Effective ways to combat online medical and scientific misinformation: A hermeneutic narrative review and analysis.

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Abstract

Scientific and medical misinformation is proliferating and undermining public health efforts. To promote changes in behavior more in line with scientific consensus it is urgent that we understand the most effective ways to combat online misinformation. In this review, we undertook a hermeneutic narrative framework to iteratively examine the evidence for different ways to combat medical and scientific misinformation online. After reviewing common descriptions and definitions along the spectrum of misinformation, we examine the mostly regulatory and technological efforts to constrain the supply/distribution of misinformation. Next, we describe research focused on the information consumer, including inoculation, warnings and efforts to promote critical thinking and media literacy. Next, in examining the vast literature on debunking, refutations and rebuttals, we note the myriad factors that affect the persistence or displacement of information after a corrective message, including the topic, framing, source, audience and overall context in which the message is received. We note that each of these methods to combat misinformation online has had success in particular contexts and support efforts suggesting multipronged solutions. Finally, we discuss how the complex nature of the misinformation problem poses challenges to reductionist empirical studies. We suggest some alternative frameworks drawing from complex problems in medicine and public health research.

Introduction: The Expected “Infodemic”

Online misinformation about the COVID-19 pandemic has become so prevalent that the World Health Organization labelled it an “infodemic” - an over-abundance of information – some accurate and some not – that makes it hard for people to find trustworthy sources and reliable guidance when they need it (Zarocostas, 2020). Conspiracy theories proliferate, claiming that the Chinese government created the virus as a bioweapon; the severity of the coronavirus infection is being exaggerated to damage the Trump presidency; and the belief that taking vitamin C and other “immune boosters” can prevent infection or limit its severity (Stecula et al., 2020). Misinformation is not benign, as one paper found that counties with increased exposure to a Fox News host that dismissed coronavirus risks were associated with more coronavirus cases and deaths compared to exposure to a Fox host who took the issue more seriously (Bursztyn et al., 2020).

Misinformation posed a problem to public health long before the Coronavirus pandemic (Swire-Thompson & Lazer, 2019). What can be done about it? In this review, we examine the evidence for different ways to combat medical and scientific misinformation online. Misinformation can have real impacts on people’s behavior, either those who propagate it, or those who act by not vaccinating their child, for example. It is crucial to understand the most effective ways to combat misinformation to promote changes in health behavior more in line with scientific consensus.

This raises a number of complex issues, like who people trust, where people seek health information, what methods are most effective at persuasion, and how the online information environment has shaped these issues. It also raises questions about what researchers mean by “effective” - are measures effective if they change someone’s mind? Or should it be necessary to demonstrate behavior change?

After defining a number of contentious terms, this review will take a broad view to answering these questions, drawing from diverse literatures to better inform the debate about how to combat misinformation online. Ultimately, we recommend considering more holistic approaches with “bundles” of evidence-based communication techniques coupled with psychology-informed adjustments to automated systems, though recognizing there are still a number of areas where more empirical research and methodological improvement is needed.

Time is of the essence. It is important to maximize the impact of campaigns to combat misinformation as soon as possible as it is often more difficult to change people’s minds than to sway them toward a particular view from the start. Propagators of misinformation have had a head start and there is much catching up to do.

Definitions: Information disorder and misperceptions

There are myriad terms to describe the types of information disorder that have been observed online, each with their own definition (see Figure 1). Each type can be further distinguished by the intent and mode of spread. Misinformation is information that is false or where the context is misleading and where users share it without an intent to cause harm (see Figure 2). Disinformation, on the other hand, is false information where a user either creates or shares it with an intent to harm (Wardle & Derakhshan, 2017). Misinformation or disinformation can lead users to have misperceptions, which are individual beliefs about factual matters unsupported by clear evidence and expert opinion (Nyhan & Reifler, 2010).

Figure 1: Seven types of mis- and disinformation along a spectrum from misinformation on the left to disinformation on the right (Koulolias et al., 2018).

As types of dis- and misinformation have proliferated, so have definitions, starting with Harry Frankfurt's seminal 1986 book *Bullshit* (Frankfurt, 2009). Since then, terms like trolling and "fake news" have become common in online communities. For a more complete explication of the various types of dis- and misinformation found online, see Spies (Spies, 2019b).

Figure 2:

The spectrum of information disorder (Goldzweig et al., 2018; Wardle & Derakhshan, 2017)

Similar to Wang and colleagues, we use the term misinformation throughout this review when referring to all types of information disorder because user intent is impossible to obtain. This gives users the benefit of the doubt that they are not spreading it with an intent to harm. Additionally, while the term “fake news” is common, there is no widely accepted definition so it will not be used in this review (Wang et al., 2019).

Methods

We approached this review through an iterative hermeneutic approach that began with multidisciplinary literature searching, then reference combing from those initial sources, which led to further iterative cycles of searching and more references. Such a strategy was employed in the hope that it would allow a deeper understanding of the connections between different literatures than mapping the literature with a scoping review would allow. With notable exceptions specifically on coronavirus, research published up to January 2020 was included in this review.

The body of work from known researchers prominent in various fields were also searched, with combing of references and assessments of other work by co-authors. Efforts were made to locate think-tank and government reports as well as related Masters’ or PhD theses. Throughout these iterative searches the studies were classified and mapped, critically assessed and, ultimately, an argument developed based on the studies reviewed. These cycles were continued until topic saturation was reached (Boell & Cecez-Kecmanovic, 2014). It is important to note that, following Greenhalgh and colleagues, we chose this review strategy with the goal to deepen understanding as well as provide context and critique (Greenhalgh et al., 2018).

The main question examined was: What are effective ways to combat medical and scientific misinformation online? This included both research directly examining online forums as well as research where the recruitment and experiment took place online. For some relevant topics, it includes offline efforts to make people more resistant to online misinformation. Less emphasis was placed on simulated modeling studies of rumor contagion (for example (Zeng & Zhu, 2019) and some work by Centola), as these studies still need to prove their real-world applicability.

Why such a wide scope?

Misinformation often spreads more quickly than any attempts to correct it (A. Marwick & Lewis, 2017). Researchers recognize that a wide array of individual, group, and societal factors contributing to misinformation's spread are influenced by regulatory and technological structures (Scheufele & Krause, 2019; Southwell et al., 2018). Indeed, in a recent National Academies of Sciences report, experts recommended taking a holistic systems approach to research in science communication, starting with comprehensive reviews "related to each of the elements that research indicates could be important to communicating in a particular context to achieve specific goals and how these elements may interrelate as well as identification of specific gaps in knowledge" (National Academies of Sciences, Engineering, and Medicine et al., 2017), pg 85).

Yet even since that report was published, researchers' empirical scope for analyzing solutions has, so far, generally been narrow. Studies are often defined by finding solutions based on the type of misinformation being propagated, whether scientific, medical or political information, like climate change or anti-vaccine sentiment. However, this is an etic perspective. The climate change crisis should remind us that the distinction between science and other fields - politics, business, religion - can disappear in the eyes of the public. Medical topics can carry similar political valence, as demonstrated by the Ohio draft bill requiring physicians to "reimplant" ectopic pregnancies into the uterus - a procedure physicians do not think is feasible (Kennedy, 2020). Therefore, while our goals are to improve communication about science and medicine, we believe it is crucial to have an emic view of misinformation to combat it effectively, i.e. classifying it according to how those receiving the information would define it. To avoid a priori and possibly inaccurate divisions between scientific or other types of misinformation, we must examine solutions to misinformation writ large.

Similarly, this review is agnostic in terms of platform. Limiting the scope of the review to the particular environments - either online or offline, or even particular forums online like social media or fact-checking websites - seems artificial when few live exclusively online or visit only one website. The propagation of misinformation is a complex social and psychological phenomenon resulting from iterative engagement with multiple information sources of which someone's online social media presence and

behavior is only one part. As Benkler and colleagues' note on the 2016 election, online propaganda efforts were prominent, but their effect was dwarfed by traditional media, especially Fox News (Benkler et al., 2018). As a result, fully understanding this phenomenon both in terms of its origins and potential solutions, requires us to look beyond only one variable - online, platform, etc. - but instead attempt to view evidence from multiple and different contexts with an eye to crafting multidimensional solutions.

