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ARTICLE

Characterization of polarized scientific digital messages: a scoping review

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Abstract

This scoping review elucidated the characteristics of polarized scientific digital messages credited by researchers for studying the impact of content on people's perceptions. Inclusion criteria encompassed discourse and content analysis studies examining the syntactic and lexical features of polarized messages in online science communication, as well as crossover and randomized information intervention studies. Studies without sufficient detail for data extraction or that did not address message characteristics were excluded. After these exclusions, 10 studies were evaluated for the outcomes. Characteristics of polarized messages were observed to include topic dependency, single viewpoint, discredit of opposing views, emphasis on the minority and flaws of concurrent discourses, and uses of assertive statements, intensifiers, controversy, partisanship, skepticism, sarcasm, vague lexicons, and expert opinion support. As a result, we propose a system of codification for identifying and characterizing polarized discourses in science communication digital messages that can be employed in further content analysis studies.

Keywords

Health communication; Science and media; Science communication: theory and models

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1 ▪ Context

Social psychology defines polarization as a deliberate process within a group where members tend to adopt more extreme opinions after discussion [Moscovici & Zavalloni, 1969]. This process fosters a collective narrative, creating a fertile environment for developing and reinforcing identity and cohesion in homophilic groups [Turner et al., 1989; Hogg et al., 1990; McPherson et al., 2001; Postmes et al., 2005; Bliuc et al., 2021]. Within this context, polarization can be categorized into three distinct forms [Arguedas et al., 2022]: (a) ideological polarization, which pertains to the extent of disagreement among individuals regarding political issues; (b) affective polarization, which relates to the emotional responses individuals have toward opposing groups with differing views; and (c) audience polarization, which describes the degree to which audiences of news channels exhibit political partisanship or diversity. As a result, polarized messages often amplify these forms of polarization by reinforcing extreme viewpoints, evoking strong emotional responses, and deepening divides between different audience segments. Consequently, polarized messages not only reflect but also perpetuate polarization processes, reinforcing group identities and solidifying divisive narratives within society. It is noteworthy that these forms of polarization can individually and collectively impact various social aspects, underscoring the importance of understanding these phenomena in scientific research.

In the communication of science, polarization arises from debates over the duality of results and methods, as well as from the discrediting or manipulation of findings by both specialized and non-specialized communities [O'Connor & Weatherall, 2018; Abramowitz & Saunders, 2008; Ploug & Holm, 2015]. As a result, the polarization of scientific discourse can lead to disputes affecting science's objectivity, progress, social reputation, and impact. It biases debates and public decisions and affects scientists' motivation, shifting from scientific interest to personal visibility [Sharpe, 2002; van Kolfschooten, 2002; Ziman, 2002]. For instance, the debate over consensus-based anthropogenic global warming versus alternative oil industry's views has delayed global efforts to reduce carbon emissions significantly [Franta, 2021]. Similarly, discussions on the efficacy of vaccines intensified during the COVID-19 pandemic led to preventable deaths, particularly in countries with political leaders who deny scientific evidence [Morris, 2024].

The polarization process is markedly intensified in digital relationships on social media. Within this context, while compelling empirical evidence for the existence of platform- or algorithmically-induced echo chambers is lacking [Bruns, 2019; Arguedas et al., 2022], people actively choose to engage with content that aligns with their pre-existing beliefs, avoiding contradictory information [Marozzo & Bessi, 2018; Kim & Kim, 2019; Chinn et al., 2020; Choi et al., 2020; Kubin & von Sikorski, 2021]. Consequently, personal characteristics appear to play a more significant influence in the polarization process than content suggested by digital platforms, because users are also exposed to opposing viewpoints in some media [Arguedas et al., 2022]. On the other hand, the role of polarized messages within this scenario remains underexplored, particularly from a scientific perspective. While numerous studies have examined the traits of misinformation and disinformation in digital media, there is a significant gap in the literature regarding the characteristics of scientific polarized messages [Bryanov & Vziatysheva, 2021; Molina et al., 2021; Hamby et al., 2024].

Based on the aforementioned research literature, this scoping review aimed to identify studies that characterized polarized scientific digital messages from the perspective of

authors of science communication. To achieve this aim, the PCC (Population/Concept/Context) framework was used to define the research questions. Specifically, this framework is structured around three pillars that guide the theoretical background: population (the group or entity being studied), concept (the main idea or issue being explored), and context (the setting or environment). In this study, 'population' refers to science communication messages, 'concept' denotes polarization, and 'context' encompasses the internet [Peters et al., 2024]. As a result, the review addresses the following questions:

Q.1. What are the characteristics of polarized scientific digital messages found in papers, science communication articles, or specialized discourses?

Q.2. What definitions and synonyms exist for polarized scientific digital messages?

Q.3. How are studies on polarized scientific digital messages characterized by their countries of origin, fields of knowledge, and themes?

Q.4. Can polarized scientific digital messages be linked to specific authors, receivers, textual marks, or interest issues?

Q.5. Are there distinct patterns in polarized scientific digital messages found in scientific papers, science communication articles, and specialized discourses?

Addressing the main question (Q.1) of this study, the synthesis of content and discourse characteristics of polarized messages in science communication can facilitate their identification across diverse digital contexts. This is relevant to a range of current situations, from the increased production of digital materials by professionals without formal media training to prestige disputes or discourses with hidden agendas posted as pieces of genuine scientific education on social media. Moreover, these results can guide future research in this area, highlighting the knowledge gaps and challenges that emerged from the disproportionate discursive battle observed in fields of public interest within democratic societies. Based on the systematization of findings from this scoping review, we also aim to propose a codification system for identifying and characterizing polarized digital messages in the context of science communication.

2 ▪ Materials and methods

This scoping review was developed according to the recommendations of The Joanna Briggs Institute Reviewer's Manual — Methodology for Scoping Reviews [Peters et al., 2024]. These results are reported following the Preferred Reporting Items for Systematic reviews and Meta-Analysis extension for Scoping Reviews (PRISMA-ScR) checklist [Tricco et al., 2018].

The protocol of this study was registered in Open Science Framework platform in October 20, 2022, which can be accessed in https://osf.io/t8a6f/.

2.1 ▪ *Eligibility criteria*

Initially, according to the registered protocol for this review, the inclusion criteria were limited to studies on discourse and content analysis that focused on the specific syntactic and lexical characteristics of polarized messages within the context of science

communication in cyberspace. However, upon identifying a scarcity of literature, the inclusion criteria were revised and broadened to incorporate other studies with distinct designs that presented polarized messages, as recognized by their own authors. In this context, crossover and randomized information intervention studies were included in the analysis. This investigation considered references published in any year and language available on October 29, 2022 (date of collection). Scientific papers lacking sufficient detail for data extraction (see details below) or failing to address the characteristics of the messages were excluded from the study.

