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PERSPECTIVE

Vaccines and the social amplification of risk

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Abstract

In 2019, the World Health Organization (WHO) named "Vaccine Hesitancy" one of the top 10 threats to global health. Shortly afterward, the COVID-19 pandemic emerged as the world's predominant health concern. COVID-19 vaccines of several types have been developed, tested, and partially deployed with remarkable speed; vaccines are now the primary control measure and hope for a return to normalcy. However, hesitancy concerning these vaccines, along with resistance to masking and other control measures, remains a substantial obstacle. The previous waves of vaccine hesitancy that led to the WHO threat designation, together with recent COVID-19 experience, provide a window for viewing new forms of social amplification of risk (SAR). Not surprisingly, vaccines provide fertile ground for questions, anxieties, concerns, and rumors. These appear in new globalized hyperconnected communications landscapes and in the context of complex human (social, economic, and political) systems that exhibit evolving concerns about vaccines and authorities. We look at drivers, impacts, and implications for vaccine initiatives in several recent historical examples and in the current efforts with COVID-19 vaccination. Findings and insights were drawn from the Vaccine Confidence Project's decade long monitoring of media and social media and its related research efforts. The trends in vaccine confidence and resistance have implications for updating the social amplification of risk framework (SARF); in turn, SARF has practical implications for guiding efforts to alleviate vaccine hesitancy and to mitigate harms from intentional and unintentional vaccine scares.

KEYWORDS
social amplification, systemic risk, trust, vaccine hesitancy

1 | INTRODUCTION

In 2019, the World Health Organization named "Vaccine Hesitancy" as one of the top 10 threats to global health (World Health Organization [WHO], 2019a). Shortly afterward, the COVID-19 pandemic emerged as the world's predominant health concern, the disease, less than 2 years later, has sickened over 280 million people around the world, and caused over 5.4 million deaths (Kaiser Family Foundation [KFF], 2022). Vaccines of several types have been developed and tested with remarkable speed and are now the primary control measure and hope for a return to normalcy. However, hesitancy concerning these vaccines, along with resistance to masking and other control measures, is a substantial obstacle.

The social amplification of risk framework (SARF) was developed more than 30 years ago (Kasperson et al., 1988; Pidgeon et al., 2003). It was motivated by empirical observations in many settings that reported: (1) there were substantial differences between expert and lay perceptions of the nature and/or seriousness of a risk, (2) such differences can have substantial impacts on behaviors that can amplify or mitigate the risk, and (3) the perceptions and consequent behaviors may have spill-over effects on other risks as well. SARF was put forward not as a theory but as a conceptual framework intended to guide and integrate various investigations into how perceptions may be influenced, change, and affect behavior, and how behavioral change leads to potential risk consequences. The current state of vaccine hesitancy falls squarely within the SARF: public perceptions vary widely, with much divergence from mainstream expert perceptions: there has been significant resistance to vaccine uptake and the result has been higher risks of infection, as well as economic and social risks.

