3. Discussion

The results show that a majority ISNA can enhance persuasive outcomes; however, the effects are small. Regarding the DSNAs, however, there were differences only between dynamic DSNA and the message without a DSNA with respect to the attitude towards VCO, which for the most part confirmed the null results of the first study. The results of the mediation analysis suggest that the direct effects on intention to offset are mediated through perceived norms.

Regarding RQ1, our results differ somewhat from those of He et al. (2019), who concluded that ordinary exemplars are more successful in combination with DSNAs in terms of their effect on the intention to act in an environmentally friendly manner. In the present study, only ISNA had a significant direct effect. Nevertheless, as stated previously, He et al. (2019) operationalised ISNA differently. Furthermore, the results show no interaction effects between DSNAs and ISNA, implying that social norm conflict did not lead to undesired effects. Nevertheless, the combination of ISNA and dynamic DSNA yielded the highest values descriptively.

8. General Discussion

This study aimed to determine how explainer videos regarding VCO could be designed to be highly persuasive and to foster participation in VCO. We focused on different stylistic devices of explainer videos applying the "meet Bob" trope and normative appeals. There were no differences based on the narrative perspective or the destination used in the video. However, the results of the second study show that watching an explainer video including an SNA, in general, can strengthen the intention to offset and obtain further information about VCO. Overall, this confirms the results of other studies demonstrating that providing people with information about VCO can increase their willingness to offset (e.g., Denton et al., 2020; Gössling et al., 2009; Lu & Wang, 2018).

Nevertheless, we were not able to find positive or negative effects regarding minority DSNAs in the two studies. In the second study, we found a positive effect of dynamic DSNA on the attitude towards VCO compared to the condition without DSNA. At the same time, no backfire effects were caused by static DSNA. These results are mostly in line with studies suggesting that static DSNAs are not effective in promoting sustainable minority behaviour (e.g., Aldoh et al., 2021; Richter et al., 2018), but other studies have concluded that dynamic DSNAs are more effective than static DSNAs (Loschelder et al., 2019; Mortensen et al., 2019; Sparkman & Walton, 2017). However, the latter studies were conducted with minority behaviours that were more prevalent than VCO. Nevertheless, our results confirm that the effects on the intention to act might be mediated through perceived social norms or pre-conformity, which is in line with Mortensen et al. (2019) and Sparkman and Walton

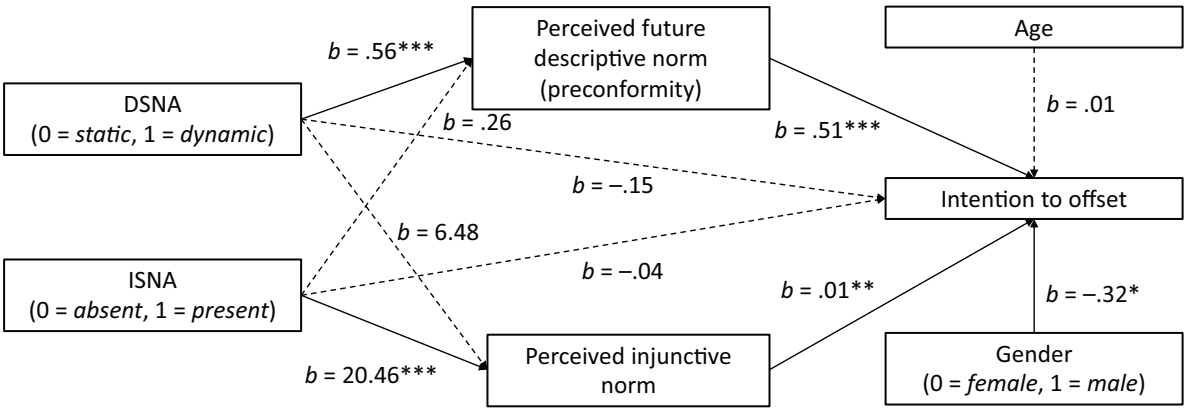

Figure 1. Mediation model. Notes: Non-standardised regression coefficients; * $p < .05$, ** $p < .01$, *** $p < .001$; effects of DSNA and ISNA on the intention to offset are fully mediated by pre-conformity (*ab* = .28, 95% CI [.12, .45]) and perceived injunctive norm (*ab* = .20, 95% CI [.05, .35]).

(2017). Furthermore, Melnyk et al. (2019) implied that DSNAs act as heuristics, whereas ISNAs are processed more elaborately. Following this assumption, DSNAs might be less effective than ISNAs when embedded in an explainer video because it is precisely the aim of explainer videos to impart knowledge, which leads to elaborate processing.

In line with this, the results show that a majority ISNA can improve the attitude towards VCO and the perceived effectiveness of VCO. Overall, this is consistent with previous studies demonstrating the positive effects of ISNAs on different persuasive outcomes (see Rhodes et al., 2020). Nevertheless, the effects on the intention to offset and the intention to obtain more information on the topic were only marginally significant. However, the results of the mediation analysis suggest that these effects may be mediated by perceived norms, which can be affected by SNA. These results should not be neglected; a meta-analysis by Yeganeh et al. (2020) concluded that public (community) support for climate policy and environmental activism has the largest positive impact on policy adoption. This public support can be improved through the use of majority ISNAs (Nolan, 2021).

This was the first study to combine a majority ISNA with a dynamic minority DSNA to address behaviour approved by a majority but only expressed by a minority. The combination of majority ISNA and static minority DSNA did not lead to undesired effects caused by social norm conflict or a nullification of main effects (cf. Schultz et al., 2007; Smith et al., 2012). However, dynamic DSNA did not significantly reinforce the positive effects of ISNA. These results are somewhat similar to those of Habib et al. (2021), who, unlike Smith et al. (2012), did not find negative effects caused by social norm conflict but rather a reversed positive effect: The combination of a majority ISNA and a minority DSNA increased organ donor registration. In their recent field experiment, they showed that unaligned SNAs could lead to better results than a minority DSNA or a majority ISNA alone, which is descriptively also reflected in our data. However, in an online panel experiment, Habib et al. (2021) found differences between unaligned SNAs and a minority DSNA, but not between unaligned SNAs and a majority ISNA. They suggested that this might be caused by the online environment because a majority ISNA shows participants the "right" thing to do, and since there is no cost of providing that answer, they do so. In our research, only marginally significant effects of ISNA on behavioural intention were found, but this might still limit our results.