2.2 ▪ *Search strategy*

On October 4, 2022, a search strategy combining representative keywords of the population (science communication messages) and concept (polarization) was employed for retrieving references on Medline. The first ten articles related to the themes were screened to obtain a list of additional keywords. The relevance of keywords for search strategy was discussed between two investigators (AMJ and TC) and included in the search strategy after consensus. These procedures were repeated on the Web of Science. After that, a final search strategy was determined, as follows: ((“polarized” OR “polarization” OR “partisan” OR “polarised” OR “polarisation” OR “opposing” OR “one-sided” OR “tendentious” OR “authoritarianism” OR “politization” OR “biased judgment” OR “conservative ideology” OR “expert consensus” OR “ideological bias” OR “ideological belief” OR “misleading argumentation” OR “motivated reasoning” OR “perceived consensus” OR “political ideology” OR “political orientation” OR “scientific ideology” OR “partisanship” OR “reactance” OR “scientism”) AND (“scientific news” OR “science news” OR “scientific information” OR “science information” OR “science content” OR “scientific content” OR “science discourse” OR “scientific discourse” OR “scientific communication” OR “science communication” OR “scientific message” OR “science message” OR “science publication” OR “scientific publication” OR “scientific publications” OR “scientific dissemination” OR “science dissemination” OR “scientific divulgation” OR “scientific press” OR “science press” OR “science journalism” OR “scientific journalism” OR “science communicators” OR “science thinking” OR “scientific belief” OR “scientific consensus”)).

On October 29, 2022, references were retrieved by searches conducted on the following databases: Medline, Web of Science, Cochrane, EMBASE, Portal BVS, Clinical Trials, Scopus, ERIC, Human Resources Abstracts and PsycINFO.

2.3 ▪ *Study selection*

The references retrieved were uploaded into Endnote Web® Reference Manager (Clarivate, London, U.K.) to remove duplicates. Titles and abstracts were screened by two independent investigators (AMJ and ML) to exclude studies not related to polarized scientific digital messages. Papers judged by at least one of the investigators as related to the topics of interest were then fully screened by one investigator (AMJ) to ensure adherence to the selection criteria. Additionally, the reference citations of the selected papers were manually checked by the same investigator to identify any references not retrieved by the databases. Those papers with titles that seemed significant to this review were annotated and retrieved. Finally, the two investigators (AMJ and ML) performed an independent full reading of

selected publications. After that, both investigators selected the papers for the scoping review consensually, considering the eligibility criteria aforementioned.

2.4 ▪ *Data charting*

The investigators (AMJ and ML) independently charted data from the included papers using Microsoft Excel. This process involved synthesizing the main characteristics of the studies, such as the authors' names, type of study (e.g., content analysis, discourse analysis, cross-over, or randomized information intervention), year of publication, country of origin, field of knowledge, subjects of the messages, aims of the study, sample size, characteristics of the messages, and main findings. Additionally, the investigators identified definitions, synonyms, and alternative terms for polarized scientific messages used in these studies. The data charted similarly by both investigators were considered as valid results; otherwise, discrepancies were solved by re-analysis and consensus to validate the results.

This scoping review did not include a critical appraisal of the studies, as its purpose was to summarize the existing evidence on the topic to inform future research, policy, and practice.

The Litmaps (litmaps.com, Wellington, New Zealand) was used to determine the relationships among the references of the included papers. This application was employed to produce a visual map of these relationships and to elucidate the influence of cited references on the development of this issue through citation metrics.

2.5 ▪ *Codification system*

Based on the independent analysis of results, two independent investigators (AMJ and TC) listed possible codes to enable the identification and characterization of polarized digital messages in science communication . After that, redundant codes were removed by consensus. The significant codes were aggregated into categories of similarity.

3 ▪ Results

3.1 ▪ *Selection of sources of evidence*

In Figure 1, it is shown that 3,320 references were initially retrieved from the databases. After removing 888 duplicates, the remaining 2,432 titles and abstracts were evaluated for their relevance to polarized scientific digital messages, leading to the exclusion of 2,177 references. The subsequent assessment of titles and abstracts of the remaining 255 references were made against additional eligibility criteria, resulting in the exclusion of 134 studies for lacking digital messages, 30 for not being authored by experts or science communicators, and 51 for methodological designs not focused on message analysis. Then, 40 papers were selected for full reading, with addition of 4 papers found through cross-checking their reference lists. After full reading, 34 out of the 44 papers were excluded for not focusing on polarized scientific digital messages [Kata et al., 2012; Hall Jamieson & Hardy, 2014; Scheufele, 2014; Myers et al., 2015; Pearce et al., 2015; Dalrymple et al., 2016; Dixon, 2016; Winter & Krämer, 2016; Hardy & Hall Jamieson, 2017; Zielińska, 2017; Bolsen & Shapiro, 2018; Harvey et al., 2018; Jiang et al., 2018; Lee et al., 2018; Merkley & Stecula, 2018; Hardy et al., 2019; Iyengar & Massey 2019; Lenzi, 2019; Nagler et al., 2019; Pearce et al.,

2019; Yuan et al., 2019; De Cruz, 2020; Landrum & Slater, 2020; Pontalti Monari et al., 2020; Baldi & Gala, 2021; Haupt et al., 2021; Hernandez et al., 2021; Rode et al., 2021; Schneider, 2021; Zhang et al., 2021; Boyd, 2022; Jia, 2022; Wirz et al., 2022; Nagler et al., 2023].