Techniques used to combat misinformation online and their effectiveness

The online information environment is a complex network of discussion forums (Reddit, 4chan), multimedia websites (traditional news sources, YouTube), social media (Facebook, Twitter) and peer-to-peer sharing (WhatsApp), to name a few examples. (For more on the context of misinformation propagation online via filter bubbles and echo chambers, see (Spies, 2019a)). The review below will examine various efforts to prevent, minimize and mitigate the spread, amplification and effect of misinformation on these online platforms. However, misinformation propagating online does not do so in a vacuum. Significant steps are being taken offline, often specifically designed to affect the online information ecosystem. Notably, such initiatives generally fall under three main types of efforts that will structure this review: first, efforts to constrain the supply or distribution of misinformation, then efforts at the site of production to stymie the influence or otherwise prevent amplification of misinformation, and finally, interventions aimed at the information consumer, the latter of which is where most empirical research has focused. This review will draw on offline literature as needed to better inform the context of research focused on online environments.

Constraining the supply/distribution of misinformation

Governments recognize the threat of misinformation on democracy and national security, with a number proposing legislation to constrain the supply and/or distribution of misinformation. Over 50 governments have some type of misinformation regulation in the works (Funke & Flamini, 2019).

Much of the draft legislation holds the technology companies themselves responsible for misinformation propagated by third parties on their site (Haciyakupoglu et al., 2018), though there are other efforts to police information. The European Union, for example, has created an office for Disinformation Review that includes hundreds of experts, journalists, officials, NGOs and think tanks in over 30 European countries who report potential misinformation to the EU and the public (Alemanno, 2018).

Top-down regulation in Germany, France, Italy and Malaysia has successfully pressured social media companies to adjust their platform algorithms and apply additional content moderation. For example, Germany's law requires social media companies to remove misinformation within 24 hours or

face fines (Koulolias et al., 2018). The UK and Czech Republic chose to have a task-force issue non-binding recommendations prior to pursuing legislation (Goldzweig et al., 2018; Rusu & Herman, 2019).

Researchers recognize that regulating social media platforms without recognizing the various policies and societal shifts that have led to the fragmentation of the media landscape is likely to lead to less effective legislation (Benkler et al., 2018; Goldzweig et al., 2018). Still, these initiatives are difficult to evaluate. Similar to technological/platform-based solutions discussed in the next section, these changes are not studied rigorously (or at least such studies are not made public), making it difficult to objectively evaluate how these changes are affecting the spread of misinformation.

In addition, there are concerns about potential unintended consequences. Two major concerns often arise in these debates: whether regulation will make platforms or governments the arbiters of truth and whether such legislation will curb free speech in addition to misinformation (Funke & Flamini, 2019; Goldzweig et al., 2018). Singapore, for example, is coming under fire for using its law as a way to suppress political dissent (The Economist, 2020).

Interventions at the site of production/dissemination

Social media platforms, most of which are publicly traded companies, face tension in maximizing shareholder value and revenue generation through user-tailored advertisements while also recognizing that people use their platforms as media and communication tools (Karr et al., 2019). YouTube in particular has come under fire for its algorithms that, some argue, radicalize viewers through auto-play videos that become increasingly conspiratorial (A. Marwick & Lewis, 2017; Ribeiro et al., 2019). After the 2016 election, where social media platforms were blamed for the spread of misinformation via bots and Russian disinformation campaigns (Benkler et al., 2018), platforms are under pressure to minimize the influence and prevent the amplification of misinformation, both by governments and regulations as noted above, and by users.

Social media platforms allow for rapid sharing of information, algorithmically programmed to funnel information of interest to a user toward their feeds. In these environments, repetition has been shown to lead people to have greater faith in misinformation that then becomes more difficult to debunk (Gordon Pennycook et al., 2018). Computational social science researchers have suggested that algorithmic design to limit such exposure should have a large role in combating misinformation (Ciampaglia, 2018). Ozturk and colleagues also note that a number of other technical design ideas could be useful to minimize the spread of disinformation on Twitter (Ozturk et al., 2015). Particularly concerning is the fact that novelty is a driver in the spread of misinformation on platforms like Twitter, making it difficult for less novel corrective information to respond quickly enough (Vosoughi et al., 2018).

Platforms have responded in a number of ways, notably by setting policies for advertisements that require more transparency and veracity from ad purchasers, fine tuning news feed and search query algorithms to promote real over misinformation, minimizing financial incentives for advertisers and promoters to spread misinformation, closing automated accounts, issuing automated corrections, rebuttals or flagging posts with warning labels and related stories, employing manual monitoring and curation and banning information from non-specialized sources (see Figure 3; (Goldzweig et al., 2018; Wardle, 2017; Wardle & Derakhshan, 2017)).

Figure 3: Some actions taken to combat misinformation by Facebook, YouTube and Twitter (Goldzweig et al., 2018).

Unfortunately, online platforms are not always transparent about what changes they make or when they are made. As a result, there is no (public) way to test the effectiveness of their interventions. Still, researchers have been able to test some methods in simulated environments mimicking a platform. In one example, Facebook has experimented with different types of tagging or flagging of stories. Though “disputed” tags seem to modestly reduce belief in false news head-lines, they may fail to counteract exposure effects over time (Pennycook et al. 2017). Tagging a Facebook headline with “disputed” or “rated false” reduces perceived accuracy regardless of prior political views, with the latter being more effective, though both with modest effect sizes (Clayton et al., 2019). Still, such explicit warnings mitigate but do not eliminate the effect of misinforming posts (Ecker et al., 2010).

Flagging a Facebook post with different tags that were either fact-checking, peer-generated or identified by the publisher as humor with humor being the only approach has been found effective at reducing beliefs and intentions to share and were particularly effective among individuals ideologically predisposed to believe the misinformation (Garrett & Poulsen, 2019). “Disputed” tags did increase viewers’ perception that false stories were indeed false, leading to reduced intent to share them (Gordon Pennycook et al., 2018), with tags stating “Disputed by Snopes.com and PolitiFact” having a modest effect size (Mena, 2019). Subsequent research found a “rated false” tag to be more effective (Clayton et al., 2019). Similar peer truthfulness ratings in addition to retweet counts on Twitter can reduce the spread of health misinformation (Li & Sakamoto, 2015). A study of graduate students at Haifa University in Israel varied corrective information by the Ministry of Health as either factual rebuttals of a fictitious mother’s anti-vaccine Facebook post, or a more empathic rebuttal specifically addressing the parent’s concerns, finding the latter more effective (Gesser-Edelsburg et al., 2018). Others have suggested “swamping fake news with the truth” via Facebook’s “related articles” feature (Alemanno, 2018), and one small study suggests that this method is effective at reducing misperceptions (Bode & Vraga, 2015).

It is worth noting the presence of a publication bias, with more studies published using publicly available social media feed data. As Benkler and colleagues point out, while there were dis- and misinformation campaigns on Facebook and Twitter during the 2016 election, their effect was likely smaller than the news media has projected (Benkler et al., 2018). Similarly, in the peer-reviewed literature there is a large number of papers about Facebook and Twitter, the latter because the data are relatively easy for researchers to access. As a result, researchers tend to overlook other social media networks where data are harder to access and about which there may be less concern about spreading misinformation. However, some platforms may already be employing strategies to minimize the amplification or spread of misinformation that are going unnoticed and little discussed in the peer-reviewed literature.

One case in particular is Pinterest, which “has established a quietly radical approach to search: deliberately engineering results to avoid harm, and holding itself accountable for unintended consequences.” The platform noticed people were searching for vaccine-related information, but Pinterest restricted any medical information to that posted by the National Institutes of Health or the Centers for Disease Control. Pinterest CEO Ben Silberman says, “If you don’t take some responsibility for what people see, you’re at some level responsible for the downstream consequences of that” (Nadi, 2020).