Vaccine hesitancy is not new, nor is it always unjustified. The original smallpox vaccination campaigns in the 1800s already evoked controversy—particularly with the introduction of a vaccination mandate (Wolfe & Sharp, 2002). In the more than two centuries since, vaccines have assumed a major role in the management of infectious disease (Greenwood, 2014) alongside other public health measures that reduce transmission such as public water and sewage and drugs such as antibiotics that treat diseases. More recently, there has been a proliferation of new vaccines (Piot et al., 2019). In 1974, the World Health Organization launched an initiative called the "Expanded Program of Immunization" (EPI) to expand the reach of six basic vaccines—against diphtheria, whooping cough, tetanus, measles, poliomyelitis, and tuberculosis—to reach children around the world (Keja et al., 1988). From just under 5% of the world's children getting the six EPI vaccines in 1974, with the investment and efforts of the EPI initiative, global immunization rates of vaccines increased to 86% by 2010 (Peck et al., 2019). Today, vaccines against more than 25 infectious diseases are internationally recommended (WHO, 2021a), and many more are in trial or in development. Smallpox was eradicated by 1980 (Freund, 2020; Tognotti, 2010), and while the campaign to eradicate polio has been challenged by residual reservoirs of wild polio virus together with recent difficulties and lapses in vaccination efforts (Tomori, 2018), the global effort has made tremendous progress (Matlin et al., 2017): the Global Polio Eradication Initiative (GPEI) has certified global eradication of wild poliovirus serotypes 2 and 3, and serotype 1 wild poliovirus transmission now remains only in Afghanistan and Pakistan. (Chumakov et al., 2021; Thompson, 2021; Thompson & Kalkowska, 2020; Thompson & Kalkowska, 2021; WHO, 2021b). With these advances, immunization has been lauded as one of the biggest public health successes, saving 2–3 million lives a year without counting the contribution of COVID-19 vaccines (United Nations Children's Fund [UNICEF], 2021).

Increased reliance on vaccines has been accompanied by increased hesitancy, with outbreaks of vaccine scares and refusals around the world. Some hesitancy concerning vaccine use is to be expected as no vaccine provides perfect immunity and there is always a risk of some side effects, albeit rarely serious. However, as we describe later, the phenomenon of vaccine hesitancy took a new turn with concerns about the now debunked claim by Wakefield in 1998 that the Measles, Mumps, Rubella (MMR) vaccine could be linked to autism in children (Taylor et al., 2014), and an even more widespread amplification of perceived vaccine risks has occurred during the COVID-19 pandemic. Both have been fueled by the context of a fast-changing digital environment: social media platforms with their algorithms facilitate the rapid spread of information, but also rumors and misinformation 2013, and importantly, these new platforms allow for groups to self-organize around shared beliefs across the world. While these features of information sharing and online meeting and group formation can be an asset, these platforms are also subject to abuse as they can be used to sell dubious products and intentionally undermine public trust and polarize the sentiments and political leanings of publics (Kata et al., 2013; Broniatowski et al., 2018; Jamison et al., 2020; Greenslade, 2013; Kennedy, 2019; Wikipedia, 2021).

While the MMR experience, experience with other vaccines, and the current experience with COVID-19 vaccine hesitancy exhibit clearly the linkages within the SARF, these experiences also reveal aspects of SARF that were not anticipated or fully developed in its initial formulation. The most prominent missing aspect is the transformed nature of communication through social media, its speed, its global reach, its interactive character, and its internal, algorithm-driven dynamics. More attention is also needed (1) to tendencies toward increased politicization and polarization both in communication channels and as a component of perceptions; and (2) to the upstream context in which communications take place and perceptions are formed. The original formulation of SARF and the applications that have followed tended primarily to look downstream at the interpretation and consequences of an event. We do not in this paper attempt a comprehensive update of the SARF; however, we have noted some relevant observations from vaccine experiences and have made some adjustments in our use of the framework to accommodate these.

Our approach in this paper is to use a suitably adjusted SARF as an organizing framework for characterizing and interpreting the complex experiences of vaccine hesitancy concerning a number of vaccines including the current struggles with COVID-19. We draw lessons of three sorts: lessons from the historical experience with several vaccines that may help with current efforts at managing COVID-19; insights from the COVID-19 experience that may help in future efforts to improve the use of vaccines; lessons from both sets of experiences about needed improvements in the SARF to make it more responsive to contemporary risk challenges.

Our paper is organized as follows: in the next section we consider how the SARF may be applied to vaccine hesitancy. We follow by using the SARF in describing several historical examples of vaccine scares and hesitancy with data and interpretation largely derived from the work of the Vaccine Confidence Project (VCP) 2020. In doing so we note key aspects that were not prominent in the original formulation of the SARF. Based on the observations of vaccine experiences including a section describing some of the challenges with COVID-19, we suggest updates to the SARF that make it more suitable for characterizing current social amplification phenomena. We conclude with some recommendations for further development of the SARF and for its practical use in addressing vaccine hesitancy.