Another possible explanation for the inconsistent results with regard to social norm conflict could be the nature of the research subject. Smith et al. (2012) reported that in the minority DSNA condition, 22% of students engaged in energy conservation. The inconsistent results may have been a consequence of surprise that only 22% made any effort at all to save energy, even though 82% were in favour of doing so. In contrast, offsetting an airplane flight (or registering as an organ donor) is an explicit behaviour, and 10% participation might seem relatively legitimate, even if the behaviour is approved by the majority.

Generally, our results may be limited by the coronavirus pandemic, as air travel was restricted, and people have travelled less by airplanes since then. Moreover, a "meet Bob" explainer video was combined with a whiteboard explainer video, which might have limited the external validity of the study. We included several control groups and a baseline measurement, but did not compare the explainer video with other formats, such as short science documentaries or reportages. Regarding SNAs, only weak effects on persuasive outcomes were observed. This may be because SNAs were embedded in longer explainer videos. Consequently, the manipulation was only one small part of a complex media stimulus, possibly including several new, overwhelming pieces of information apart from SNAs (cf. Tyers, 2018).

9. Conclusion

To summarise, explainer videos aiming to promote sustainable minority behaviour, emphasising that this behaviour is approved and desired by a majority, or that an increasing number of people have been adopting the desired behaviour, appears to be a promising approach. Furthermore, SNAs might be able to make social norms salient and influence perceived norms, at least in the short term, leading to stronger behavioural intentions. Watching different videos over time may induce behavioural changes in the long term when social norms are internalised. Therefore, including SNAs in science communication tools such as explainer videos can help promote pro-environment behaviours, even if the effects are weak, because including such SNAs does not involve any costs but ensures that a large and broad audience is reached. Consequently, explainer videos not only represent a useful channel for presenting science information online and sharing knowledge but also offer an opportunity for science journalists or activists to address climate change and actively target behavioural changes.

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Conflict of Interests

The author declares no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the author (unedited).

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Article

How Politicians' Attacks on Science Communication Influence Public Perceptions of Journalists and Scientists

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Abstract
In today's "post-truth" world, concerns over political attacks on the legitimacy of expert knowledge and scientific facts are growing. Especially populist politicians frequently use their social media platforms to target science and journalism, arguing these are part of an "evil elite," deliberately misleading the public by spreading disinformation. While this type of discourse is highly concerning, thus far, we lack empirical evidence on how these accusations affect the public perceptions of scientists and journalists. To fill this gap, this study tests how politicians' attacks affect citizens' trust in journalists and scientists and the information provided by them. Furthermore, it investigates whether this discourse renders hostility towards journalists and scientists acceptable and whether there are effects on the image of politicians using such anti-science rhetoric. Findings suggest that the effects of politicians' attacks on citizens' perceptions of scientists and journalists are limited. Only individuals with strong anti-elitist attitudes are susceptible to disinformation accusations and indicate less belief in discredited scientific information. Interestingly, these individuals also perceive politicians using such attacks as more trustworthy and authentic.

Keywords
anti-elitist attitudes; disinformation accusations; incivility; media trust; political attacks; populist communication; science communication; science trust

Issue
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1. Introduction

While not new, concern over harsh criticism and direct attacks on scientists and journalists—also expressed by political officials—has been growing in recent years (Krämer & Klingler, 2020; Nogrady, 2021; United Nations et al., 2021). Especially on social media, which has become a growing platform for science communication (Schäfer, 2017), accurate media portrayals of scientific findings are frequently shared alongside critical commentary and anti-science rhetoric (Schäfer et al., 2019). Political actors regularly attack media and science when it contradicts their political agenda (Druckman, 2017; Krämer & Klingler, 2020; Smith, 2010), frequently portraying them as a source of "fake news" and disinformation. This disinformation discourse is particularly popular among populist politicians, who argue that scientists and journalists are part of an "evil elite," deliberately misleading the public (Egelhofer et al., 2021; Egelhofer & Lecheler, 2019; Hameleers & Van der Meer, 2021; Mede & Schäfer, 2020). In the context of decreasing trust in science and journalism and growing online hostility towards experts, this type of discourse is highly concerning and has been characterized as "one of the most important challenges to science communication today" (Krämer & Klingler, 2020, p. 254). If these verbal attacks impede effective science communication on pressing challenges such as climate change or pandemics, it can have severe consequences for humanity (e.g., Druckman, 2017). However, thus far, there is minimal evidence of the effects of politicians' attacks on science and journalism (but see Hameleers & Van der Meer, 2021). Against this backdrop, this pre-registered survey experiment (N = 548) explores how politicians' attacks

affect citizens' perceptions of scientists and journalists, the information they provide, and the perceptions of the politicians using these accusations. It furthermore considers whether anti-elitist attitudes moderate any of these effects.

2. Politicians' Attacks Against Journalists and Scientists on Social Media

Public perceptions of science are not only determined by the communicative efforts of science itself but shaped by (political) communication *about* science (Akin & Scheufele, 2017). Given that most people only come in contact with science through its media portrayals, media presentation is a crucial factor influencing citizens' trust in science and scientific knowledge (Schäfer, 2016; Schäfer et al., 2019). However, today, news consumption increasingly takes place on social media (Newman et al., 2019), where (science) news is not presented in isolation but is frequently accompanied by harsh criticism (Schäfer et al., 2019; Wyatt, 2018). In other words, the consumption of science communication on social media is often intertwined with the consumption of its criticism.

Of course, criticism of science and journalism is not destructive per se; it is even necessary to ensure that these institutions fulfill their democratic functions (e.g., Wyatt, 2018). However, many political actors increasingly discredit science and media strategically to undermine narratives that contradict their political agenda (Corbyn, 2019; Druckman, 2017; Egelhofer et al., 2021). While politicians' criticism of science or media is nothing new (Oreskes & Conway, 2011; Watts et al., 1999), social media enable the dissemination of attacks that otherwise would not have passed through journalistic gatekeeping. Especially populist politicians frequently use social media to spread anti-media and anti-science criticism and highlight their opposition to elite institutions (Egelhofer et al., 2021; Engesser et al., 2017; Hameleers & Van der Meer, 2021).

Such criticism is likely with consequences. There is considerable evidence of the persuasiveness of political elite cues. Verbal cues from politicians can serve as heuristics that people rely on to form beliefs without investing much mental energy (Smith, 2010; Watts et al., 1999). For example, extant research shows that media bias accusations—a persistent theme in politicians' media criticism—increase citizens' bias perceptions, even for unbiased news coverage (Smith, 2010).