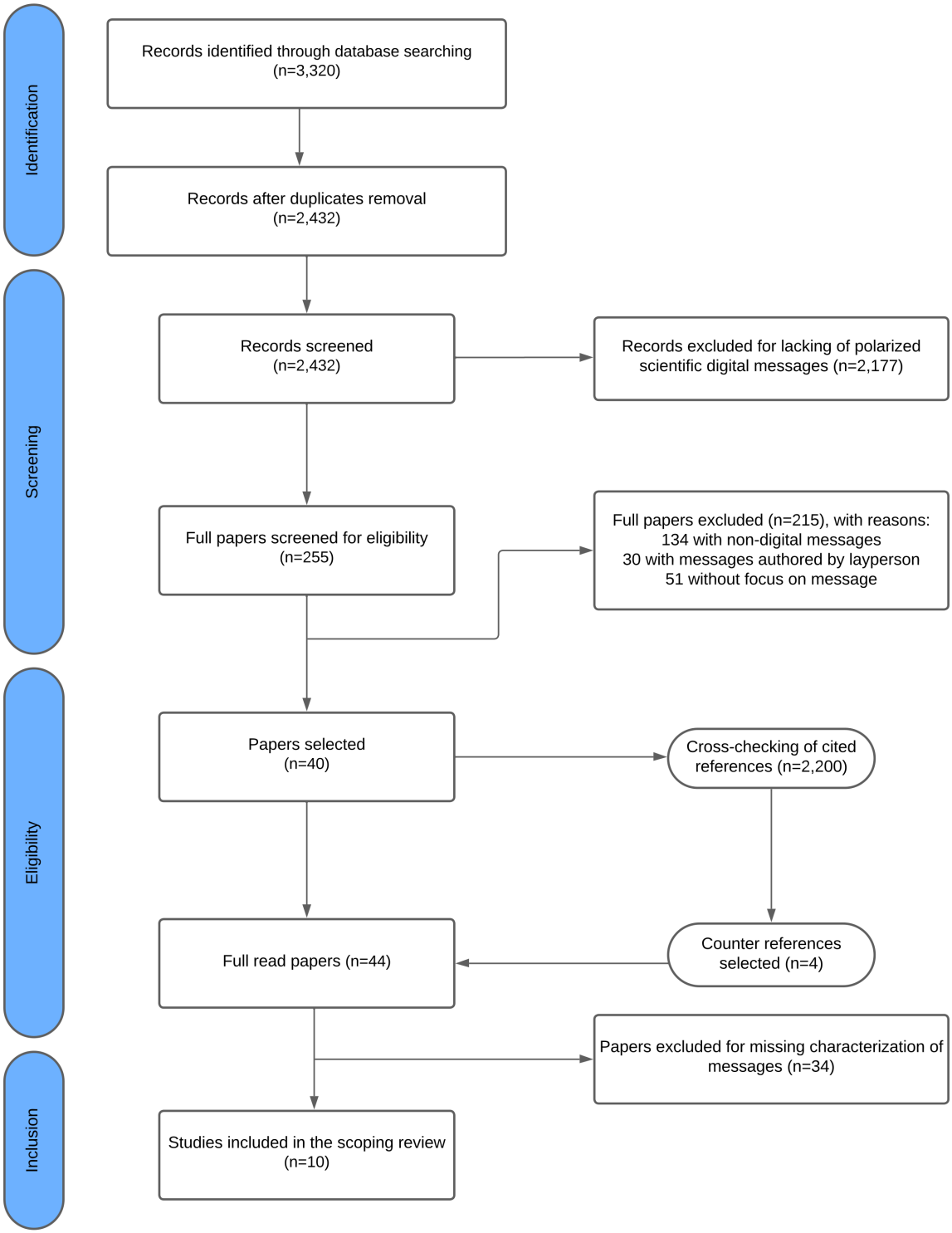

Figure 1. Flow diagram of study selection.

3.2 ▪ *Characteristics of sources of evidence*

The 10 papers included in this review [Kortenkamp & Basten, 2015; Winter et al., 2015; Roper et al., 2016; Dunwoody & Kohl, 2017; Anderson & Becker, 2018; Becker & Anderson, 2019; Lyons et al., 2019; Sol Hart et al., 2020; Wang & Huang, 2021; Iles et al., 2022] are summarized in Table 1.

3.3 ▪ *What are the characteristics of polarized scientific digital messages in papers, science communication articles, or specialized discourses?*

Although the syntax of polarized messages was not detailed in the studies, the lexical characteristics were well-described. These messages typically presented a single viewpoint. Polarizing techniques included associating viewpoints with minority organizations and emphasizing flaws [Kortenkamp & Basten, 2015]. Other forms involved assertive statements and strong intensifiers while avoiding lexical hedges [Winter et al., 2015]. The discourse often featured power vs. resistance, corruption vs. purity, and hysteria vs. reason discourses [Roper et al., 2016]. Strategies like supporting an argument with the consensus of expert opinion [Dunwoody & Kohl, 2017] or employing sarcasm [Anderson & Becker, 2018; Becker & Anderson, 2019] also contributed to polarization.

In synthesis, the following concepts were associated with polarized messages: controversy, opposition, minority, majority, conflict, sidedness, failureness, topic dependency, skepticism, confrontation, partisanship, unilateralism, unbalancement, singleness, assertiveness, intensiveness, empowerment, resistance, corruptness, pureness, hysteria, reason, supportiveness, sarcasm, persuasiveness, refutation, contestation, politization, and uncertainty.

In contrast, non-polarized messages were recognized for their neutral and balanced arguments [Kortenkamp & Basten, 2015; Wang & Huang, 2021], the presentation of multiple viewpoints [Kortenkamp & Basten, 2015], and the use of lexical hedges and terms that indicate uncertainty [Winter et al., 2015]. Most studies emphasized the presence of diverse opinions [Kortenkamp & Basten, 2015; Dunwoody & Kohl, 2017; Anderson & Becker, 2018; Lyons et al., 2019; Wang & Huang, 2021; Iles et al., 2022]. The following concepts were associated with non-polarized messages: inclusion, multiplicity, impartialism, objectiveness, credibility, equality, neutrality, balancement, attenuation, uncertainty, diversity, and conformity.

To generate a codification system for identifying and characterizing polarized digital messages for science communication, two independent investigators (AMJ and TC) proposed 48 codes according to these findings. Then, 28 codes were removed by consensus of redundancy. Based on similarity, the remaining 20 codes were organized into five categories, called sidedness, criticism, emphasis, discordance, and non-polarized. The complete list of codes and their definitions is presented in Table 2.

3.4 ▪ *What definitions and synonyms exist for polarized scientific digital messages?*

Although the papers did not mention specific definitions of polarized scientific messages, they offered concepts in their introductions or conceptual frameworks that shed light on their approach to the topic. Kortenkamp and Basten [2015] characterized polarized journalistic

Table 1. Synthesis of studies examining the characteristics and effects of polarized science communication in digital messages.