Interventions at the site of the information consumer

Researchers have examined a number of interventions targeting the individual consumers of information in efforts to mitigate the effect of misinformation. These generally fall along two lines: those actions taken in advance of consumers seeing information so as to render them more resistant to any

potential effects of the misinformation (pre-emptive actions, or “pre-bunking” (Cook, 2016)), which I will call “resistance,” and those actions taken after a consumer has been exposed to misinformation, to mitigate or reverse any potential effects such as correction, rebuttals and refutations.

A full review of the psychological and cognitive predispositions that lead to bias and belief in misinformation is beyond the scope of this review; see the following: (Michael V. Bronstein et al., 2019; Garrett, 2017; Jamieson et al., 2017; Soon & Goh, 2018). However, beyond belief in misinformation itself, why people share it is also challenging to ascertain. Researchers have proposed different reasons like distraction (Gordon Pennycook et al., 2019) but generally agree that the deficit model - that people will not share misinformation if they know it is not true - is insufficient. Some empirical research has shown that people who engage less in critical or analytical thinking or rely more on emotion for decision-making are more susceptible to misleading information (M. V. Bronstein et al., 2019; Martel et al., 2019), and, conversely, those with more open-minded thinking about evidence are more open to revising their beliefs based on evidence (G. Pennycook et al., n.d.). Therefore, researchers have suggested that while motivated reasoning plays a role in believing misinformation, a lack of reasoning is likely more to blame (Gordon Pennycook & Rand, 2019c).

But the decision to share news on social media is a complicated function of at least three key interacting factors: actors who have distinct identities, social positioning, skills and rationale; messages that are strategically structured to boost the agendas of particular stakeholders; and platforms with particular functionalities that shape both the personal characteristics of the actors and the meaning of the messages (A. E. Marwick, 2018). This suggests the decision to share information is a complex social process that cannot be divorced from key contextual factors.

Therefore, any interventions aimed at the information consumer must consider both the environment and motivations of the user. On Twitter, for example, users often try various techniques to debunk rumors, from providing evidence for refutation, expressing disbelief, employing sarcasm, or suggesting actions to refute the rumor (Goh et al., 2017). At least some types of people, like journalists, are more likely to correct misinformation on Twitter (Arif et al., 2017; Starbird et al., 2018), suggesting that some behaviors aiming to stop the amplification and influence of misinformation can be promoted.

Indeed, a number of pre-emptive strategies to ensure information consumers are resistant to the manipulative effects of misinformation have been examined, with efforts often linking the concepts of inoculation, critical thinking and media literacy (Vraga & Bode, 2017a). The lines between these various techniques are not bright or strictly defined. Therefore, we separate inoculation from information literacy and note that each of these ideas draws heavily on empirical literature that is not well integrated into research looking at how to best combat misinformation online. Future research should better correlate

these offline initiatives to assess their impact on online behavior across key variables that have already been identified in these literatures like age or cognitive evaluation style.

Attitudinal inoculation and warnings

With roots in the early 1960s (W. J. McGuire & Papageorgis, 1961; Papageorgis & McGuire, 1961), inoculation theory conceptualized misinformation spreading like a viral contagion (Lynch, 2008), leading researchers to the metaphorical potential of attitudinal inoculation, or pre-emptively highlighting false claims and refuting potential counterarguments (S. Van der Linden et al., 2017). Carrying the metaphor further, an immune consumer of misinformation would then more quickly recognize and cognitively respond to a misleading message, rendering it harmless.

An inoculation message should have two parts, a threat then a refutational pre-emption. The threat should create anxiety about the future stability of the message receiver's current beliefs. Then, the refutational preemption should include as many identified counterarguments that a message receiver is likely to encounter, within realistic constraints of someone's likely attention span (Pfau, 1995).

Inoculation is an attractive strategy because research shows that it is generally easier to prevent people from believing in false information in the first place than convince committed acolytes that information they believe is indeed false (much of the work by Dan Kahan's Cultural Cognition project speaks to this phenomenon, for example (Kahan, 2012, 2017)). While inoculation theory research among psychologists that study persuasion is not new (see (W. J. McGuire & Papageorgis, 1961; Papageorgis & McGuire, 1961) and has already shown promising results (Banas & Rains, 2010), empirical research testing inoculation specifically in the scientific misinformation context, however, is still relatively new, outside of a rare example for health (Pfau, 1995). van der Linden and colleagues found inoculation to be effective in pre-emptively countering messages that undermined the idea of a scientific consensus for anthropomorphic climate change (S. Van der Linden et al., 2017). When undergraduate and graduate student participants were exposed to criticisms of rumors before the rumors themselves, they were less likely to share the misinformation via Twitter than when they were exposed to the rumors first (Y. Tanaka et al., 2013). Other empirical examples come from a game that requires participants to emulate tactics used by propagators of "fake news." A pilot and large follow-up study both showed that, after playing the game, participants rated the reliability of tweets and headlines significantly lower when they used common online misinformation strategies. Interestingly, these inoculation effects appear to be robust regardless of education, age, political orientation and cognitive style.

Inoculation is not without potential risks, however. As one study by Miller and colleagues noted, inoculation messages can generate psychological reactance, "an unpleasant motivational arousal that emerges when people experience a threat to or loss of their free behaviors" (Steindl et al., 2015), eliciting

negative emotions like anger toward the message and/or the source (Dillard & Shen, 2005; Rains, 2013). Modulating inoculation messages with messages that precipitate psychological resistance can therefore reinforce the inoculation effect (Miller et al., 2013), or the negative emotions can lead to a “boomerang” effect where recipients are then more prone to seek out the behavior or freedom because it is perceived to be at risk (Byrne & Hart, 2009). More research is needed to better understand the messages and conditions in which inoculation is most effective.

Researchers have also studied “warnings” using principles similar to inoculation. Chen and colleagues used a simulated Facebook environment to examine participant’s sharing of health-related misinformation, finding that those who were pre-warned about the potential harmful effects of spreading misinformation were less likely to share or like misinforming posts (Chen et al., 2015), see also Chen’s PhD dissertation (Chen, 2018). Ecker and colleagues observed that specific warnings about the continued influence effect - i.e. the possibility that misconceptions may persist even after effective debunking - reduced that effect and were more effective than generalized warnings about being vigilant about misinformation, though, worryingly, neither intervention eliminated the effect (Ecker et al., 2010). There is some suggestion that warnings are more effective than corrections when trying to counter misconceptions about science driven by motivated reasoning (Bolsen & Druckman, 2015). Warnings do come with risks, however, as they can create an “implied truth effect,” where stories that are not tagged are considered more truthful regardless of whether the information contained in them is true or false (G. Pennycook et al., 2017).

The overall success of inoculation and warnings as techniques of persuasion has led researchers to question various aspects of their construction. For example, some researchers have advocated for the inoculating information to specifically demonstrate the fallacious reasoning of misleading claims rather than simply factual evidence (Cook et al., 2018). Others wonder whether it could be used not just as a pre-exposure preventive strategy but also post-exposure, i.e. inoculation for both prophylaxis and treatment (Compton, 2019). No empirical studies yet exist to test this hypothesis.

Critical thinking and information literacy

Education - and especially science education - scholars are prolific in examining how to encourage critical thinking and media literacy to help learners discern fact from fiction. However, evaluating literacy interventions across topics, ages and other factors is challenging, with experts noting that such assessment is context dependent, costly, and time consuming (Schilder et al., 2016), leading to results that are notably mixed (Bergsma & Carney, 2008; Swire-Thompson & Lazer, 2019). A full review of these rich literatures is beyond the scope of this paper, but some aspects of it are particularly revealing when thinking about combatting scientific misinformation online.