2 | SARF: ITS APPLICATION TO VACCINE HESITANCY

The SARF was introduced (Kasperson et al., 1988; Pidgeon, Kasperson, & Slovic, 2003) as a response to a plethora of observations which collectively showed that purely

technical risk assessments did not take into account people's experience of risk, nor did they have sufficient predictive capability to assess how risks might change over time in response to risk management efforts and the public response. The key observations were: (1) individual perceptions of a particular risk can vary considerably and can diverge quite sharply from the empirically based risk assessment by experts; (2) relevant perceptions include perceptions about the likelihood and magnitude of potential harm, perceptions about attributes of the risk, familiarity, dread, people's sense of control, etc., and indirect associations including trust in institutions, stigma, people's sense of identity, and political concerns; (3) perceptions often change with time and circumstance; (4) perceptions are strongly influenced by communications about the particular risk, and also by communication about news and events that are seen as related to the risk; (5) perceptions will influence behavioral responses whose consequences may affect the risk people experience; (6) people's behavioral response may also create ripple effects that extend to impacts on other risks.

A further observation was that the preceding list emerged from a fragmented social science scene with the observations presented from differing disciplinary viewpoints. The framework was not put forward or intended as an explanatory theory. Rather it was intended as a conceptual framework that could be used to organize and integrate the wide variety of research findings on perceptions, on communications, and, importantly, the dynamics of their interactions. Practical implications for risks and for risk management were also a primary concern in the creation of the framework though it was considered too early to provide specific applications.

In its simplest form, the framework identifies three stages for analysis:

Stage 1: A risk-related event or other news item relating to a risk is communicated and transformed through communication channels; the communication is further transformed as it is interpreted by an individual or organization and interpretation may alter individual or organizational perceptions.

Stage 2: The individual's or organization's altered perceptions of risk influence their behavior.

Stage 3: Individual or organizational behavior will affect risk experiences; there may be direct impacts on the risk associated with the initiating event; there may also be secondary and tertiary impacts on other risks.

Feedback: The framework also anticipates feedback: thus, behavioral responses may influence further communications as communicators react to their audience and attempt to encourage or discourage particular behaviors.

Some care should be taken in applying the framework's analogy of an amplifier. In an acoustic system, an amplifier processes a signal: it may make it louder (amplification); it may make it softer (attenuation); or it may change the mixture of frequencies (distortion) including the possibility of adding new sounds. If we consider the initial event or news item as a signal, it will be potentially subject to each of these kinds of transformation as it passes through communication channels. But this only characterizes a portion of the relevant processes. An interpretation which leads to altered perceptions by an individual or organization of that transformed signal can also be considered an amplification process: so we may speak of the amplification, attenuation, or distortion of risk perceptions. Or we can consider the impacts of individual or organizational behavior: so, for instance, attenuated risk perceptions may lead to careless behavior that amplifies the risk.

Three complications of the simple version were in the original framework and are worth noting: (1) multiple entities (individuals or organizations) may be engaged in each stage (in keeping with the acoustic analogy, the original paper called them "stations"); 2) more than one step may be needed to describe the processes that form a particular stage; 3) in particular in considering the secondary and tertiary impacts in stage 3, these may be initiated by further communications.