Today, one central theme of politicians' anti-media and anti-science communication is accusing these sources of spreading disinformation, "fake news," or "fake science." In doing so, these media and science are portrayed as malicious groups that intentionally lie and pursue hidden interests (Egelhofer & Lecheler, 2019; Hameleers & Van der Meer, 2021). The threat of (scientific) mis-and disinformation is a prominent theme in public discourse (Scheufele & Krause, 2019), leaving citizens highly concerned about being deceived by available information (Newman et al., 2019). Thus, citizens are likely susceptible to politicians' attacks featuring disinformation accusations.

Politicians' attacks can aim at two different addressees relevant to science communication: (a) scientific actors and institutions as the original source of science communication and (b) journalistic actors and institutions as the mediating source of science communication. In this study, we test the effects of attacks against both types. Specifically, we expose participants to social media posts by a politician who shares science news stories accompanied by disinformation attacks that either target the journalists as the source of the news stories or the scientists as the source of the scientific findings that the news report on.

First, politicians' media attacks likely impact citizens' trust in journalists. Journalists hold a central role as mediators of science communication (Schäfer, 2016). That is, most citizens have no direct interaction with scientific actors or institutions. Their knowledge and perceptions about science are thus primarily based on media representations (Schäfer, 2016). Unable to fact-check each piece of information themselves, citizens need to trust journalists' intentions and capabilities to provide them with accurate scientific knowledge (Strömbäck et al., 2020). However, extant research shows that trust in journalists is vulnerable to politicians' criticism (Ladd, 2012). Specifically, if politicians accuse them of spreading disinformation, citizens might conclude that journalists intentionally disseminate inaccurate scientific information. Thus, these attacks might harm their trust in journalists:

> H1a: Exposure to politicians' attacks against journalists decreases trust in journalists.

Second, politicians' science attacks likely also affect citizens' trust in scientists as the source of scientific information. As "science is a specialized, expert endeavor difficult to comprehend for outsiders" (Schäfer, 2016, p. 1), to learn about and make use of science, citizens need to trust that scientists have the expertise, integrity, and benevolence to provide them with factual scientific information (Hendriks et al., 2016). However, if scientists are accused of intentionally spreading false information, it likely hurts public perceptions of their integrity and benevolence and thus results in decreased trust in scientists. In line with this, Hameleers and Van der Meer (2021) find that when scientists are blamed for being dishonest, it has adverse effects on how the public perceives them:

> H1b: Exposure to politicians' attacks against scientists decreases trust in scientists.

In addition, we expect a spill-over effect in that politicians' attacks on journalists might also decrease trust in scientists, while politicians' attacks on science might also decrease trust in journalists. There are several reasons

for this assumption: First, when politicians' attacks are attached to science news on social media, both journalistic actors (source of the news story) and scientific actors (source of scientific information) are salient. Thus, even though the actual attack might target only one of these actor groups, people might interpret it as criticism of both the involved journalistic and science actors. Second, since most people only come across scientific information through *mediated* science communication (Schäfer, 2016), some people might generally not differentiate between the originating (scientific) and the mediating (journalistic) source. These people might lack knowledge about the science communication process and may consequently perceive scientific information as a product of one common group of knowledge-generating actors. Therefore, when a politician attacks one part of this group, people might infer that the entire group is not trustworthy. Third, people who differentiate between scientists and journalists might still be prone to this spill-over effect. On the one hand, they may assume that if a journalist is spreading disinformation about a study, the scientists must also be unreliable because they did not prevent or even support the spread of false reports of their study. On the other hand, people may react with decreased trust in journalists when a politician accuses the scientists of disinformation because they assume the journalist did not fact-check the scientific information and allowed the misleading information to be disseminated:

> H2: There are spillover effects such that politicians' attacks against journalists decrease trust in scientists, while attacks against scientists decrease trust in journalists.

These attacks might also have negative consequences beyond trust perceptions. For example, it is argued that politicians' increasing usage of incivility, untruths, and "outright denials of facts" has helped normalize such discursive practices (Higgins, 2016, p. 9; see also Levitsky & Ziblatt, 2018). Accusing others of intentionally lying is usually considered disrespectful or uncivil (Coe et al., 2014). However, witnessing political elites using these harsh accusations might desensitize citizens to uncivil behavior toward scientists and journalists:

> H3a: Exposure to politicians' attacks against scientists increases the acceptance of incivility toward scientists.

> H3b: Exposure to politicians' attacks against journalists increases the acceptance of incivility toward journalists.

Moreover, attacks featuring disinformation accusations likely also affect attitudes toward the information journalists and scientists provide. As outlined before, citizens are likely quite susceptible to disinformation accusations and, thus, potentially misled in their assessment of the accuracy of accused information. Indeed, initial studies show that when disinformation accusations accompany news stories on social media, citizens perceive discredited news content as less accurate (e.g., Egelhofer et al., 2022). Furthermore, citizens who feel disinformed about scientific issues are likely less willing to conform to policies based on scientific evidence (Hameleers et al., 2020). Therefore, the following hypothesis reads:

> H4: Exposure to politicians' attacks against scientists or journalists has a negative effect on belief in discredited scientific information and support for related policies.

Lastly, we pre-registered an exploratory analysis of whether using attacks against science and journalism might also affect citizens' perceptions of the politician using such attacks. Specifically, we consider how this rhetoric affects politicians' perceived trustworthiness and authenticity. On the one hand, uncivil lying attacks violate citizens' social norms about public discourse. In line with this, politicians' use of uncivil rhetoric has been found to decrease their perceived trustworthiness (Goovaerts & Marien, 2020). On the other hand, such violations of conversational norms might affect their perceived authenticity (Hahl et al., 2018). Authenticity is a fluid concept that can be defined in different ways. Still, many scholars agree that the perceived authenticity of politicians can be understood as the degree to which they remain true to themselves (Luebke, 2021, p. 635). Thus, violating social norms of discourse by attacking established institutions in an uncivil way might be perceived as authentic in times of anti-establishment politics (Hahl et al., 2018). Therefore, we investigate the following:

> RQ1: How does exposure to politicians' attacks against scientists or journalists affect the perceived trustworthiness and authenticity of politicians?