For example, through multi-session programs with students, (Muis & Duffy, 2013) and (McGrew, 2020) demonstrate both the time and effort required to instill in learners the value of critical thinking such that they are imparted with the skills to use it independently. Still, perhaps because the goal for education researchers is developing these skills in general and assuming it extends to online behavior, there is a surprising relative paucity of studies examining it specifically in the online context. Similarly, other scholars have advocated for increased instruction in media literacy skills, particularly in the online context (Lewandowsky et al., 2017; Vraga & Bode, 2017a), despite the fact there may be no added benefit to targeting specific types of literacy beyond basic information literacy (Jones-Jang et al., 2019)). As one study of three different cases of online peer-to-peer health forums showed, misinformation can spread quickly in an echo-chamber environment, and the need for online media literacy is acute (Peterson et al., 2019).

For the few examples that exist, science teachers advocate teaching critical thinking, asking questions about the purpose, author, timeliness, personal relevance, and sources of an article to better prepare learners to be able to process and reject potential misinformation (Zucker, 2019), which are all aspects of information and media literacy, or “the ability to access, analyze, evaluate, and communicate messages in a variety of forms” (Potter, 2018). However, it is clear that reasoning errors contribute to the spread of misinformation messages about climate change (Cook et al., 2018), and researchers posit that critical or analytical thinking can help people overcome cognitive biases, such as partisan bias (Ross et al., 2019).

But the origins of those reasoning errors in the online context remains understudied, as do specific solutions. One study of students in Cyprus showed that participants used the epistemic standard of scientific research (e.g., asking themselves questions like “How do I know this?” or “Do I believe this?”) to evaluate online information more if they were adults, had an evaluativist epistemic perspective (critically evaluating information for its veracity), and high prior knowledge, though this effect was domain specific, with participants using these critical thinking skills more for history than science. Unsurprisingly, those with an absolutist perspective, i.e. relying on authority for knowledge, seeking facts as an objective, external entity, which is knowable with certainty were less likely to take evaluativist perspectives (Iordanou et al., 2019). This research corresponds to prior epistemic cognition research outside of the online context showing variation based on age (adolescent vs adult), subject matter (science vs non-science), and epistemic perspective (i.e., absolutists, multiplists, evaluativists). See, for example, (Greene et al., 2016; Sandoval et al., 2016).

In another online experiment people were exposed to either nothing, simple guidelines for evaluating fake news online, or “enhanced” guidelines where they were asked to rank those same guidelines. The theory being that people would be primed into critical thinking, and, while the authors do

not cite it, this could be considered an inoculation technique. Participants were then exposed to either true or misinformation about climate change, with the study finding that participants were less likely to trust, like or share misleading information on Facebook, mostly mediated through their ability to identify untrustworthy sources (Lutzke et al., 2019).

Media literacy advocates suggest that improved cognitive skills will equip consumers with a better ability to distinguish between facts and misinformation (Flynn et al., 2017). Evidence supports their claim as a meta analysis showed that as people are more media savvy they exhibit more skepticism and realistic expectations about media messages (Jeong et al., 2012), and in a health context, pre-emptive messages or education can modulate how people respond after being exposed to messages about sexual behaviors or alcohol consumption (Austin et al., 2015), and multiple news literacy messages on Twitter mitigated the effect of misinformation about the flu vaccine and genetically modified foods, as measured by tweet credibility and self-reported measures of media literacy (Tully et al., 2019).

Others have suggested deliberation to promote critical engagement that can help people sort fact from fiction. In an online environment using subjects recruited via Mechanical Turk, (Bago et al., 2019) indeed found that, at least in studying “fake news,” the research subjects developed more accurate beliefs via deliberation without exacerbating partisan bias.

Notably, some have questioned the value of media literacy, asking if it has backfired by making consumers skeptical of all media, regardless of source reliability (Boyd, 2017, 2018). While such arguments raise important questions about the nature of media literacy and the skills and values with which it seeks to impart, such critiques seem to suggest that it is not the value of media literacy, per se, itself that is in question as much as how media literacy should be integrated with other key values like epistemic humility and reflections on bias. Much more integrative work still needs to be done on this topic, both in coordinating and evaluating the various streams of media literacy research (Bulger & Davison, 2018).

Debunking, Refutation, Rebuttals and Corrective Information

Decades of research across many disciplines have revealed both the prevalence of misconceptions and also how persistent such misconceptions can be despite corrective information. As such, research into attempted correctives is vast, disparate, and, unfortunately, does not lend itself to broad coherent conclusions (Jerit & Zhao, n.d.). This has led to research examining what refutation strategies are most effective to counter misinformation and correct misperceptions by acknowledging a misconception, directly refuting it and (at times) providing an explanation (Sinatra & Broughton, 2011). In education literature, evidence supports the use of refutation texts looking at “revision” in epistemic cognition with much of it supporting the practice (Braasch et al., 2013; Cordova et al., 2014; Danielson et al., 2016;

Kendeou et al., 2016; Mason et al., 2017). It is worth noting that there is a debate in the education literature about whether these refutations lead to knowledge revision rather than broader conceptual change (Thacker et al., n.d.).

Overall, refutation has been shown to be at least modestly successful at modulating beliefs. One meta-analysis of refutation messages across different subject matters found that corrections were more successful for health, marketing and least successful in the political context (Walter & Murphy, 2018). Another found corrective messages most successful under particular circumstances, notably when they match the worldview of the message recipient and were delivered by the source of the misinformation itself. But corrections were less effective when the source of the misinformation was trusted, if the misinformation had already been echoed prior to being corrected, or too much time passed between the misinformation and the correction (Walter & Tukachinsky, 2020). A third meta-analysis found debunking worked best under certain circumstances: message receivers did not already have rationalizations for supporting the misinformation and the debunking message was detailed. Based on these results, the authors recommended finding ways to minimize arguments that aligned with prevalent misinformation, promoting critical thinking and skepticism and correcting misinformation with new detailed information (Chan et al., 2017).

Still, refutation may have unintended effects where misinformation may persist even after correction, called the “continued influence effect” (see (Ecker et al., 2011; Lewandowsky et al., 2012), or it may lead to a “backfire effect” in which the receiver of information rejects the refutation message and hardens their original beliefs (Nyhan et al., 2013; Nyhan & Reifler, 2010), possibly based on certain individual psycho-emotional factors (Trevors et al., 2016). Even correctives that in some populations are shown to debunk falsehoods in some studies have been shown to reinforce the persistence of misinformation in others (Chan et al., 2017).

The significant existing literature on refutation and knowledge revision has explored numerous factors that affect the efficacy of a refutation text such as source, message, recipient and context (L. Shen & Bigsby, 2012). These include refutation text design features such as using graphics or other visuals, message framing (declarative/factual vs emotive, loss or gain framing, visual, appeals to fear), anecdote/narrative vs elaboration (Braasch et al., 2013; Danielson et al., 2016; Mason et al., 2017; Sangalang et al., 2019).

Indeed, message framing has long been studied elsewhere in public health literature (Guenther et al., 2020; D. J. O’Keefe & Jensen, 2009; D. J. O’Keefe & Nan, 2012; A. J. Rothman et al., 2006; A. J. Rothman & Salovey, 1997; Alexander J. Rothman et al., 1993). Per one recent systematic review of framing in health literature, studies focused on cancer, obesity, nutrition, or vaccines, relied on

quantitative analysis, and focused on gain versus loss framing, leaving gaps for other types of framing such as visual or competitive frames (Guenther et al., 2020).

The impact of refutation texts is also modulated by receiver characteristics such as reading comprehension, personality or emotion (Braasch et al., 2013; Cordova et al., 2014; Hirsh et al., 2012; Lombardi et al., 2016; Gordon Pennycook & Rand, 2019b). The message source, such as a peer or a trusted authority, also impacts its efficacy, and a number of studies have shown the public continues to have relatively high trust in scientific and medical professionals (Swire-Thompson & Lazer, 2019).

Additionally, most online research only captures a snapshot in time, rarely following study populations to determine the endurance of any persuasion or refutation effect. Nor does the literature capture how message receivers respond over time to messages of similar characteristics - do they become more likely to respond, or more inured to the message in a form of tachyphylaxis?