When applying SARF to vaccine hesitancy, multiple risks must be considered in parallel: the risk of the diseases which the vaccine aims to prevent; the risks of the vaccine, and the contextual risks, such as the launch of Google in 1998. The framework can then be applied to both in a straightforward manner. The initial appearance of the Wakefield report linking the MMR vaccine with autism can serve as an illustration of such an application:

Stage 1: Triggering event: a research article is published in *Lancet* (Wakefield et al., 1998), suggesting a link between the MMR vaccine to the development of autism: stories followed in various news media, popular magazines, tv shows, professional journals, and official recommendations: these describe in various ways the study, the vaccine, its expected efficacy, the possible side effects, with particular focus on the possibility of autism, the nature of autism and what is known and not known, the prevalence and nature of measles, mumps, and rubella, and the trustworthiness of information about entities recommending the vaccine; multiple conversations occurred among individuals and groups in an effort to interpret this barrage of information; perceptions form about the risks of the vaccine and perceptions of the risk of the disease are adjusted; and perceptions on various related issues, including other vaccines and the institutions that manufacture, regulate, and recommend vaccines are reconsidered.

Stage 2: Based on their recently formed perceptions, individuals choose to respond by following or not following recommendations to have their children vaccinated. They may also choose to engage in further communication about the possible issues or even to join groups concerned to promote or debunk the claims. Feedback from these responses may encourage further communication about the study. Institutions consider whether to respond with further studies or with recommendations to the public.

Stage 3: The choices to vaccinate or not directly affect the risks that the children experience from the diseases the vaccine aimed to prevent. Other choices may be about other health decisions—for example due to loss of trust—and provoke risks of other types.

Feedback: Parents who already had anxieties about autism as well as some parents with autistic children embraced the findings as it gave an explanation for the seemingly growing

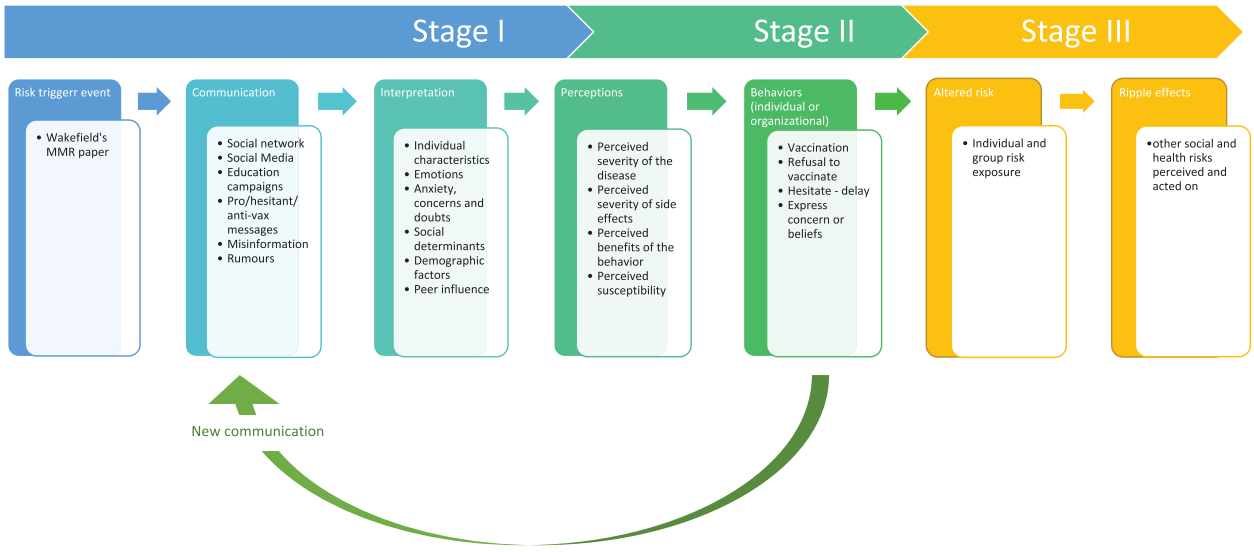

FIGURE 1 Application of social amplification of risk framework to consequences following Wakefield's MMR paper

phenomena of autism. Some organized groups and individuals communicated messages against the MMR vaccine, while others joined campaigns to debunk the proposed autism link and promote the MMR vaccine. Health institutions responded with their own communication efforts; these were intensified as further studies contradicted Wakefield's and his article was retracted by *Lancet* (Taylor et al., 2014).