3. The Role of Anti-Elitist Attitudes

Attacks against science and journalism are arguably most effective for people who are already skeptical of these actors. When individuals hold anti-elitist attitudes, i.e., hostile and distrustful views of elites, they are likely more easily convinced that these actors are lying. Anti-elitism is the core of populism and describes a view of an inherent conflict between "good" and ordinary people and an "evil" privileged societal elite (Jagers & Walgrave, 2007; Merkley, 2020; Mudde, 2004). Importantly, this Manichean worldview "stands in opposition to the possibility of truth-telling as a collective effort to produce agreed-upon facts and reach consensus on the correspondence between assertions and reality" (Waisbord, 2018, p. 18). Therefore, anti-elitism is directed toward all elite institutions that once held a hegemonic position

in defining what is true, mainly the political elites, mainstream news media, and scientific actors and institutions (Waisbord, 2018). In line with that, populist actors not only attack the political establishment but increasingly target media and science elites. These are often blamed for either conspiring with or being instrumentalized by the political elites (Eberl et al., 2021; Fawzi, 2020; Jagers & Walgrave, 2007; Krämer, 2018; Mede & Schäfer, 2020). While populism research long conceptualized the political establishment as the main elite that populists are opposed to, recent work stresses the importance of expanding this conceptualization to the media elites (coined as "anti-media populism"; Krämer, 2018) and scientific or academic elites (coined as "science-related populism"; Mede & Schäfer, 2020; see also Eberl et al., 2021). Therefore, in this study, we conceptualize anti-elitism as negative attitudes towards the political elite, the media elite, *and* the academic elite.

Importantly, extant research shows that anti-elitist attitudes are related to negative attitudes toward the media (Fawzi, 2019) and science (Eberl et al., 2021). Specifically, studies that investigate how the individual components of populist attitudes (i.e., anti-elitism, homogeneity of the people, demand for sovereignty, and anti-outgroup attitudes) each relate to negative media perceptions suggest that anti-elitist attitudes are the strongest predictor of negative media perceptions (e.g., Fawzi, 2019). Anti-elitism is furthermore linked to conspirational thinking, another attitude related to mistrust of experts and established knowledge (Castanho Silva et al., 2017). Therefore, we expect that:

> H5: The negative effects of politicians' attacks on (a) trust in journalists and scientists, (b) acceptance of incivility towards journalists and scientists, and (c) issue perceptions are stronger for individuals with strong anti-elitist attitudes.

4. Method

4.1. Design and Procedure

This study was preregistered (https://bit.ly/3SBvpJ3) and approved by the university institutional review board. We deviate from this preregistration in two ways: First, the wording and numbering of the hypotheses changed slightly (but the expectations remain the same); second, we preregistered a sample size of 750 to account for main and interaction effects. However, due to a large part of the sample failing the attention checks, the sample size is smaller (as discussed in Section 4.3).

Our study is set in Austria, where populist anti-elite rhetoric and disinformation accusations against media and science have been used frequently by political actors (e.g., by the Austrian Freedom Party and the People's Party; e.g., Wodak, 2019). Furthermore, in a recent survey of public attitudes towards science across European countries, Austrians rank below the European average for most surveyed attitudes (European Commission, 2021). For example, almost one-third of Austrians indicated that the characteristic "honest" describes scientists badly (European Commission, 2021, p. 182), and more than half (54%) think scientists are not altruistic (European Commission, 2021, p. 184).

We used a between-subjects online survey experiment, including a 3 (journalism attack vs. science attack vs. control) factorial design. Participants were randomly assigned to one of the three groups. After providing informed consent, participants answered questions about their socio-demographics and anti-elitist attitudes. Then, they were exposed to the stimulus and responded to questions measuring the dependent variables, followed by manipulation checks and a thorough debrief.

4.2. Stimulus

All groups were exposed to a fictional politician's Twitter page on which two news article previews are shared that each report on the findings of a scientific study. One news headline reports the scientific finding that e-cars are more environmentally friendly than diesel/gas cars. The second news article covers research that finds that women are considered more competent in leadership positions. Some tweets by the politician provide additional information from these articles. In the science attack condition, the politicians' tweets included accusations against scientists as the producers of the studies (e.g., "What the scientists have come up with again #fakescience" or "it is hardly news that scientists lie"). In the journalism attack condition, the politician attacked journalists as the messengers of the scientific studies (e.g., "What the journalists have come up with again #fakenews'' or "it is hardly news that journalists lie"). In the control condition, there are no attacks.

To ensure mundane realism to the best extent, a real news outlet was indicated as the source (i.e., the Austrian daily newspaper *Kleine Zeitung*). The news previews focused on factual information from actual news coverage of existing scientific studies. Furthermore, the page featured some non-related, private tweets (e.g., "Happy weekend"). The entire stimulus material is provided as supplementary materials.

4.3. Sample

A varied sample of Austrian citizens (18 and older; M = 47.85, SE = 0.66; 51.09% female) was recruited by panel agency *Dynata*. Power analysis with G*power estimated that a sample size of 550 is necessary to identify even small main effects (f^2 = 0.02, power of 0.80, given α = 0.05). We included two attention checks in our survey. One was an instructed-response item inserted in the item battery on trust in journalists asking respondents to "please select '10 Agree completely'" (see, e.g., Kung et al., 2018). The second attention check entailed a multiple-choice question, asking for the topics of the

two news article previews that were present in all three conditions (one correct answer out of four options). Participants who failed one of them were excluded, resulting in a final sample of N = 548. It is important to note that this sample size might be suboptimal for analyzing interaction effects which are said to require up to 16 times bigger sample sizes. Therefore, we will interpret these effects with caution (see also Hameleers & Van der Meer, 2021)

4.4. Manipulation Check

Respondents indicated their agreement with two statements about the Twitter page: "The politician criticized journalists" and "the politician criticized scientists." Participants in the science attack condition were more certain that scientists were criticized (M = 4.95, SE = 1.69) than participants in the journalism attack condition (M = 4.05, SE = 1.76) and the control condition (M = 2.69, SE = 1.61), F(2, 548) = 84.47, p < 0.001. Post hoc analyses indicated that all three conditions significantly differed from each other in their assessment of science criticism.

Participants in the journalism attack condition (M = 4.92, SE = 1.67) were slightly more convinced that journalists were criticized than participants in the science attack condition (M = 4.64, SE = 1.70) and control condition (M = 2.98, SE = 1.77), F(2, 548) = 66.69, p < 0.001. However, post hoc analyses indicated that the attack conditions significantly differed from the control condition but not from each other. Therefore, we will treat direct comparisons between the experimental conditions with caution.