Topic

Some researchers have varied the type of information subject to misinformation and rebuttal, including, for example, science, health, and political misinformation (Vraga et al., 2019). Another group examined different, relatively uncontroversial scientific topics including deep brain stimulation, hypnotherapy and oceanic plastic pollution finding that refutation texts noting the tentativeness of research were effective at changing opinions and, in one case, affecting behavior (Flemming et al., 2019). For more controversial misinformation, however, such as whether genetically modified organisms cause illness or the false link between vaccines and autism, researchers have found refutation texts more effective with the former than with the latter (Bode & Vraga, 2015). Similarly, misconceptions on gun control and climate change were more resistant to revision than those related to HPV vaccination (Vraga et al., 2019).

While researchers do observe differential effects based on topic, with misconceptions about vaccines perhaps more resistant to correction than others, a large challenge to this aspect of the literature is that researchers often define these categories. As noted above, researchers may apply these definitions without recognizing the etic vs emic differences in how the issues may be viewed by the participants of their study. This leaves a gap in the online literature. Studies examining beliefs offline have demonstrated phenomena like “identity based cognition” - the idea that someone’s beliefs are less a marker of facts than a marker of particular political or religious identities - or carry a high degree of political valence, like issues of gun control or abortion that make viewpoints and behavior difficult to change through short term experimental design.

Message characteristics

Growing literature suggesting that message characteristics like argument strength or framing, for example, with humor, entertainment or gain/loss perspectives, are an important factor in persuasive health messaging (see, for example, (Cappella et al., 2015; Lister et al., 2015; Pența & Băban, 2018; Schumacher, 2017). Framing also seems important in online message persuasion, particularly with refutation messages. For example, logic and humor-based messages were effective for HPV vaccination, though not effective for correcting misperceptions about gun control or climate change (Vraga et al., 2019). While informativeness, credible sources, and persuasive arguments were important, the sequence at which participants were exposed also affected whether participants were more accepting of a rebuttal (Anjan Pal et al., 2020).

Beyond framing, researchers have examined messages with different potential to elicit emotional effects in message receivers. One study using an online survey examined common misconceptions about physics, finding that even an implied refutation through a warning was as effective at knowledge revision as a direct refutation (Weingartner & Masnick, 2019). Another example is comparing simple factually declarative messages versus more elaborative refutations. Here the data are mixed as in one case factual elaboration was found to be more effective (van der Meer & Jin, 2019), yet in another, single messages from authoritative sources can help change opinions about misinformation (Vraga & Bode, 2017b). Similarly, in his PhD dissertation, Kim used Twitter to vary argument strength (as determined through a pilot study), participants' prior beliefs/attitude, and source expertise. He found that if a trusted source like the CDC made a strong argument, or a weak argument from a non-expert, then people became more willing to vaccinate. But a non-expert making a strong argument seemed to backfire (J. W. Kim, 2019).

Narrative communication styles have also been well studied in health communications in offline contexts (Dahlstrom, 2012; Hinyard & Kreuter, 2007), with scholars suggesting it is likely to be important in online contexts (Cappella et al., 2015; Lewandowsky et al., 2012). One study using an online survey about smoking misperceptions and narrative rebuttals to misinformation about smoking found simple and emotional narratives both effective rebuttal strategies. Given literature offline, however, it will be important to consider the potential for backfire effects. One Canadian focus group study looking at emotive messages found them effective for some people, but others found them manipulative (Paradis, 2018). Another small study of Japanese adults found a similar phenomenon when subjective counter messages strengthened false beliefs (Yuko Tanaka & Hirayama, 2019).

Importantly, if the framing of the refutation message appears to have an impact on how it is received, the framing of the misinformation is also likely to be important. Lee tested this by using a Mechanical Turk simulation to see the effect of either simple or narrative types of corrective information on fear-based and non-fear based misinformation, finding that simple corrective information was effective

for non-fear based misinformation but could backfire in the face of fear-arousing misinformation (Lee, 2019).

There is much more work needed in this space, for example, drawing from offline literature looking at augmenting refutation messages with analogies and graphics (Danielson et al., 2016; Mason et al., 2017).

Source: peer vs authority vs algorithm

A number of studies have shown that source credibility is an important factor in refuting misinformation online and on social media (Anjan Pal et al., 2019). Most studies examine users' response to information from a peer or authority of some type. Vraga and Bode found that peer corrections about Zika on Facebook and Twitter required a more authoritative source to be effective (Vraga & Bode, 2018), and in a simulated Facebook environment, algorithmic and social corrections were equally effective in combating misperceptions about Zika, regardless of the participant's tendency toward conspiracy beliefs (Bode & Vraga, 2018). This led the authors to recommend the encouragement of peer corrections on social media, with health authorities seeking to provide appropriate sources to augment their refutations. Indeed, the same authors demonstrated that even single messages from authoritative sources can help change opinions about misinformation in an online survey (Vraga & Bode, 2017b). Kim found that intentions to vaccinate increased when anti-vaccine messages on Twitter were countered with both strong arguments and authoritative sources like the CDC (J. W. Kim, 2019). Others have shown this effect beyond health information, using an online experiment to show that corrections can debunk misinformation, with corrections from government agencies and news media sources more effective than social peers (van der Meer & Jin, 2019)).

On the other hand, negative responses and poor popularity metrics negatively affected message credibility on Twitter, even if that message was from a reputable source, suggesting that concerted campaigns negatively responding to credible information from authoritative sources may broadly diminish trust in those messages (Waddell, 2018b). Additionally, public figures may have outsize influence even when they are not experts. One study found that when public figures like Oprah Winfrey or Dr. Oz share a news article on social media, people's attitude toward the article is linked to how much they trust the public figure. A news outlet's reputation appears to have far less impact (Sterrett et al., 2019). Still, news written by journalists is deemed more credible than algorithmically written stories (Waddell, 2018a).

While researchers have examined individual peers or authorities, there are studies looking at how higher numbers of those groups affects credibility in online media. Aggregates of peer opinion, often referred to as crowdsourcing, have provided accurate judgments of news accuracy, leading researchers to

suggest they could be incorporated into algorithmic responses to up-rank higher quality news and downrank news with likely misinformation (Gordon Pennycook & Rand, 2019a). On Twitter, crowd-sourced truthfulness ratings may be effective at reducing retweets according to one study (Li & Sakamoto, 2015)

Emphasizing scientific consensus has a significant positive impact on perceptions of credibility and has been shown to effectively counter misinformation (Bolsen & Druckman, 2015). Known as the “Gateway Belief Model,” this approach has been effective in offline studies on vaccine safety and climate change (E. W. Maibach & van der Linden, 2016; S. L. Van der Linden et al., 2014; van der Linden et al., 2015). In an online experiment, emphasizing consensus on the safety of genetically modified foods was less effective on people with low prior support for GM foods (G. Dixon, 2016); however, in a different study attempting to correct misinformation about vaccines causing autism such resistance could be somewhat overcome through visual depictions of the consensus (G. N. Dixon et al., 2015).

One major factor missing in research on the effect of rebuttals’ source is the closeness of the tie providing the rebuttal. Studies using Facebook look mostly to corrections by “peers,” which seems to be defined as other individuals on the platform rather than leveraging the Facebook Friends feature or asking about the closeness of the tie. These studies unfortunately do not examine the real-world social media environment where we all have friends we trust for their expertise in particular areas or because we are emotionally close to them. Someone who has a friend who is a nurse, for example, may trust health information posted by them over someone who is an electrician, even if both post the same information. In short, different peers on social media are not likely to be equally persuasive with correction messaging.

Corrections by “known others” have indeed been shown to be more effective, at least in the case of political misinformation on Twitter (Margolin et al., 2018). One paper, looking at information-seeking for Alzheimer’s disease, compared “friendsourcing” - a type of crowdsourcing through known friend networks (Bernstein et al., 2008) - with true crowdsourcing, though the study was too small to develop reasonable generalizations (Bateman et al., 2017). A study using Facebook examined misinformation about either Facebook’s privacy policies or Kentucky Fried Chicken using rat meat, analyzing about 2000 comments in each case. Researchers found that social ties were found frequently in counter-rumor comments, suggesting they play a significant role in the online community to refute rumors (A. Pal & Chua, 2017).