This example is illustrated in Figure 1. Of course, a more thorough analysis would require filling in considerable detail for each stage. For instance, public health professionals have identified three important factors that influence vaccine hesitancy (WHO, 2014): (i) level of confidence in the vaccines and the vaccine administrators, (ii) complacency about the disease, and (iii) level of convenience, that is, how difficult it is to get vaccination. Some health researchers have extended the list to five influences: see, for instance, Betsch et al. (2018).

3 | THE VACCINE CONFIDENCE PROJECT™

Polarization, mistrust, and disinformation were growing long before the COVID-19 pandemic emerged, but these societal dysfunctions have grown more prevalent and more prominent since the pandemic began in early 2020. The VCP was founded in 2010 to establish a systematic approach to monitoring public confidence in vaccines through population-based surveys and ongoing media-surveillance, mapping the global spread of vaccine sentiment, and conducting in-depth analyses of vaccine confidence issues and their impacts (2020 Hou et al., 2020, 2021; Zhou et al., 2021). A data-driven system was set up for early detection of public concerns about vaccines and with which the VCP collects data and applies a diagnostic tool to determine the risk level as to whether those concerns could disrupt vaccine programmes and uptake. Further, in 2015, the VCP launched a Vaccine Confidence Index™ (VCI) (Larson et al., 2016, 2018), based on a select number of factors identified through extensive analysis of areas of both low and high vaccine coverage and has surveyed over 300,000 individuals, some over multiple waves, revealing a variety of trends and other signals (de Figueiredo et al., 2020). In addition to in-depth qualitative research, the VCI investigates four dimensions of vaccine confidence: confidence in the importance, the safety, and the effectiveness of vaccines and confidence that vaccination is compatible with one's religious beliefs (Larson et al., 2016).

The VCP's compilation is the most comprehensive collection of information available on vaccine hesitancy. Much of the data and findings that we describe in the following sections were gathered through the VCP's media and social media monitoring, VCI™ surveys, and local in-depth qualitative research on drivers of vaccine resistance.

4 | VACCINE EXPERIENCES EXHIBITING SOCIAL AMPLIFICATION OF RISK

4.1 | The MMR experience

The quintessential example of social amplification of risk in the context of vaccines is the perception that the MMR vaccine can cause autism, sparked and fueled by a publication by Andrew Wakefield (Wakefield et al., 1998). Although his article was published over two decades ago and was retracted by the journal, *Lancet*, in 2010 (Lancet Editors, 2010) and although many research reports before and after the retraction have countered Wakefield's findings (Taylor et al., 2014), perceptions that MMR caused autism have persisted and spread globally. These perceptions reduced MMR vaccine acceptance leading to increased measles cases and measles-related deaths; they also created distrust in medical establishments and other vaccines.

Figure 1 shown earlier describes how the original SARF can be used to synthesize information about impacts of the Wakefield report. The initial claim served as a potent triggering event. A number of reasons contributed to its powerful impacts on perceptions and behavior. One reason lies in the SARF stage 1 movement from interpretation to changed perceptions. The messages were heard by sensitized listeners, especially parents who were already questioning what could be causing autism. There was considerable uncertainty about why there seem to be higher numbers of children developing symptoms now characterized as being an autism spectrum disorder (ASD). With no clear scientific explanation, although more evidence is pointing to some cases having genetic links, "MMR causes autism" appeared a plausible explanation to the many parents eager to find a reason for why their child developed autism. Early signs of autism usually manifest around the same time that children usually get their MMR vaccines and the timing seemed to explain the link, rather than to just be seen as coincidental. At the time, there was considerable skepticism and controversy about the claim, but that controversy also drew attention to it.