4.5. Measures

If not stated otherwise, all items were measured on 7-point scales. Trust in Journalists was adapted from Strömbäck et al. (2020), asking how suitable the characteristics "fair," "unbiased," "tell the whole story," "accurate," and "separate facts from fiction" are to describe journalists in Austria, who work for major TV stations and newspaper publishers (Cronbach's α = 0.90, M = 3.77, SE = 0.5). Trust in Scientists was measured by two items for three dimensions (expertise, integrity, benevolence; Hendriks et al., 2016): Again, participants rated the suitability of different characteristics to describe scientists in Austria: competent, qualified, honest, sincere, responsible, moral (Cronbach's α = 0.94, M = 4.89, SE = 0.5).

The measurement of Acceptance of Incivility Towards Journalists [Scientists] was adapted from Post (2017). Participants rated whether an example of an uncivil social media comment is (a) justified, (b) understandable, or (c) unacceptable (Journalists: Cronbach's α = 0.78, M = 2.86, SE = 0.07; scientists: Cronbach's α = 0.75, M = 2.66, SE = 0.06).

Politician Perceptions were measured by asking respondents to indicate how trustworthy (M = 4.74, SE = 0.07) and authentic (M = 4.61, SE = 0.07) they perceived the politician.

As explained above, we conceptualize Anti-Elitist Attitudes as negative attitudes toward the political, journalistic, *and* academic elite. However, to the best of our knowledge, no scale currently exists that assesses negative attitudes towards all three of these groups. Therefore, we have utilized items from established scales that measure negative attitudes towards one of these elite groups, which have been validated in prior research. Specifically, for the political elite, we chose two items with the highest factor loadings from Schulz et al. (2018), e.g., "Politicians are not really interested in what people like me think." For the scientific elite, we chose those two items from Mede et al. (2021) that measure anti-science elite attitudes: "Scientists are in cahoots with politics and business" and "scientists are only after their own advantage." To the best of our knowledge, there is no validated scale for measuring anti-media-elite attitudes. Therefore, we selected one item from Fawzi (2019, p. 159) that alludes to anti-elite perceptions of news media: "With their media coverage, the media support the country's powerful, that is, the state, government or businesses." Additionally, we adapted one item from Mede et al. (2021): "Journalists are only after their own advantage." This combination showed sufficient scale reliability (Cronbach's α = 0.83, M = 4.36, SE = 0.06).

5. Results

5.1. Effects on Perceptions of Scientists and Journalists

To test the effects of politicians' attacks on the perceptions of scientists and journalists (H1a–H5b), a series of OLS regressions were conducted (see Table 1). The main effect analyses were conducted on the whole sample, while the models, including the interaction coefficients, compared one experimental group with the control.

We expected that exposure to politicians' attacks on journalism decreases trust in journalists (H1a) and politicians' attacks on science decrease trust in scientists (H1b). As shown in Table 1, there is no effect of an accusation against journalism on trust in journalists (b = −0.17, SE = 0.13 p = 0.18, Model 1) and no effect of an accusation against science on trust in scientists (b = 0.11, SE = 0.11, p = 0.31, Model 4). Next, we expected that there would be spillover effects such that the politicians' attacks against journalists (scientists) decrease trust in scientists (journalists; H2). Again, there is no effect of a science attack on trust in journalists (b = −0.17, SE = 0.12 p = 0.15, Model 1) and no effect of a journalism attack on trust in scientists (b = 0.15, SE = 0.11, p = 0.18, Model 4). In sum, reported levels of trust in journalists did not differ between the control group (M = 3.86, SE = 0.09) and two experimental groups (journalism attack: M = 3.74, SE = 0.1 Cohen's d = 0.1; science attack: M = 3.71, SE = 0.09, Cohen's d = 0.12). Similarly, reported levels of trust in scientists did not differ between the control

Table 1. OLS regression models predicting citizens' perceptions of scientists and journalists.

	Trust						Acceptance of Incivility			
	Journalists			Scientists			Journalists		Scientists	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
Journalism attack	–0.166	–0.120		–0.148	–0.091		0.056	–0.619	0.051	
	(0.125)	(0.452)		(0.110)	(0.396)		(0.148)	(0.521)	(0.141)	
Science attack	–0.174		0.467	–0.109		0.173	–0.027		0.024	0.261
	(0.121)		(0.420)	(0.107)		(0.366)	(0.144)		(0.137)	(0.484)
Anti-elitist attitudes	–0.379***	–0.321***	–0.321***	–0.412***	–0.383***	–0.383***	0.492***	0.408***	0.507***	0.506***
	(0.038)	(0.072)	(0.069)	(0.034)	(0.063)	(0.060)	(0.046)	(0.083)	(0.043)	(0.079)
Journalism attack * anti-elitist attitudes		–0.009			–0.013			0.154		
		(0.099)			(0.087)			(0.114)		
Science attack * anti-elitist attitudes			–0.146			–0.064				–0.055
			(0.092)			(0.080)				(0.106)
Constant	5.541***	5.284***	5.284***	6.770***	6.645***	6.645***	0.707***	1.081***	0.425**	0.431
	(0.191)	(0.329)	(0.315)	(0.168)	(0.288)	(0.274)	(0.226)	(0.379)	(0.215)	(0.363)
Observations	548	#	373	548	352	373	548	352	548	373
Adj. *R*-squared	0.151	0.105	0.176	0.212	0.182	0.228	0.173	0.170	0.198	0.175

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

group (M = 4.95, SE = 0.07) and the two experimental groups (journalism: M = 4.85, SE = 0.09, Cohen's d = .09; science: M = 4.87, SE = 0.83, Cohen's d = 0.07).

Moreover, there is no significant interaction between anti-elitist attitudes and the journalism attack on trust in either journalists (b = −0.01, SE = 0.1, p = 0.93, Model 2) or scientists (b = −0.01, SE = 0.09, p = 0.89, Model 5). Similarly, there is no interaction between anti-elitist attitudes and the science attack on trust in either journalists (b = −15, SE = 0.09 p = 0.11, Model 3) or scientists (b = −0.06, SE = 0.08, p = 0.42, Model 6). We thus find no support for H1a, H1b, H2, and H5a.