Study	*Type of study*	*Year*	*Country*	*Area*	*Subject of the message*	*Objectives*	*Sample size*	*Message characteristics*	*Main findings*
Kortenkamp & Basten	Randomized information intervention	2015	U.S.A.	Agricultural and Biological Sciences	Environmental risks	To explore how the portrayal of balanced and unbalanced opposing scientific viewpoints in the news media influences people's perceptions of environmental risks, scientific uncertainty, and the credibility of journalists and scientists	247 college students (mean: 19 yrs.-old)	Balanced opposing scientific viewpoint: this entails presenting both arguments neutrally on the subject. Discrediting information about the second opposing viewpoint: this involves associating the second scientist with a specific organization or a minority viewpoint, as well as highlighting any potential flaws or shortcomings in their arguments.	Journalists who presented opposing scientific views on environmental risks were perceived as less biased, but this did not necessarily enhance their credibility compared to those presenting a single viewpoint. It is noteworthy that scientists' credibility appeared higher and their perceived bias lower when only one viewpoint was presented.
Winter et al.	Randomized information intervention	2015	Germany	Psychology	Computer games psychological effects	To investigate how laypersons are influenced by textual representations of scientific uncertainty	78 parents or caregivers of children and adolescents (mean: 40.27 yrs-old)	One-sided/basic: presented unilaterally in a neutral style. One-sided/assertive: conveyed unilaterally with assertive statements and strong intensifiers, leaving no room for doubt or ambiguity. One-sided/hedged: presented unilaterally, but with lexical hedges or acknowledgments of potential limitations. Two-sided: features a positive counterpoint to the one-sided, hedged version, providing a balanced perspective.	Readers exposed to two-sided arguments about the negative effects of computer games on children adopted a more balanced perspective than those who encountered one-sided basic arguments. Interestingly, assertive arguments with intensifiers were found to be more persuasive than the basic arguments.
Roper et al.	Discourse analysis	2016	New Zealand	Agricultural and Biological Sciences	Climate change	To propose a theoretical framework explaining the persuasive discursive strategies of climate skeptics against anthropogenic global warming	1,215 news, reports or blog posts	Polarized messages: power versus resistance, corruption versus purity, and hysteria versus reason.	Skeptics foster identification by articulating their positions through prominent discourses of purity, resistance, and reason. Conversely, polarization is intensified when proponents articulate their positions in opposition to the prevailing discourses of corruption, power, and hysteria.

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Study	*Type of study*	*Year*	*Country*	*Area*	*Subject of the message*	*Objectives*	*Sample size*	*Message characteristics*	*Main findings*
Dunwoody & Kohl	Randomized information intervention	2017	U.S.A.	Agricultural and Biological Sciences	Pharmaceutical pollution on water resources	To examine how audiences react to news coverage of a contested science issue	759 U.S. residents (mean: 39 yrs.-old)	Contrasting views: the article presents two opposing scientific viewpoints on the risks associated with pharmaceutical pollutants, without indicating whether one opinion has greater expert support than the other. Weight of experts: the article acknowledges opposing viewpoints while indicating that one set of opinions is supported by a majority of experts. Single view: the article presents claims about pharmaceutical pollution without countering them with contrasting views.	In the exposure to three distinct conditions (contrasting views, weight of experts, and single view), the weight of experts narrative enhanced participants' confidence in the judgments made by scientists, consequently increasing their inclination to align with and embrace those judgments themselves.
Anderson & Becker	Randomized information intervention	2018	U.S.A.	Agricultural and Biological Sciences	Climate change	To examine how exposure to one-sided versus two-sided sarcastic perspectives on climate change influences beliefs about climate change	141 undergraduate students (mean: 19.51 yrs.-old)	Two-sided sarcasm: showcases sarcastic behavior and conversation surrounding both the positive and negative aspects of rising temperatures and climate change. One-sided sarcasm: presents a sarcastic argument about the effort to create a conspiracy to persuade the public and scientists that global warming is a hoax.	One-sided sarcasm can engage less interested individuals with the issue of climate change, even after controlling for demographics and other antecedent variables.
Becker & Anderson	Randomized information intervention	2019	U.S.A.	Agricultural and Biological Sciences	Climate change	To evaluate the differential impact of exposure to one-sided versus two-sided satire about climate change on message processing	141 undergraduate students (mean: 19.51 yrs.-old)	The one-sided video presents a highly critical satirical argument about a conspiracy among scientists, politicians, and celebrities to persuade the public that global warming is a hoax, employing ironic statements as well.	A one-sided satirical approach, asserting that global warming is a hoax, stimulates viewers to engage in more profound message elaboration and counterarguing. Conversely, a two-sided satire that ridicules both believers and skeptics of human involvement in climate change is swiftly dismissed.
Lyons et al.	Randomized information intervention	2019	U.S.A./ United Kingdom	Agricultural and Biological Sciences	Genetically modified foods (GMF)	To evaluate the influence of conversion narratives on audience attitudes about controversial science	727 adults (mean: 45.6 yrs.-old)	A one-sided message presents only the speaker's opinion, whereas a two-sided message acknowledges the previous speaker's view and explains why the current speaker has adopted a new position.	Conversion messages can influence attitudes through perceived argument strength but not through speaker credibility.

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Study	*Type of study*	*Year*	*Country*	*Area*	*Subject of the message*	*Objectives*	*Sample size*	*Message characteristics*	*Main findings*
Sol Hart et al.	Content analysis	2020	U.S.A.	Medicine	COVID-19	To examine the level of politicization and polarization in COVID-19 news in the U.S.A.	6,985 stories from broadcasted daily news about COVID-19	Politicization was measured by the frequency with which news articles mentioned political and scientific actors. Polarization was assessed through scores derived from text analysis, partisan separation, and analysis of terms.	Coverage of COVID-19 in newspapers exhibited a high degree of politicization, whereas network news coverage displayed a somewhat lower level of politicization. Notably, both newspaper and network news coverage were marked by significant polarization.
Wang & Huang	Crossover study (2×2)	2021	U.S.A.	Medicine	E-cigarette use	To examine the effects of message format and sidedness in counteracting misinformation related to e-cigarettes and promoting support for regulatory policies	271 adults (mean: 35 yrs-old)	A two-sided story distinguished THC-based e-cigarettes as a concern and regarded nicotine-based ones as safe, whereas a one-sided narrative solely cautioned against all e-cigarettes.	Message format significantly influenced transportation, identification, and emotional involvement, but message sidedness had no impact on perceived credibility, positive perceptions, counterarguing, attitudes, or policy support. The interaction between message format and message sidedness was moderated by prior experience with e-cigarette use.
Iles et al.	Randomized information intervention	2022	U.S.A.	Medicine	Cancer	To understand how individuals respond to different types of conflicting information regarding cancer prevention	1,027 American adults (18+ yrs.)	Conflict in evidence: this arises from the presence of ambiguous evidence, where expert sources do not necessarily disagree with one another, but rather acknowledge that the existing evidence is mixed. Conflict between two expert sources about the evidence: this occurs when one expert source, typically a team of scientists, presents findings that directly contradict another source or an established guideline. Conflict within the same expert source: this type of conflict arises when the source of a guideline, often a public health organization, is described as altering its recommendation over time due to the accumulation of new evidence.	Although exposure to conflicting information on nutrition and cancer risk does not seem to negatively affect behavioral intentions, it reduces key public health perceptions, including trust in scientists and disease-specific fatalism.

Table 2. Codification system for the identification and characterization of polarized digital messages for science communication.