Another reason for the impact was that not all communication came through traditional reports of scientific and medical findings. One of the biggest amplifiers of the "vaccines cause autism" meme was that Andrew Wakefield's paper came out the same year that Google opened their doors, followed in the coming years by Facebook, Twitter, and multiple other social media platforms. Since Wakefield's publication, hundreds of highly organized groups have taken on a vaccine critical stance or fully devoted their website and networks to what has been termed "anti-vax" narratives. Johnson et al. analyze over 100 million Facebook users to study their pro- and anti-vaccine sentiments and found that, while the numbers expressing clearly anti-views were fewer than the pro-views, with 50 million individuals in the middle being "undecided," the anti-groups were recruiting the undecided individuals at a rate much faster than the pro-groups, with some anti-vaccine groups growing 300% in size, compared to between 50–100% growth on the pro-vaccine side (Johnson et al., 2020). The amplification enabled with these social media platforms went beyond what Wakefield could have imagined, allowing his meme, among others, to travel algorithmically through social networks of concerned parents seeking an answer to explain their child's autism or other vaccine-related concerns. These groups and channels kept the Wakefield claims alive long after their debunking and retraction (Larson, 2020). Figure 2 shows the global reach of news mentions almost two decades later. A further reason for the persistence of the MMR vaccine fears, is that unlike many scientists who might have moved on and accepted that their hypothesis might not have been correct after multiple other studies disproved their findings, Wakefield instead started a campaign to make his case that he was right. He turned to the many parents who had believed and responded to him; encouraged by their feedback he started a movement, which has since become globally connected. Neither did he stop with his initial paper, he amplified his message through popular media. He wrote a book for the popular press, made a movie, and turned a bus into a campaign van which traveled long distances showing the movie and gathering testimonies to support his theory.

The consequence of these factors captured in Stage 1, are reflected in stage 2 of the SARF. In the UK where Wakefield had his start, MMR vaccine uptake rates dropped from 92% in 1998 to 79% in 2003 (Ellman & Bedford, 2007). The loss of confidence in vaccines led, stage 3 of the SARF, to rising measles rates; there was also increased questioning of vaccines and distrust of medical providers (Motta & Stecula, 2021). The impacts after the first few years became more intense and the pathways for impact were intricate and persistent.

In recent years the impacts, stage 3 direct and indirect, have been large: the changes in behavior, fewer people having their children vaccinated with MMR vaccine, contributed to a surge in measles cases globally. WHO estimated that in, 2018, there were 9,769,400 estimated measles cases and 142,300 deaths around the world, despite the availability of a safe and effective vaccine to prevent measles (United Nations [UN] News, 2019). In addition to the usual vaccine access issues, particularly in conflict and migrant populations, the other problem now was that not everyone wanted it.

The consequences were not limited to measles, mumps, and rubella, the diseases which the MMR vaccine targets. Concerns about vaccines spread from MMR to other vaccines and to a loss of confidence in medical authorities which meant that not everyone who needed medical treatment sought it (WHO, 2019b).

4.2 | The HPV experience

Vaccines against human papillomavirus virus (HPV) were introduced in the United States in 2006 (Markowitz et al., 2016). The history of acceptance and resistance over the following decade provides another view on the features of social amplification of risk. These include the important role of social media and rapid communications, the significance of local contexts, and the potential for political influence.

The issues surrounding HPV are significantly different from other childhood and adolescent vaccines. The viruses are transmitted through sexual contact: sexual activity, especially of minors, raises a host of cultural-specific and religion-specific concerns among parents and in their social settings (Ferrer et al., 2014; Madhivanan et al., 2016, Siu et al., 2019; Wong et al., 2020); HPV is the major cause of cervical cancer in women, so the potential consequences of disease differ between men and women, thus complicating assessments of benefits of vaccination for men and women. Furthermore, since transmission does not occur during normal school activity, school mandates must have other justifications. All of these issues have been prominent in shaping perceptions, and in parental decisions about vaccinations for their children. In this context, many healthcare providers have been reluctant to actively encourage parents to vaccinate their children for HPV. Overall, HPV uptake has been significantly lower