Furthermore, there are no significant effects of the attacks on acceptance of incivility towards journalists (journalism attack: b = 0.06, SE = 0.15, p = 0.71; science attack: b = −0.03, SE = 0.14, p = 0.85, Model 7) or scientists (b = 0.05, SE = 0.14, p = 0.72, b = 0.02, SE = .14, p = 0.87, Model 9). That is, individuals exposed to a journalism attack did not indicate higher levels of acceptance of incivility towards journalists (M = 2.88, SE = 0.12, Cohen's d = −0.00) compared to individuals in the control condition (M = 2.88, SE = 0.11). Participants exposed to a science attack did not indicate higher levels of acceptance of incivility towards scientists (M = 2.67, SE = 0.11, Cohen's d = 0.06) than participants in the control group (M = 2.66, SE = 0.11). Lastly, there is no significant interaction between anti-elitist attitudes and the journalism attack on acceptance of incivility towards journalists (b = 0.15, SE = 0.11, p = 0.18, Model 8) or scientists (b = −0.06, SE = 0.11, p = 0.61, Model 10). The results do not support H3 and H5b.

5.2. Effects on Issue Perceptions

To test the effects of politicians' attacks on belief in the scientific information and support for related policies (H4), as well as the moderating role of anti-elitist attitudes for these effects (H5c), we pooled the two attack conditions (see Table 2). Model 1 shows that there is no effect of the attacks on participants' belief that women have better leadership competence (b = −0.10, SE = 0.14, p = 0.46, Model 1; attack conditions: M = 4.05, SE = 0.08; control: M = 4.15, SE = 0.11; Cohen's d = 0.07). Similarly, there are no direct effects of the accusations on participants' belief that E-cars elicit fewer greenhouse gases than conventional cars (b = −0.24, SE = 0.17, p = 0.15, Model 3; attack conditions M = 4.60, SE = 0.10; control: M = 4.81, SE = 0.14; Cohen's d = 0.11). There is no support for H4. However, there are marginally significant interaction effects of anti-elitist attitudes and the attack conditions on both the belief that women have better leadership competence (b = −0.21, SE = 0.11, p = 0.05, Model 2) and the belief that E-cars elicit fewer greenhouse gases than conventional cars (b = −0.26, SE = 0.13, p = 0.05, Model 4). Figure 1 plots the marginal effects and shows that the attacks (versus the control condition) only have a negative effect on individuals with very strong anti-elitist attitudes.

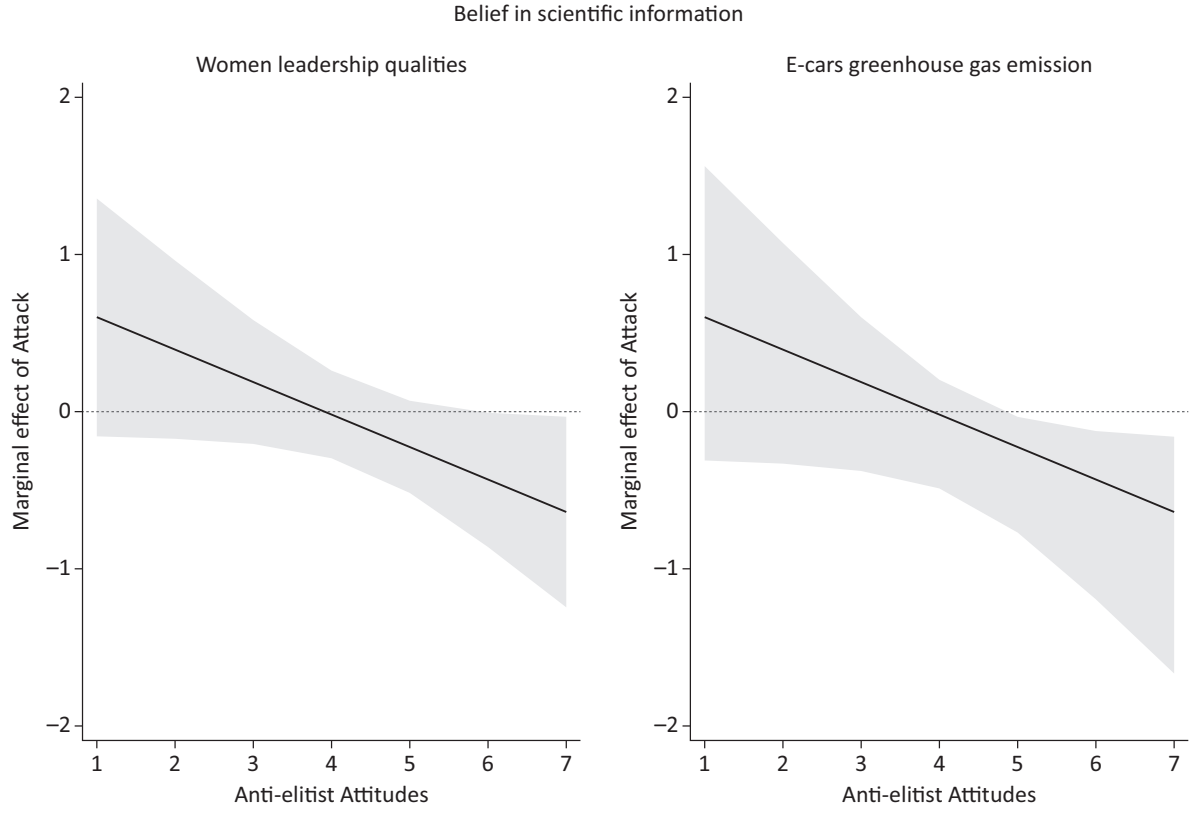

Figure 1. Average marginal effects of attack conditions (vs. control) on belief in scientific information for different levels of anti-elitist attitudes.

Next, we find no effect of the accusations on participants' support for policies relating to the scientific information (i.e., policy 1—a gender quota in supervisory boards: b = 0.00, SE = 0.18, p = 0.98, Model 5; attack conditions: M = 4.55, SE = 0.10, control condition: M = 4.54, SE = 0.15, Cohen's d = −0.01; and policy 2—governmental subsidies for the purchase of e-cars: b = −0.03, SE = 0.18, p = 0.89, Model 7; attack conditions: M = 4.43, SE = 0.12, control condition: M = 4.41, SE = 0.15, Cohen's d = −0.01). Moreover, there is also no interaction between anti-elitist attitudes and attacks on support for related policies (policy 1: b = −0.23, SE = 0.14, p = 0.1, Model 6; policy 2: b = −0.03, SE = 0.14, p = 0.86, Model 8). Taken together, these findings provide only limited support for H5c.