To get some insight into this phenomenon, we can draw from the rich literature examining trust and credibility in online health information, focusing on websites and discussion forums (see, for example, (Y. Kim, 2016; Sbaffi & Rowley, 2017). There are clear website factors like professional design, clear layout and the authority of the owner that positively influence credibility, while advertising

undermines trust. However, most of the literature in this space examines the impact of various individual demographic factors like age, personality, gender or perceived health status.

Analysis of these forums demonstrates users weigh a number of important factors for information credibility. First, while people seek out health-related information from peers, they are not always primed to trust shared anecdotes (Elizabeth Sillence et al., 2013). In analysis of a cancer-related forum, there were clear self-appointed authorities who see their role as giving advice and have ways to communicate their authority, competence and trustworthiness (Elizabeth Sillence, 2010). Participation in the forums also depends on both the interpersonal bonds with members as well as identification with the community, with one qualitative study showing the latter to have a stronger effect on participation in the online health support network and perceptions of social support (Zhu & Stephens, 2019). For more on factors that increase trust in online websites and forums, see foundational work by Sillence (E. Sillence et al., 2006, 2007).

In discussion forums, both closeness of the tie and authority seem to be important factors as users weigh whether to trust the information. One study examined online community forums on WebMD after the platform discontinued moderators, finding that participants were well aware of the risks of misinformation on such online forums and appreciated the well-known moderators for their compassion, expertise, reigning in destructive posts, and their ability to either help answer questions and provide support or point users to helpful resources (Huh et al., 2016).

While peer and authority messaging is important for correcting misinformation online, future research will need to incorporate the closeness of ties into their analysis.

Individual factors - psychology, personality, emotions, and culture

Enough research has demonstrated that different factors associated with individual characteristics of the message receiver affect the reception of misinformation or correcting information. Overall, individual variables are myriad and not well studied systematically, making it difficult to generalize from the disparate data. Future research will need to better break down individual characteristics and how they respond under different conditions.

Of course, people have myriad reasons to seek health information online and on social media. Yet while people aim for such forums for the social and emotional support that peer-to-peer networks allow, the health issue the user has is an important factor determining whether they turn to social media support (Zhao & Zhang, 2017). And individualizing any countering information has shown promising results. One small study asked the 300 participants what structure of counter rumors they believed would be most effective. They then matched participants with messages of the type the participant believed would be

effective, including the credibility of the source, finding that this individualized framing was indeed effective at influencing users' tendency to share them (Anjan Pal et al., 2019).

Political ideology has probably been one of the best studied individual factors. Much of Gordon Pennycook and his collaborators' work uses some aspect of political polarization as a dependent variable (see, for example (Gordon Pennycook & Rand, 2019a, 2019b). Other studies have examined links between variation in someone's ability to process conflict (Michael V. Bronstein et al., 2019) or whether they are prone to believe in conspiracies and responses to corrective information (Bode & Vraga, 2018). Another study using Mechanical Turk participants found evidence for both racial and gender bias when evaluating truthfulness claims in online fact-checking platforms (Mejia & Ramaprasad, 2019). Other research examining how people process scientific information has also examined religiosity, beliefs about the role scientists should play in policy-making, and levels of trust in institutions that disseminate scientific information or geographical context (Farrell et al., 2019). However, as noted in research examining whether ideological differences lend themselves to more susceptibility to misinformation, there is evidence that would allow someone to argue either side of these debates (Lewandowsky et al., 2017; Vraga & Bode, 2017a).

Culture may be an important factor in health communication involving risk. Different cultures put weight on different factors when making decisions about trust and credibility of information (Khosrowjerdi, 2019). One study comparing Koreans, Hongkongers and Americans showed that while trust in scientific authorities was consistent across all groups, Koreans and Hongkongers put more trust in experience-based health information (i.e. personal narratives of individual experience with health issues) than did Americans (Song et al., 2016). Moreover, differences in communication techniques by pro- and anti-vaccine advocates have also been observed in discourse analysis of the debates in different countries, suggesting that cultural differences in communication styles may play a role in effective persuasion messaging like inoculation or refutations (Tsuda & Muis, 2018). On the other hand, one study of American and German audiences did not find a difference in the effectiveness of a refutation text (Flemming et al., 2019), suggesting that while cultural differences in health information seeking and response do exist, there may be some universal factors.

This reflects a growing trend to consider cultural aspects in health communication. Recently, researchers called for culturally-sensitive health communication to better assist medical decision making and health promotion (Betsch et al., 2016; Betsch & Böhm, 2016). Indeed, a large amount of research on decision-making surrounding antibiotic use and prescribing has shown cultural differences, such as power distance or tolerance of uncertainty, as key factors contributing to such decisions (Borg, 2011, 2013). In particular, the effectiveness of health message framing appears to be particularly relevant with gain-framed messages most effective for individualistic cultures and loss-framed message more effective for

collectivistic cultures. Much more research needs to be done to effectively tailor culturally-appropriate persuasion methods either off- or online (Betsch et al., 2016), suggesting we are barely scratching the surface in understanding how personality, emotions or culture factor into message receivers' responses to misinformation.

Different individual decision-making styles have also been postulated to affect responses to information designed for persuasion (Hirsh et al., 2012). In an online experiment, Peer and colleagues found that customizing messages based on decision-making traits is more effective than "one size fits all" messaging at persuading users to create stronger passwords (Peer et al., 2019). Unfortunately, the literature on personalized nudging online seems limited to the privacy/password sphere or user interface design (Schneider et al., 2018; Warberg et al., 2019). Much more work needs to be done in this area to determine whether such techniques would be as effective in promoting behavior in the face of misinformation.

Context (i.e. Platform, misinformation campaign characteristics)

Truth is nuanced and can be context dependent (Webb & Jirotko, 2017). Yet most empirical research testing rebuttals to misinformation tests them in highly controlled environments. However, a handful of studies have examined effective messaging retrospectively, which allows for more understanding of how contextual factors might play a role in either believing misinformation or lending credibility to refutation messages. For example, in her dissertation, Vos analyzed Tweets related to a public health crisis (Ebola), finding that specific content, such as info about hazards, instructions on response, or official actions, format with word structures or additional images/graphics, and certain framing such as figurative language, and the use of hashtags were most successful at being amplified (Vos, 2016). Pal and Chua's study of Facebook's privacy policies or KFC using rat meat was also retrospective, allowing them to analyze more carefully the social ties that became important in the network of correcting information (A. Pal & Chua, 2017). Another interesting prospective experiment found no difference in the effectiveness of refutation texts when comparing online versus laboratory testing, finding both effective (Flemming et al., 2019).

Interestingly, evidence suggests that ways to amplify and refute messages on Twitter are almost opposite. In one experiment about skin cancer information, researchers reached 23% of the population of Northern Ireland, finding that messages with shock and humor frames received the most interactions (Gough et al., 2017). Conversely, researchers found that effective rumor correction messages on Twitter have almost opposite formats: lower emotion use, clarity, and credible source attribution (Chua & Banerjee, 2018).

As noted above, the online environment may be crucial in determining the strength of social ties, and different technical features of each social network may facilitate or undermine the sharing of information and interactive discourse (Lyons, 2017). Relative to Twitter, for example, social ties may be stronger on Facebook, and, as one study of university students suggests, the strength of online social ties may affect the influence of advertising on social media by mitigating the impact of other factors like message format or the message receiver's advertising literacy (G. C.-C. Shen et al., 2016). While Vraga and Bode did not find much difference in the effectiveness of refutation messages between Facebook vs Twitter, the mechanism for that acceptance differed, they hypothesized, based on both the varied strength of social ties between the two networks and how Twitter is seen as a source for news (Vraga & Bode, 2018). Unfortunately, there is some evidence that while Facebook was a prominent platform for misinformation, it has been overtaken by the increasing numbers of interactions with misinformation on Twitter (Allcott et al., 2019). The cultivation of a community of shared values on internet platforms like Facebook and YouTube is an important factor in radicalization (Badalich, 2019; Koehler, 2014; A. Marwick & Lewis, 2017), suggesting that leveraging online social ties will also be important to combat misinformation.