FIGURE 2 Number and reach of on-line news articles between 2016–2017 mentioning Andrew Wakefield's, 1998 research published in the United Kingdom [Credit: W. Schulz, The Vaccine Confidence Project™]

than for other childhood and adolescent vaccines and significantly lower for boys than girls. Improved vaccination rates, if obtainable, could lead to substantial numbers of lives saved as well as reduced rates of illness (Simms et al., 2020).

Another remarkable phenomenon has been the emergence of emotional contagion and anxieties around the HPV vaccine—from Japan to Denmark, Ireland, and Colombia—where girls experienced a range of symptoms including fainting, para-paralysis, mobility problems, eating problems, and chronic pain; these led to significant declines in HPV vaccine uptake in some settings. These reactions were different from the parental concerns mentioned above; these reactions were immediate—sometimes dramatically displayed—which some of the girls were capturing on video and sharing across YouTube and other social media platforms. While the symptoms were very tangible, most were assessed as being psychosomatic or what the World Health Organization now characterize as "immunization stress-related responses" (WHO, 2019c).

In 2013, in Japan, a mix of symptoms—fainting, twitching, mobility issues, chronic pain, following HPV vaccination provoked anxiety and anger among the parents. They organized a highly active "Victims" group on social media, causing widespread panic and paralyzing the government, who suspended their pro-active recommendation of HPV vaccination (Simms et al., 2020). Despite investigations finding no link between the vaccine and the symptoms and the reaction characterized as mass psychosomatic illness (MPI), now named as immunization stress-related responses, it is only now, 8 years later, that the Japanese Ministry of Health, Labor, and Welfare, is preparing to resume the active recommendation of the vaccines (Iwanaga, 2021). Modeling has since found that the suspension, and the consequent drop in vaccine uptake because of the amplification of risk, are likely to result in an additional 24,600−27,300 cervical cancer cases and 5,000−5,700 deaths that could have been averted if the proactive recommendation of the HPV vaccine had not been suspended (Simms et al., 2020).

These HPV vaccine reactions spread well beyond Japan to Denmark, the Netherlands, and Ireland. There, vaccine uptake also plummeted; however, rapid response by government agencies meant that the decline lasted only a few years. Significantly, neighboring countries, where the reactions did not occur showed only a small effect. The reactions spread as far as Colombia—where over 500 girls across multiple schools had similar reactions of dizziness, fainting, twitching and pseudo-paralysis (Simas et al., 2019), all in the course of 1 year. In Colombia, too, vaccine acceptance dropped dramatically. Before the 2014 mass fainting in Colombia, HPV vaccine acceptance was as high as 98% for the first dose and 88% for the second dose, but by 2016 HPV vaccine uptake dropped to 14% for the first dose and 5% for additional dose. As MPI expert Robert Bartholomew notes, "We may be witnessing a milestone in the history of MPI where the primary agent of spread will be the Internet and social media networks (Bartholomew et al., 2012)."

4.3 | The Ebola vaccine experience

Vaccine trials often function as initiating events for social amplification. Different experiences of changed perceptions and changed behaviors, individual and institutional, show clearly the importance of the context in which a trial is placed. Clinical trials by nature have uncertain outcomes, including risks. But the Ebola vaccine trials in the context of the 2014–2016 Ebola outbreaks in West Africa were a particularly heightened time of real as well as amplified risks. While some

denied that Ebola was even real, others feared the highly fatal virus. Some families hid sick family members, afraid that they would be taken away to treatment centers, never to come out again.