5.3. Effects on Politician Perceptions

Lastly, we again pooled the attack conditions to test the effects of science/media attacks on perceptions of the politician using these. As shown in Table 3, attacks on science and media have a significant main effect on how authentic (b = −0.52, SE = 0.14, p = 0.00, Model 1) and trustworthy (b = −0.66, SE = 0.14, p = 0.00, Model 3) people perceive politicians using these accusations. That is, participants in the attack conditions perceived the politician as less authentic (M = 3.12, SE = 0.08) compared to the control condition (M = 3.71, SE = 0.10; Cohen's d = 0.40) and less trustworthy (M = 3.05, SE = 0.09) compared to the control condition (M = 3.71, SE = 0.10; Cohen's d = 0.42). Furthermore, there are significant interaction effects of the attacks and anti-elitist attitudes on perceived authenticity (b = 0.57, SE = 0.42, p = 0.00, model 2) and trustworthiness (b = 0.56, SE = 0.11, p = 0.00., Model 4). Figure 2 plots the marginal effects and shows that the attacks only appear to have a negative effect on individuals with weak to medium anti-elitist attitudes. However, individuals with strong anti-elitist attitudes perceive politicians using these attacks as more authentic and trustworthy.

6. Conclusions

In today's digitalized information environment, science communication is increasingly accompanied by politicians' criticism. Particularly notable are disinformation accusations as a political strategy to exploit citizens' fears about being fooled by fake news and pseudo-science. While concerns about this discourse of science denial are growing, thus far, we do not know much about its consequences.

Our findings suggest that politicians' attacks on science and journalism have no impact on citizens' general trust in these institutions. We also do not find evidence that these attacks desensitize people to incivility toward scientists and journalists. Thus, our study provides initial evidence that public perceptions of scientists and journalists are quite resistant to criticism by unknown politicians. In this aspect, the null findings provide evidence for the stability of *generalized* attitudes toward these institutions. However, suppose we had tested the effects of attacks on the perceptions of a

Table 2. OLS regression models predicting citizens' perceptions of scientific information.

	Belief in Information				Policy Support			
	Women leadership competence		E-cars greenhouse gas emission		Women leadership competence		E-cars greenhouse gas emission	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
	b(*SE*)	*b*(*SE*)	*b*(*SE*)	*b*(*SE*)	*b*(*SE*)	*b*(*SE*)	*b*(*SE*)	*b*(*SE*)
Attack (Science/ journalism)	−0.102 (0.137)	0.806* (0.488)	−0.244 (0.169)	0.884 (0.605)	0.004 (0.179)	1.025 (0.640)	−0.025 (0.184)	0.085 (0.660)
Anti-elitist attitudes	−0.0410 (0.049)	0.104 (0.089)	−0.363*** (0.061)	−0.183* (0.111)	−0.070 (0.064)	0.093 (0.117)	−0.479*** (0.066)	−0.461*** (0.121)
Attack * anti-elitist attitudes		−0.207* (0.107)		−0.257* (0.132)		−0.232 (0.140)		−0.025 (0.144)
Constant	4.334*** (0.244)	3.694*** (0.410)	6.411*** (0.302)	5.616*** (0.508)	4.851*** (0.319)	4.132*** (0.537)	6.529*** (0.329)	6.451*** (0.555)
Observations	548	548	548	548	548	548	548	548
Adj. R-squared	−0.001	0.004	0.061	0.065	−0.002	0.002	0.085	0.083

Note: *** p < 0.01, ** p < 0.05, * p < 0.1.

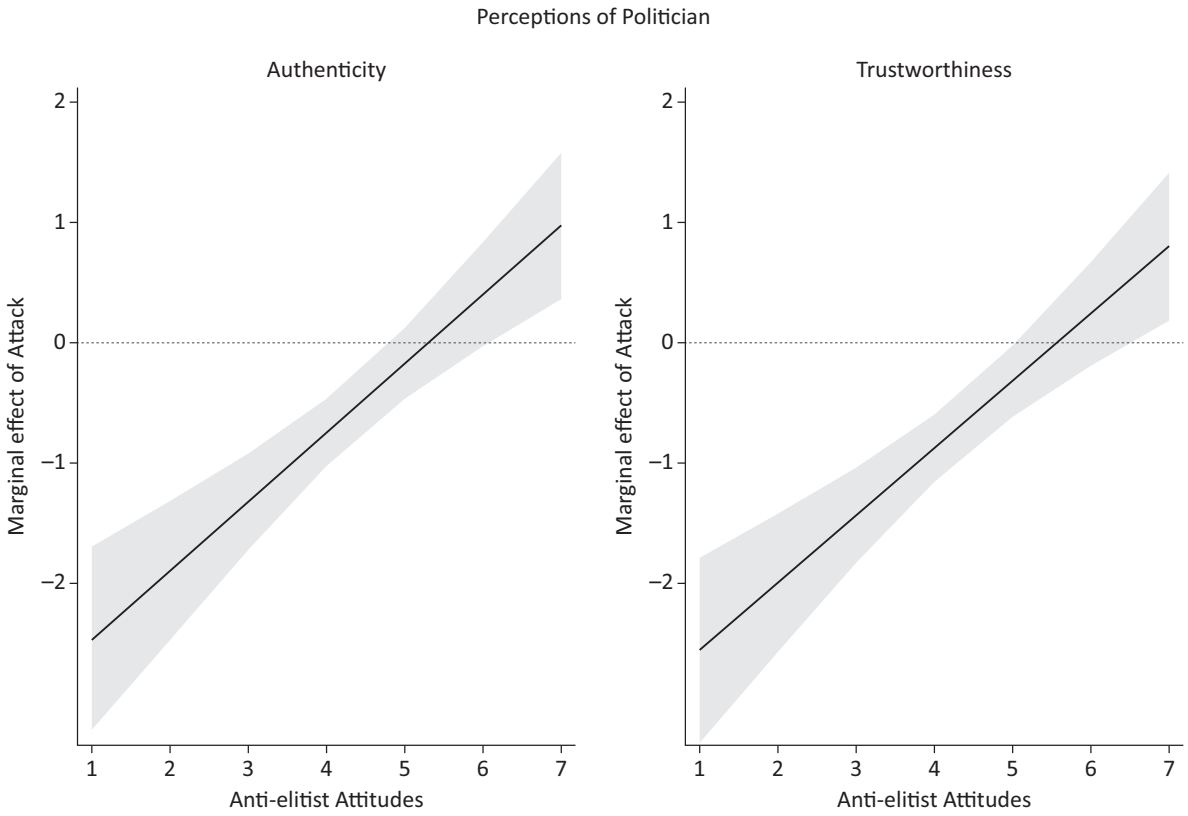

Figure 2. Average marginal effects of attack conditions (vs. control) on perceptions of politicians for different levels of anti-elitist attitudes.