Categories	*Codes*	*Definition*
Sidedness	Unilateralism	One-sided message, with no opposing opinion
	Lack of equal space for two sides	The message presents two or more available views, but in an unbalanced way
Criticism	Minority view	When the author criticizes the opposite viewpoint, saying that it is a minority view
	Conflict of interest	The author criticizes the opposite viewpoint by reporting that people have a conflict of interest
	Highlighting flaws	When the author criticizes the opposite viewpoint by reporting flaws in thinking or science
	Sarcasm	When the author criticizes the opposite viewpoint through sarcasm
Emphasis	Demonstration of a clear consensus	The message emphasizes the presence of consensus, from the population or scientists
	Demonstration of a 'correct' view	The message asserts that a particular viewpoint is the correct one
	Assertive statements	The message uses assertive statements to emphasize its viewpoint
	Strong intensifiers	Use of intense words (e.g. a lot, many) or use of capslock
	Dramatization of narratives	The message uses dramatization to support its viewpoint
	Persuasion	The message uses persuasion to support its viewpoint
	Expert opinion arguments	The message uses the words of an expert to support its viewpoint.
Discordance	Controversy	When the author highlights the controversial aspect of a subject
	Conflict between experts about the evidence	When the author highlights the conflict between experts about current scientific evidence
	Conflict within the same expert source	When the author highlights his/her disagreement with his/her previous viewpoint
	Confrontation	When the author demonstrates a confrontation with an idea or a person
	Partisanship	When an author uses partisanship or politics to defend his/her viewpoint
	Skepticism	When the author expresses skepticism in his/her viewpoint
Non-polarized	No polarization	No identification of characteristics of polarized content

practice as presenting both sides of an issue while disproportionately criticizing one side, often portraying it as a minority view or one with a conflict of interest. They defined balanced journalism as the effort to include multiple opposing viewpoints as accurately and impartially as possible, aiming to demonstrate objectivity and credibility without taking sides. According to them, balanced reporting involves giving equal space, weight, and credibility to all views, even if they represent unequal positions like majority versus minority opinions. Similarly, Winter et al. [2015] described balanced content as presenting conflicting evidence that does

not necessarily lead to a clear consensus on the 'correct' view. In addition, the authors sub-divided one-sided messages into basic (presented unilaterally in a neutral style), assertive (conveyed unilaterally with assertive statements and strong intensifiers, leaving no room for doubt or ambiguity), and hedged (presented unilaterally, but with lexical hedges or acknowledgments of potential limitations).

Sol Hart et al. [2020] showed that polarized messages are often disseminated by actors from different poles (e.g. political parties), who craft stories focused on the contentious interactions between competing figures, to accentuate conflict and dramatize the narratives. This approach is pointed to be strategically used to engage and maintain the audience's attention by spotlighting the adversarial natures of discourses. On the other hand, the 'center' of a field, regarded as non-polarized, is occupied by discourses that are seen as 'neutral' or representative of common sense, primarily due to their lack of controversy or contestation.

Iles et al. [2022] presented the origin types of conflicting information about cancer. In this scenario, conflict in evidence occurs when different sources (e.g. sources A and B) agree that the evidence on a topic is mixed. Conflict between expert sources about the evidence arises when sources A and B present conflicting viewpoints or data regarding a topic. Lastly, conflict within the same expert source occurs when a single source changes its recommendation or stance on the evidence over time.

In addition, two studies describe the use of "polarization" in science communication. One study discussed climate change news [Roper et al., 2016], where polarization is seen as a strategy used by climate skeptics to attack the arguments of proponents of anthropogenic global warming. Another study examined COVID-19 news [Sol Hart et al., 2020], showing how discussions vary with the involvement of political parties. The term "polarized messages" was represented by 63 synonyms or substitute words. The words that composed synonyms referencing polarization that were more frequently found in the papers were "viewpoint", "opposing", and "one-sided" (Figure 2).

Some expressions such as "one-sided message" [Winter et al., 2015; Anderson & Becker, 2018; Becker & Anderson, 2019; Wang & Huang, 2021] and "single-view message" [Dunwoody & Kohl, 2017] described content presenting typically only one speaker's perspective. Other synonyms like "opposing viewpoints" [Kortenkamp & Basten, 2015; Dunwoody & Kohl, 2017] and "conflicting information" [Iles et al., 2022] indicated information polarization in the context of unbalanced arguments.

Non-polarized messages were characterized for 40 synonyms or substitute words. The words that composed synonyms referencing non-polarization more frequently in the papers were two-sided, balance, and viewpoint (Figure 3).

Terms like "two-sided messages" [Winter et al., 2015; Anderson & Becker, 2018; Lyons et al., 2019; Wang & Huang, 2021] indicated a balanced presentation of two viewpoints. Other synonyms such as "balanced opposing scientific viewpoint" [Kortenkamp & Basten, 2015] reflected a neutral presentation of arguments. The term "conflict in evidence" [Iles et al., 2022] described ambiguous evidence without implying disagreement by authors with two or more different positions.

It is important to note that some words like "viewpoint", "opposing", and "opposition" were frequently found among terms equivalently used to express polarized and non-polarized messages, depending on the context they were presented.