An additional contextual factor of social media is the fact that it is interactive. A separate literature has examined the effectiveness of fact-checking websites, which require a curious user to seek the information out. One meta-analysis found four key findings. First, that "truth scales" seemed less effective at correcting misinformation and could backfire. Second, correcting a full statement was more effective than only correcting parts. Third, fact-checking that supported someone's ideological predisposition was, perhaps not surprisingly, more effective than efforts trying to debunk information that matched someone's ideology. Given Kahan's work on identity-protective cognition, this result was not surprising (Kahan, 2017). Finally, simpler messages were more effective than more complex statements (Walter et al., 2019).

Finally, a largely overlooked contextual factor in examining the effectiveness of refutation messages is examining the robustness of the overall campaign to spread misinformation versus the campaign to spread misinformation. Such a tug-of-war has been an important component in studies understanding why certain social movements are successful (Keck et al., 1998; Maney, 2001). Viewing misinformation efforts through a social movement lens provides insight into how the anti-vaccine movement may be more resistant to refutation messages than other topics either because of particularities with the subject matter (complexity, affecting children, etc.(Gorman & Gorman, 2016)), or because there is a well funded and well organized network promoting propaganda about vaccine safety. Understandably, we might expect that different campaigns of misinformation may require different messaging to be effective. In another example, Paul and Matthews note the characteristic features of

Russian misinformation campaigns, noting it is “high-volume and multichannel,” rapidly promoting propaganda, and leveraging repetition to sow mistrust in susceptible publics. In such a context, the authors suggest: “Don't expect to counter Russia's firehose of falsehood with the squirt gun of truth. Instead, put raincoats on those at whom the firehose is aimed” (Paul and Matthews 2016).

Towards a framework for online refutation research: Leveraging research on persuasion and science communication

By a large margin, the research pertaining to the effect of refutation, rebutting and corrective information in online media vastly outstrips the research in other areas like online inoculation efforts or the further development of critical thinking online. It is not clear whether this is due to this method being the most effective; in fact, the evidence suggests refutation-type information is helpful but, given the relatively small effect sizes, not sufficient. Instead, a driving factor seems to be the ease with which researchers can test these methods. Many are done with simple pre-post surveys using online surveys, most commonly Mechanical Turk, which some researchers defend as sufficient (Anderson et al., 2019; Harms & DeSimone, 2015; Mejia & Ramaprasad, 2019), while others believe such methodology has worrisome biases in research on misinformation around climate science (Goldberg et al., 2019).

Moreover, with notable exceptions, much literature looking at combating misinformation online narrowly draws from other disciplines such as education, marketing or psychology that is deep and nuanced in recommendations for helping to prevent the development of misperceptions through the spread of misinformation. As a result, the topic suffers from a large amount of disparate, uncoordinated empirical studies, many of which lack sufficient connection to each other.

Still, the bulk of the research suggests that certain types of messages on various platforms can have a limited effect at countering misinformation, but there are many gaps that make drawing broad conclusions challenging. A framework for seeing these gaps can come from persuasion literature. Indeed, refutation and debunking messages can be seen as essentially an effort to persuade the person with a misconception to revise their view (Bordia et al., 2005). Drawing from McGuire's communication/persuasion matrix (see Figure 4), we can start to see the numerous input variables likely to affect persuasion through mass communication. McGuire's matrix (William J. McGuire et al., 2001) comes from research on communication and persuasion and has been used previously in advertising and mass media public health communications (Elder et al., 2004).

Input Communication Factors		
	<i>INPUT</i>	<i>Factors in this 'input' section include:</i>
1	Source	Demographics, credibility, attractiveness etc.
2	Message	Appeal, organization, style etc.
3	Channel	Type of media used, i.e. television
4	Receiver	Demographics, social/psychological factors
5	Destination	Immediacy/delay, prevention/cessation
Output Persuasion Techniques		
	<i>OUTPUT</i>	<i>Description of what happens at each step:</i>
1	Tuning in	Exposure to the message
2	Attending	Paying attention to the message
3	Liking	Liking and being interested in the message
4	Comprehending	Understanding the message
5	Generating	Related cognitions
6	Acquiring	Gaining the appropriate skills to act on the message
7	Agreeing	Agreeing the message is correct
8	Storing	Saving the message to memory
9	Retrieval	Retrieval of the message from memory when needed
10	Decision	Acting on the message
11	Acting	Performing the action
12	Post-action	Integration of the action into behaviour
13	Converting	Advising others to behave likewise

Figure 4. McGuire's modified information communication factors (Corcoran, 2007).

McGuire also notes the potential outputs of those persuasion techniques, along a spectrum from capturing someone's attention to precipitating them to particular decisions or actions. Unfortunately, there is no consensus among researchers on what outcome constitutes a successful correction (Jerit & Zhao, n.d.). Moreover, visualizing these variables as a matrix allows us to see the myriad possibilities of cause and effect that each input variable could have on output variables (see Figure 5). And, of course, it is unlikely that the relationship is 1:1, meaning for example that source may have an impact on both attention and agreeing, but may also be a strong enough factor to affect deciding and acting, leading to behavior change.

	Source	Message	Channel	Receiver	Context
Exposure					
Attention					
Interest/Liking					
Comprehension					
Acquisition					
Agreeing					
Memorising					
Retrieving					
Deciding					
Acting					
Reinforcement					
Consolidation					

Figure 5:

McGuire's matrix with input variables as column labels and output variables in each row.

McGuire's matrix makes the large gaps in the existing literature on combating misinformation online visually apparent. In their review, Jerit and Zhao also acknowledge some of the "myriad of other design choices" that have not been systematically analyzed but recommend a motives-based framework to resolve the lack of cohesion between disparate studies. In this framework researchers would speculate and theorize the conditions under which certain correctives are likely to be successful (Jerit & Zhao, n.d.). Given the range of permutations possible from McGuire's matrix, not to mention other contextual factors within each input variable, we are skeptical such an approach would adequately address the complexity in ways that would lead to generalizability.

Other large gaps in the literature remain beyond the matrix, notably in the type of media. Researchers have examined refutation attempts on different types of social media, but, as Benkler et al point out, at least in the case of the 2016 election, misinformation from these sources was relatively minor compared to traditional mainstream outlets like Fox News (Benkler et al., 2018), which is particularly understudied as a source in the setting of scientific and medical misinformation. Researchers have relatively neglected the effectiveness of trying to combat misinformation via television, radio/podcasts as well as online discussion boards like 4chan, Reddit or comment sections of online newspapers, despite these sources being known locations where misinformation circulates. Receiver characteristics like demographics, personality or other psychological/social factors like identity have been shown to matter

both in the effectiveness of persuasion messages and how successful those messages are likely to be. Moreover, the source of the message, whether from a peer, a platform itself or an authoritative source has also been shown to matter in corrective messages. As noted above, the effectiveness of the closeness of those peer ties has rarely been empirically examined, nor is it addressed in McGuire's matrix.

There are also gaps in measuring the diverse effects on the receiver in these messages, the "output" in McGuire's matrix. Most studies examine differences in the evaluation of information after exposure to the experimental condition. Rarely do studies look at the impact of behavior. In a rare counter-example, Flemming and colleagues looked at the impact of refutation texts on scientific misinformation, then asked student participants whether they would be willing to donate part of their participant incentive to the cause. A significant proportion agreed to donate, making it one of few studies of online refutation texts to see an effect on behavior (Flemming et al., 2019).

Additionally (or alternatively), science communication strategies could be a useful framework for structuring research on online refutations rather than McGuire's matrix. A helpful review by Fontaine and colleagues suggests nine different types of science communication strategies: varying content, maximizing credibility, increasing public engagement, personalization, focusing on linguistic/textual components, planning larger multimedia communication campaigns, varying visual or text-based presentations, linking scientists and the public through social exchange, and presenting information numerically or statistically (Fontaine et al., 2019). Many of these techniques have been attempted in online refutation research, but few have been used simultaneously or tested against each other to better understand what may work best and in what context. Whichever framework is used - McGuire's matrix, the nine communication strategies described by Fontaine and colleagues or some other - the need for coordinated and systematic research on this topic is apparent.