Table 3. OLS regression models predicting citizens' perceptions of politicians.

	Politician Perception			
	Authenticity		Trustworthiness	
	Model 1	Model 2	Model 3	Model 4
	b(*SE*)	*b*(*SE*)	*b*(*SE*)	*b*(*SE*)
Attack (Science/journalism)	−0.518***	−3.036***	−0.659***	−3.123***
	(0.141)	(0.493)	(0.143)	(0.499)
Anti-elitist attitudes	0.011	−0.391***	0.017	−0.375***
	(0.051)	(0.09)	(0.051)	(0.09)
Attack * anti-elitist attitudes		0.573***		0.561***
		(0.108)		(0.109)
Constant	3.70***	5.47***	3.63***	5.37***
	(0.25)	(0.42)	(0.26	(0.42)
Observations	548	548	548	548
Adj. *R*-squared	0.02	0.07	0.04	0.08

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

specific journalist/scientist (e.g., the author of the news article or scientific study at hand). In that case, the results might have been different (see Egelhofer et al., 2022). Individuals tend to make quick character judgments based on little information about unknown actors. Thus, trust in specific scientists/journalists is likely more variable (Akin & Scheufele, 2017) and thus might be more easily hurt by political attacks.

Similarly, the fact that there are no direct effects of exposure to the attacks on beliefs in scientific issues shows that citizens' attitudes towards scientific issues are rather stable and not easily influenced by anti-science communication on social media. That is, participants seem to have formed stable opinions relating to the issues of gender and cars, which are not easily influenced by a single message. However, in this context, it is important to note that we did not measure pre-existing attitudes toward these issues. Citizens form rather strong attitudes toward issues that are important to them. These have been shown to be stable over time (Howe & Krosnick, 2017) and resistant to framing effects (Lecheler et al., 2009). Thus, it is likely that citizens' existing views on feminism or alternative energies might impact their response to political attacks on these topics.

Moreover, our study provides some interesting insights into the role of anti-elitist attitudes. First, contrary to our expectation, we do not find an interaction effect between the attack and anti-elitist attitudes on perceptions of science and journalism. However, Table 1 shows that anti-elitist attitudes have a direct negative effect on trust and acceptance of incivility. Arguably, individuals with strong anti-elitist attitudes already show such negative views on journalists and scientists that they do not "need to be convinced" by political attacks. Thus, these findings indicate again that generalized attitudes towards these institutions are quite stable.

However, turning to the effects on specific issues, there is marginally significant evidence that for people with strong anti-elitist attitudes, these attacks have a negative effect on the belief in scientific information at hand. Furthermore, while for individuals with weak anti-elitist attitudes, such attacks hurt perceptions of the politician, this rhetoric leads individuals with extreme anti-elitist attitudes to perceive politicians as more trustworthy and authentic. These findings indicate that while attacking science and journalism as a political strategy might not affect perceptions of these institutions, it seems to be effective in discrediting specific science communication narratives for a sub-group of the population. Moreover, it appears to be an attractive strategy for populist or "outsider'' politicians to emphasize an anti-establishment position and thereby appeal to a specific voter base (see also Van Dalen, 2021).

Our study comes with several limitations. First, our design entails single, forced exposure to social media messages by an unknown politician. While using anonymous politicians is common practice in research on the effects of political discourse because it allows for isolating the effects of the message from any ideological predispositions (e.g., Goovaerts & Marien, 2020; Van Duyn & Collier, 2019), our design does not allow for a conclusion about the effectiveness of attacks by well-known, established politicians. Future research is thus urgently needed to investigate the effects of real-life political attacks on science communication. Furthermore, as noted in Section 4.3, our sample size might not be sufficient for analyzing interaction effects. Further studies replicating the effects we found are therefore needed. Naturally, our setting also does not allow for statements about the longevity of such effects and the likelihood that participants would expose themselves to such messages in the real world. Furthermore, while we do not find evidence for a normalization of incivility toward journalists and scientists, it is possible that repeated exposure to such attacks indeed increases the acceptance of incivility over time.

Moreover, as noted in Section 4.4, the manipulation check revealed that the experimental conditions were perceived as quite similar. While there was a significant difference between both experimental groups in the perception of whether scientists were attacked, there was no significant difference between the groups in the perception of whether journalists were attacked. Participants in the journalism attack group were convinced that journalists were attacked, while participants in the science attack group were convinced that journalists *and* scientists were attacked. The wording of the tweets might have caused this. In both conditions, the politicians' attacks contained the words "studies" and "articles." Therefore, although the politician directs his attacks against scientists or journalists, participants might have perceived them as directed at both actor groups. Another possibility could be that because, in both conditions, the politician shares journalistic news articles along with his attacks, participants in both groups might have perceived journalists as addressed by the attacks independent of the wording of the tweets. For whichever reason the manipulation failed, the analysis of H2 (spillover effect of attacks) was impeded. Future research could test different wordings of attacks that allow for a cleaner comparison between addressed actors.

Furthermore, we could only include a limited number of topics in our study. Extant research shows that scientific opinions are issue-specific and dependent on predispositions (Akin & Scheufele, 2017). Future research is thus needed to understand how the effects play out for other (new) topics. As mentioned before, this research should also consider participants' existing attitudes. Moreover, we set our study in only one country. As attacks on scientists are reported around the globe (e.g., Nogrady, 2021), testing the effects of this in other national contexts is crucial. Lastly, as previously noted, to measure anti-elitist attitudes, we have employed items from various established scales. However, further research is required to develop and validate a unified

scale that specifically assesses negative attitudes toward political, media, and scientific elite groups.

In summary, this study provides cautious optimism about the impact of unknown politicians' online attacks on generalized perceptions of science communication. However, future studies are urgently needed to test other scenarios, communicators, scientific topics, and national contexts.

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Conflict of Interests

The author declares no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the author (unedited).

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