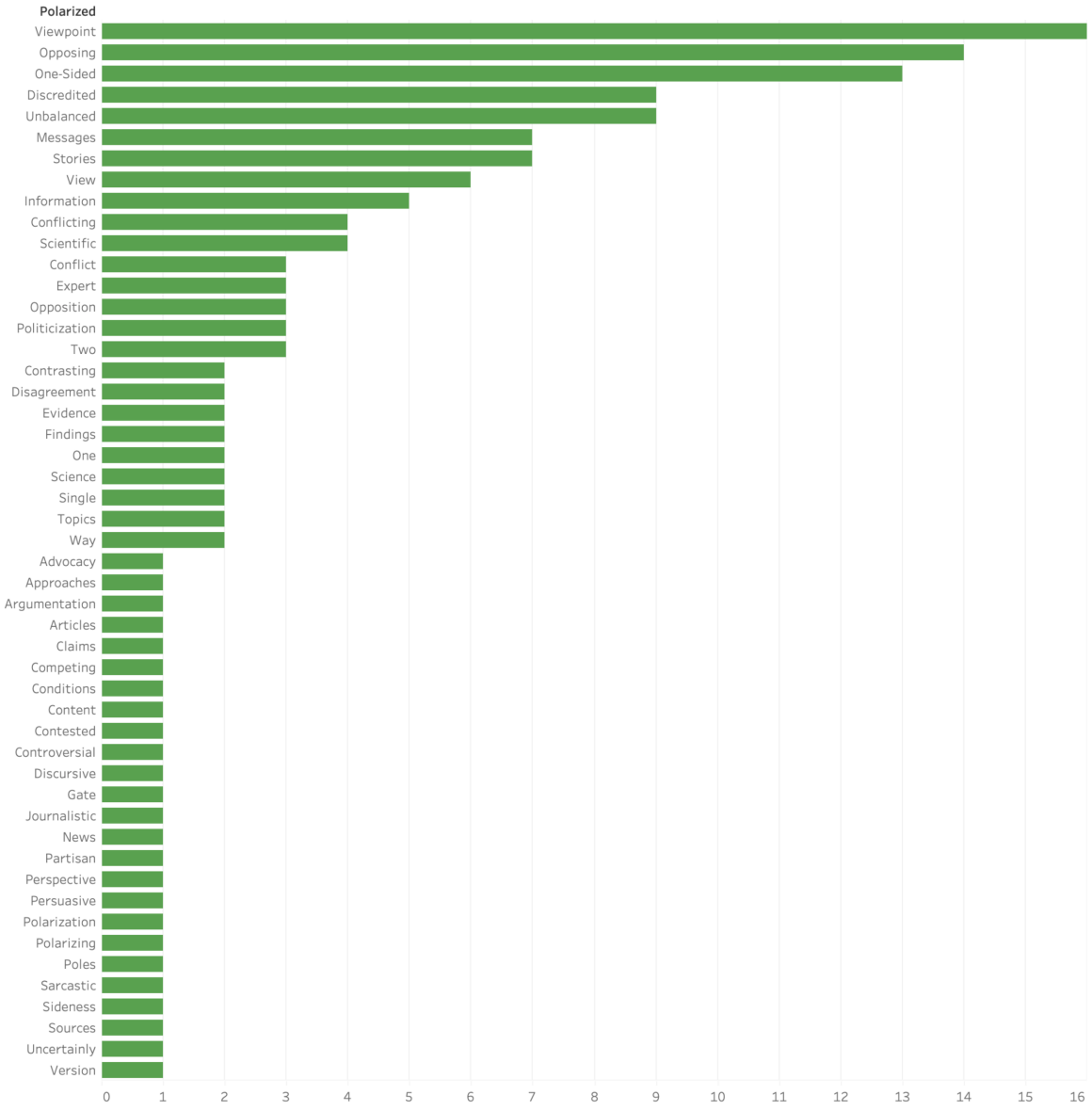

Figure 2. Bar graph representing the words used to compose the synonyms of polarized messages. The bar size corresponds to the frequency of word appearance in the included studies.

3.5 ▪ *How are studies on polarized scientific digital messages characterized by their countries of origin, fields of knowledge, and themes?*

Most studies were conducted in the U.S.A. (n = 7) [Kortenkamp & Basten, 2015; Dunwoody & Kohl, 2017; Anderson & Becker, 2018; Becker & Anderson, 2019; Sol Hart et al., 2020; Wang & Huang, 2021; Iles et al., 2022], followed by Germany (n = 1) [Winter et al., 2015], and New Zealand (n = 1) [Roper et al., 2016]. A multicenter study involved collaboration between researchers from the U.S.A. and the U.K. [Lyons et al., 2019]. The most common study design was a randomized information intervention (n = 7) [Kortenkamp & Basten, 2015; Winter et al., 2015; Dunwoody & Kohl, 2017; Anderson & Becker, 2018; Becker & Anderson, 2019; Lyons et al., 2019; Iles et al., 2022], followed by a discourse analysis (n = 1) [Roper et al., 2016], a

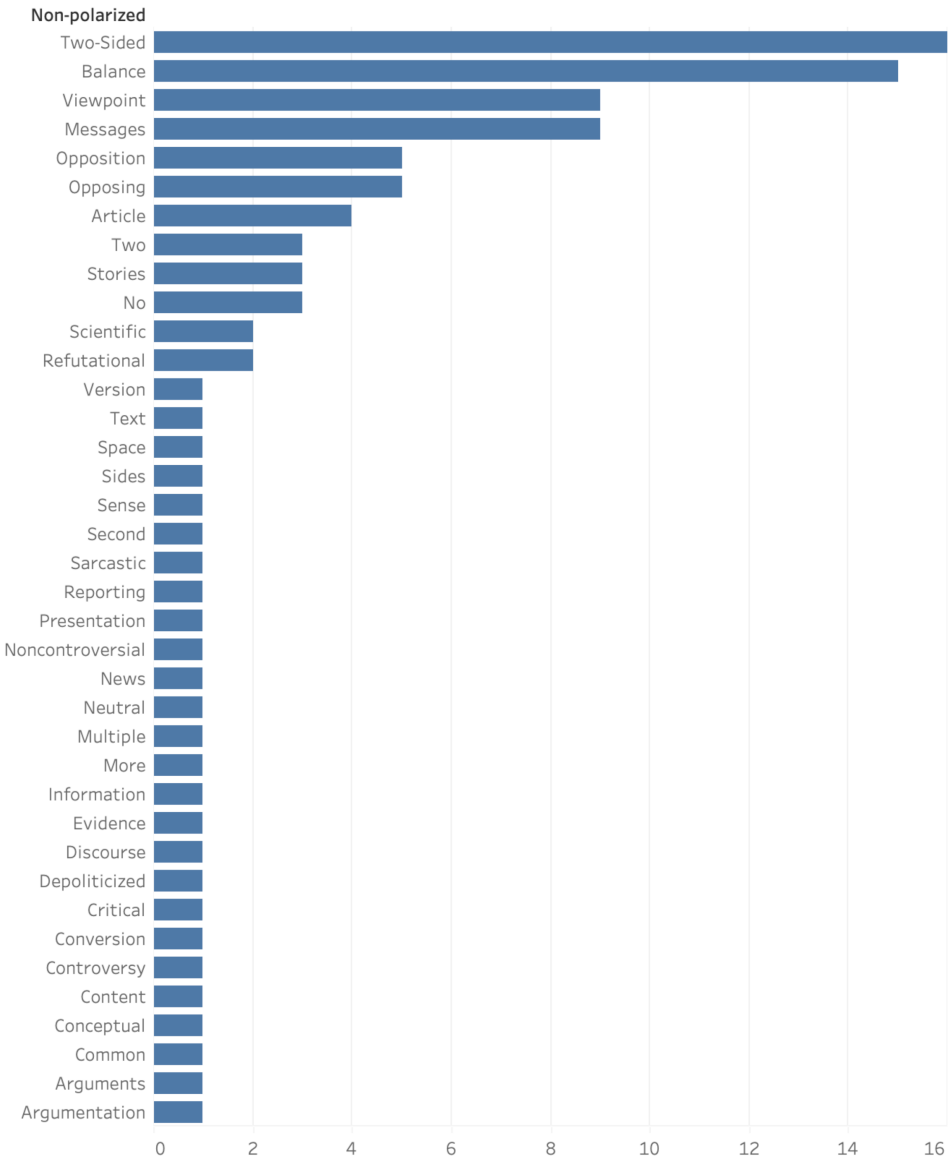

Figure 3. Bar graph representing the words used to compose the synonyms of non-polarized messages. The bar size corresponds to the frequency of word appearance in the included studies.