Even with coordinated research, it is impossible to study all contributing contextual factors at once. It would require a massive experimental design, not to mention the funds required. However, while there will always be methodological limitations, the clear risk is that researchers who do not think carefully about these various factors before study design are, at best, likely to produce research that is only minimally useful to the field, or, at worst, may contribute to the type of "medical reversal" that has significantly damaged the credibility of medical studies (Prasad & Cifu, 2015). This "medical whiplash," as the New York Times review of the book called it (Zuger, 2015), is the product of poor quality studies with conflicting results - one day a study comes out saying coffee causes cancer, the next coffee is proven to be good for you. Ironically, the rapid fire and narrow scope of this research - e.g. one current debate with conflicting evidence about whether shocking images of side effects help combat misinformation or produce a backfire effect hardening someone's beliefs - may actually be contributing to the degradation of scientific authority.

Such variability in results has been long recognized by scholars of persuasion due to the empirical challenges and conflicting results that inhibit generalization in that field: “It is difficult to identify any particular persuasion tactic that is effective in all situations” (Daniel James O’Keefe, 2004). Indeed, qualitative work in this field suggests that messages affect different people differently. For example in testing emotional narrative or factual pro-vaccination messages in Quebec, focus group results showed that some parents were drawn to the emotional messages while others felt the same messages were manipulative (Paradis, 2018).

Such variability may be linked to two larger problems in psychology research - the focus on “WEIRD” populations and the so-called “replication crisis.” As noted above, there is a heavy reliance on both Mechanical Turk and undergraduate or North American graduate students for most research on online refutation effects. Relying on these populations may skew the results toward demographics that tend to be Western, educated, industrialized, rich, and democratic (WEIRD) (Jones, 2010). For example, one systematic review of framing as a communication technique noted that international collaboration was the anomaly, with low-middle income countries being represented in a small minority of studies (Guenther et al., 2020). Despite making up only 12% of the world’s population, the bulk of psychological studies come from these countries and study these populations. Without better segmentation of the populations that are most susceptible to misinformation, we run the risk of developing communications strategies aimed at incorrect demographics, or applying studies from one context to other, international contexts where data is lacking (Swire-Thompson & Lazer, 2019). Such participant diversity is lacking in online misinformation research where there are clear communities already forming around certain health misinformation topics. While education and critical thinking are the most logical predictors, anti-vaccine advocates are also more likely to be educated.

The “replication crisis” in social science reflects the fact that many research studies - somewhere between $\frac{1}{3}$ to $\frac{2}{3}$ - cannot be replicated (Camerer et al., 2016, 2018). The possible reasons for this crisis are under debate, but some cite less rigorous data collection practices or dodgy statistics like p-hacking (Lindsay, 2015; Simmons et al., 2011). Others argue that such experimental variability is part and parcel of science, meaning we just need more time and experiments to make robust findings emerge more clearly. To be clear, there is no evidence that the researchers cited above have engaged in unusual research practices. However, studies have shown that the use of questionable research practices is quite common in the psychological literature (John et al., 2012). And many of the factors that could lead to spuriously positive results - small sample sizes, for example - are quite common in the online refutation literature.

We should be concerned that the evidence on combating misinformation may be facing similar replication problems as the field of psychology. While psychologists are only starting to attempt solutions

to the replication problem (Moshontz et al., 2018), solutions are still lacking for empirical research on combating online misinformation. As far back as 2004, O’Keefe suggested expanding research from testing differences in single message design to including multiple messages of similar type and examining average effects, a practice that is increasingly popular (Daniel James O’Keefe, 2004). Meta-analyses of single message design studies may also be feasible. Kahan recommended a different empirical framework, testing with two specially designed “science comprehension” instruments, one on general science and the other specific to the controversial question at hand (in his case climate change). This allows researchers to separate two processes: message receivers’ knowledge acquisition versus accessing knowledge based on their cultural identity to more effectively measure knowledge rather than detect their cultural identity (Kahan, 2015).

Still, more solutions are needed. For example, given the difficulty of countering misinformation in committed believers, more empirical studies focusing on effective ways to prevent curious bystanders - people who may be on the fence about a particular issue - from becoming acolytes may be a promising avenue of research.

Next steps: Further research and beyond

Given the complexity of communication with multiple variables involved, communications literature may be able to draw from other fields where similar complexities and multiple variables - many that the researcher cannot control - likely have downstream effects. For example, drawing from quality improvement research in medicine testing a suite of simultaneous interventions as a “bundle,” may be useful to find the most effective means of combating misinformation (Lavallée et al., 2017). Rather than attempt to identify individual variables that work best in which circumstances, implementing evidence-based “bundles” has been remarkably successful in improving patient outcomes in Enhanced Recovery After Surgery programs (Ljungqvist et al., 2017). Previous research demonstrated modest improvement in surgical outcomes and diminished length of stay through changes in feeding prior to and after surgery, using minimally invasive techniques, delicately managing fluid balance, early mobilization, localized rather than general anesthesia, and minimizing pain medications. Implementing these interventions as a suite has resulted in significant reductions in length of hospital stay by 30-50% with concomitant reductions in complications and costs. Bundles have also been implemented for some conditions in the intensive care unit, like delirium (Simone et al., 2017), helping reduce length of stay (Ely, 2017), though the results in ICUs are more mixed (Horner & Bellamy, 2012).

Other promising frameworks have been put forward by researchers in public health and health services research. Turning away from reductionist methods that obfuscate and confound in highly context-dependent systems, some have advocated for a “complex systems” approach (Greenhalgh &

Papoutsis, 2018; Rutter et al., 2017). Indeed, taking a “realist” perspective, Greenhalgh and colleagues note that evaluation of complex health interventions highly dependent on context and implementation requires explanation of what works, for which people, in which circumstances, in which ways, and how those interventions work (Pawson et al., 2005). Asking similar questions in communications research may prove fruitful.

In fact, similar holistic approaches have been proposed for combating misinformation yet none are yet in place (A. E. Marwick, 2018), despite the National Academies’ recommendation in 2017 for more holistic systems approaches to science communication research (National Academies of Sciences, Engineering, and Medicine et al., 2017). Such approaches would include media literacy, algorithms supplemented with human fact-checking, social media platform-level changes in how news is vetted and circulated, all joined with effective government oversight, among other interventions. One group of researchers suggests creating an “inference engine” that would draw on existing contextually-dependent social science research and apply “transport formulas” to estimate how research results from one context would transfer to another (Goroff et al., n.d.). Others cite the need for coordinated “engagement strategies” (Merchant & Asch, 2018), otherwise we will find ourselves armed “with the squirt gun of truth” countering a firehose of misinformation and propaganda (Paul and Matthews 2016).

Indeed, some misinformation experts recommend a multidisciplinary effort targeting both individuals and platforms will be needed to reverse this trend (Lazer et al., 2018). A similar approach combining technological solutions with psychological principles, labeled “technocognition,” would ensure that information architectures discouraged the spread of misinformation while encouraging the spread of high quality information (Lewandowsky et al., 2017). Others recommend approaching technocognition with a Responsible Research and Innovation framework that seeks to build close relationships between science and society through citizens and scientists to better align innovation with societal goals and values (Jirotko et al., 2017; Webb & Jirotko, 2017).

But as a solution such a complex, even chaotic, problem as misinformation, the crisis goes beyond the media ecosystem. True solutions will recognize and address the underlying social and economic forces that have led to widespread distrust in institutions and polluted our information environment (Benkler, 2019; Phillips, Fall, 2019). To extend the inoculation metaphor further, it will be insufficient to inoculate a population against the scourge of misinformation for the endurance of structural factors that make people so susceptible to diseases will only ensure another pestilence can take hold.

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