content analysis (n = 1) [Sol Hart et al., 2020], and a crossover study (n = 1) [Wang & Huang, 2021]. The studies were published between 2015 and 2022, with the years 2015 [Kortenkamp & Basten, 2015; Winter et al., 2015] and 2019 [Becker & Anderson, 2019; Lyons et al., 2019] having the highest number of papers. The longest study spanned from 2009 to 2016 [Roper et al., 2016], while others ranged from 15 to 120 days [Dunwoody & Kohl, 2017; Sol Hart et al., 2020; Wang & Huang, 2021; Iles et al., 2022]. However, some papers did not specify the period of experiments or data collection [Kortenkamp & Basten, 2015; Winter et al., 2015; Wang & Huang, 2021].

The papers reported results from three fields of knowledge: Agricultural and Biological Sciences (n = 6), covering environmental risks [Kortenkamp & Basten, 2015], climate change [Roper et al., 2016; Anderson & Becker, 2018; Becker & Anderson, 2019], pharmaceutical

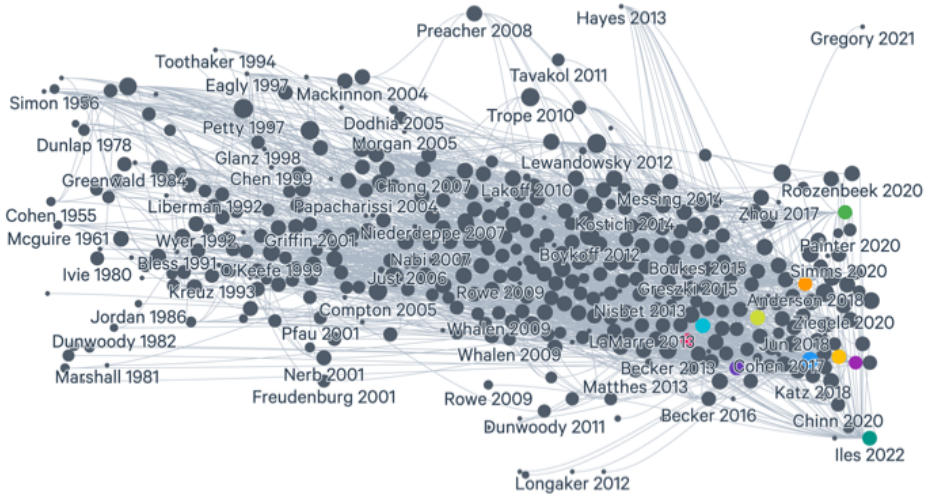

Figure 4. Visual literature map of cited references in included papers. The map highlights relationships among references, with interpretation based on publication date (x-axis), reference count (y-axis), and citation count (node size), with colors distinguishing the included papers.

water pollution [Dunwoody & Kohl, 2017], and genetically modified foods [Lyons et al., 2019]; Medicine (n = 3), focusing on COVID-19 [Sol Hart et al., 2020], e-cigarettes use [Wang & Huang, 2021], and cancer [Iles et al., 2022]; and Psychology (n = 1), exploring the psychological effects of computer games on children and adolescents [Winter et al., 2015].

Litmaps identified 417 references cited by the 10 papers included in this scoping review (Figure 4).

The earliest of these references was published in 1946 in a psychology journal [Sherif & Cantril, 1946]. The most cited reference was a programming book published in 2013, which has accumulated 29,513 citations [Hayes, 2017]. Notably, only two of the included papers [Dunwoody & Kohl, 2017; Becker & Anderson, 2019] cited another paper also included in this review [Kortenkamp & Basten, 2015; Anderson & Becker, 2018], one of which was produced by the same research group. Additionally, some papers cited studies from their own groups [Winter et al., 2015; Roper et al., 2016; Anderson & Becker, 2018; Becker & Anderson, 2019] or from other groups that had studies included in this review [Kortenkamp & Basten, 2015; Anderson & Becker, 2018; Becker & Anderson, 2019; Sol Hart et al., 2020; Iles et al., 2022].

Study limitations commonly referred by authors were small or demographically unrepresentative samples [Kortenkamp & Basten, 2015; Winter et al., 2015; Dunwoody & Kohl, 2017; Anderson & Becker, 2018; Becker & Anderson, 2019], inappropriate grouping by variables [Wang & Huang, 2021], or overly specific focuses [Kortenkamp & Basten, 2015; Roper et al., 2016; Anderson & Becker, 2018; Becker & Anderson, 2019]. Participants' low reactance or unfamiliarity with topics might skew responses [Lyons et al., 2019; Iles et al., 2022]. Environmental contexts, like the COVID-19 infodemic, could influence participant sensitivity and responsiveness [Iles et al., 2022]. Limitations also raised from single-topic studies [Winter et al., 2015; Iles et al., 2022], short stimuli [Dunwoody & Kohl, 2017; Becker & Anderson, 2019], and lack of long-term effect analysis [Iles et al., 2022]. Finally, one quantitative study measured polarization extent but not its nature [Sol Hart et al., 2020].

3.6 ▪ *Can polarized scientific digital messages be linked to specific authors, receivers, textual marks, or interest issues?*

The authorship of messages found in these studies was not always clear. One study distinguished authors' message between journalists and scientists to assess each group's credibility among laypeople [Kortenkamp & Basten, 2015], while another inferred journalistic authorship from the source of the analyzed messages (broadcast news) [Wang & Huang, 2021]. In addition, other authorships were deduced from representative sources, such as news articles from the New Zealand Climate Science Coalition websites [Roper et al., 2016], videos from The Onion and The Weather Channel [Anderson & Becker, 2018; Becker & Anderson, 2019], and a video from an environmental conference [Lyons et al., 2019]. In contrast, all papers contained information about the media vehicles where messages were made available, including digital channels of traditional news media [Kortenkamp & Basten, 2015; Dunwoody & Kohl, 2017; Anderson & Becker, 2018; Becker & Anderson, 2019; Sol Hart et al., 2020; Iles et al., 2022], blogs and websites [Winter et al., 2015; Roper et al., 2016], and social media [Lyons et al., 2019; Wang & Huang, 2021]. The authors of half of the studies (n = 5) created specific polarized messages exclusively for being applied in experimental research conditions [Kortenkamp & Basten, 2015; Winter et al., 2015; Dunwoody & Kohl, 2017; Wang & Huang, 2021; Iles et al., 2022].

The messages in randomized information intervention studies mainly targeted unspecified adults [Dunwoody & Kohl, 2017; Lyons et al., 2019; Wang & Huang, 2021; Iles et al., 2022], or specific adult groups including undergraduate students [Kortenkamp & Basten, 2015; Anderson & Becker, 2018; Becker & Anderson, 2019] and parents or caregivers of children and adolescents [Winter et al., 2015]. In two other papers [Roper et al., 2016; Sol Hart et al., 2020], the specific receptors of the messages were not identified, but they are presumed to be laypeople or news consumers based on the context of studies, using a website and traditional news media as vehicles of information.

One study demonstrated that scientists with one-sided views were seen as less biased and more credible than those with balanced views. Conversely, journalists with balanced views were deemed less biased. Despite scientists generally being viewed as more credible, those opposing the majority were seen as less trustworthy [Kortenkamp & Basten, 2015]. The impact of message-sidedness on scientists' credibility varied across studies, ranging from no effect [Wang & Huang, 2021] to a negative influence of conflict in evidence and between sources on public health perceptions [Iles et al., 2022].

The studies often reported that receptors agreed with the majority opinions [Kortenkamp & Basten, 2015] or expert-backed views [Dunwoody & Kohl, 2017]. Also, the engagement with two-sided messages was higher among those with advanced epistemological beliefs or related experiences [Winter et al., 2015; Wang & Huang, 2021]. Such messages fostered a balanced perspective [Winter et al., 2015] and did not negatively affect behavioral intentions [Iles et al., 2022]. However, sarcastic one-sided messages could reduce interest in topics like global warming [Anderson & Becker, 2018], while satirical messages could increase engagement [Becker & Anderson, 2019].

4 ▪ Discussion

These findings indicate that research on the characteristics of polarized scientific digital messages is relatively recent, limited in scope, and geographically constrained. Regarding this scenario, 4 out of 5 questions outlined in the protocol of this study were addressed fully or partially. The earliest identified study was published in 2015, with most studies concentrated in the United States. These studies predominantly focused on fields related to human health (such as medicine and psychology) and planetary health (including climate change, environmental risks, and GMOs). They mainly examined traditional news media, identifying authors as journalists or scientists, while recipients were often lay adults. Despite the scarcity of syntactic and lexical analysis, the research revealed a plethora of terms describing polarized and non-polarized messages. This variety of terms and some found concepts highlighted various aspects that researchers associated with polarization, such as controversy, topic dependency, skepticism, partisanship, and unilateralism. Characteristics of polarized messages were observed to include presentation from a single viewpoint, discrediting opposing views, emphasizing the minority and flaws of concurrent discourses, and using assertive statements, intensifiers, sarcasm, vague lexicons, and expert opinion support. Conversely, non-polarized messages tend to feature neutral and balanced arguments, use hedges and terms indicating uncertainty, include phrases that highlight the limitations of the statements, and present a diversity of opinions or points of view within the same message. Based on these results, however, the elucidation of distinct patterns of digital messages found in scientific papers, science communication articles, and specialized discourses was not possible because of the lack of comprehensive literature on the subject.

In general, leveraging consensus in science communication seems effective as it resonates with individuals lacking in-depth understanding or experience in the topic. While uncertainty drives scientific advancement, societies often influenced by cultural fears, crave certainty for comfort and reassurance [Wilson, 2000]. This dynamic can lead science and media to disseminate one-sided messages. However, simplifying and polarizing scientific information for the public might not be ideal, as it risks undermining critical thinking. In addition, treating consensus as an unchallengeable fact may foster group solidarity among its supporters while alienating skeptics, thereby intensifying issue polarization. This situation poses a challenge within the research community; the dominance of a hegemonic discourse may intimidate scientific progress by discouraging the questioning of established norms, in contradiction to the principle of falsifiability [Rekker, 2021], which is crucial for challenging and refining established theories.

The issue of polarization related to scientific topics seems underexplored. Studies on polarized scientific messages have typically focused on traditional media, with journalists as the primary sources of information. In this scenario, the production and publication of information are decentralized, allowing all users the potential to become communicators [Frewer et al., 2003]. This digital realm is typified by its open and asynchronous nature, fostering an environment where individuals can express their identities while maintaining privacy. The widespread access to information, combined with the intellectual pursuit of forming and expressing personal opinions, plays a pivotal role in shaping individuals' health values. This is guided by the principle of 'self-care', a fundamental human impulse to participate in one's own care, driven by the intrinsic need for self-preservation. [Foucault, 2005]. Consequently, there is a growing expectation for active engagement in healthcare, both directly and indirectly, reflecting the profound influence of Internet access on individual

health participation and the broader healthcare discourse. This shift could result in a scenario where political ideologies and financial interests increasingly drive the polarization of science communication in digital media. This is evident in the emergence of violence-related concepts within the discourse, such as segregation and confrontation, which are also linked to hate speech. Remarkably, most studies referenced in this review were published subsequent to the intensification of the 'fake news' discourse, which gained prominence during the 2016 U.S. presidential campaign led by then-candidate Donald Trump [Bovet & Makse, 2019]. In this sense, it is imperative to conduct further research to investigate how decentralized communication affects the quality and polarization of scientific messages on the Internet.

This review presents some limitations. First, the strict inclusion of peer-reviewed scientific papers, although beneficial for limiting uncertainties about the evidence's strength and practical significance of studies, may omit important insights from gray literature and preprints. Second, these findings also considered artificially constructed messages for research approaches, which may not accurately represent spontaneous discourse in real-life contexts of communication. Third, the analysis of messages not initially designed for digital dissemination, but later published on online media channels, might impact on the authenticity of the characteristics described in this review. Lastly, the search strategy's confinement to certain databases may have introduced selection bias, overly emphasizing the connection of the studies to human and planetary health while neglecting other fields like mathematics and social sciences.

In summary, this scoping review elucidated the characteristics and concepts of polarized scientific digital messages, as validated and employed by researchers to craft content for studying the impact of polarization on consumer perceptions. The identified characteristics not only inform the development of future infodemiology studies focused on detecting polarization in scientific discourse on the internet but also underscore the necessity of researching the public impacts of both polarized and balanced scientific communications within specific contexts. Additionally, it is crucial to investigate how political ideologies and financial interests may contribute to the polarization of science communication in digital media.

5 ▪ Declarations

5.1 ▪ *Declaration of conflicting interests*

The authors declare that there is no conflict of interests.

5.2 ▪ *Funding*

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