Some of the vaccine trials proceeded well, particularly those which invested in extensive community engagement and clear public messaging around the trials (Enria et al., 2016), thus demonstrating the merits of that sort of engagement. Other trial attempts had more challenges and were disrupted by rumors and panic. The story of two Ebola vaccine trials suspended in Ghana are a poignant example of how a contagion of fear and risk perception can have significant and damaging consequences. The rumor that an Ebola vaccine trial had started, even though that was not the case, spread like wildfire in the public as well as in political and scientific circles and the media. The public was outraged as to why an Ebola vaccine trial would be conducted in their country where there had been no Ebola cases. The outrage was more about the process—perceived as secret and untransparent—than whether or not either trial had even started. The two trials that were under discussion, not yet approved and neither started, were abruptly suspended by the Parliament (Kummervold et al., 2017).

4.4 | The dengue vaccine experience

In 2016, the Philippines was one of the first countries—alongside Brazil—that introduced a new vaccine to prevent dengue, named *Dengvaxia*. The Philippines and Brazil have among the highest rates of dengue illness and death in the world, especially among children. In 2016 alone, the Philippines had over 100,000 dengue cases and over 400 deaths (Relief Web, 2016) and great hopes were pinned on the new vaccine. But, 1 year after introducing the new vaccine and immunizing over 800,000 school children, the vaccine manufacturer announced that a new risk had been identified. For those not previously exposed to the dengue virus, the vaccine was found to have a risk of causing more serious dengue illness in those vaccinated (Sanofi, 2017).

In Brazil, the authorities amended the instructions as to who should get the vaccine, still approved as safe and effective for those who had been exposed to dengue. In the Philippines, the reaction was dramatically different. The vaccine had been launched by the previous president in the height of a national political campaign, and the news was seized upon as an opportunity to undermine the previous government. One of the key tactics was an aggressive and highly emotional campaign creating public panic around the safety and risks of the vaccine; the new dengue vaccine program was suspended, and there was a dramatic drop in public confidence in the vaccine as well as in the health authorities. The plummeting of vaccine confidence in the broader system contributed to declines in the uptake of other vaccines, such as against measles, as well as impacting the acceptance of other health interventions delivered by the health authorities such as deworming medicine in the schools (Larson et al., 2019; Lasco & Larson, 2020). The Philippine response to the news of the dengue vaccine risks is a special example of political considerations over-riding public health analysis. Unlike the HPV and Ebola experiences in which government agencies and local politicians reacted to public concerns, in this case, a national leader used vaccine concerns in pursuit of a particular political agenda. Several further such examples have appeared during the COVID-19 pandemic.

5 | SOCIAL AMPLIFICATION OF RISKS IN THE CONTEXT OF THE COVID-19 EPIDEMIC

The WHO declared COVID-19 a global pandemic on March 11, 2020; as of the end of December 2021, 280 million COVID-19 cases and 5.4 million deaths have been reported globally (KFF, 2022). However, the risk perceptions of COVID-19 disease and its vaccines still have a striking divergence within and between experts and lay opinions, leading to contrasting behavioral and policy responses, ripple effects, and subsequent psychological and socioeconomical impacts at individual and societal levels.

5.1 | Perceptions and attitudes

Denialism of presence of disease was observed during the 2014–2016 West Africa Ebola outbreaks (WHO, 2015; Brantly, 2014; National Public radio (NPR), 2014; National Research Council (NRC), 2016), and again during the current COVID-19 pandemic where individuals and groups claimed the reports of disease outbreaks or pandemics were exaggerated or even false (Miller, 2020; Klepper, 2021). Individuals minimized the severity of COVID-19 and/or underestimated the likelihood of contracting it, either because no one around them had been affected, or because those who contracted the disease did not present severe symptoms. Such denialism has inevitably led to suboptimal support and compliance with disease containment and control measures, which include social distancing, masking, testing, and vaccination (Hollingsworth, 2021).

Conspiracy theorists have also undermined vaccine acceptance, promoting the idea that the COVID-19 pandemic is some kind of hoax (BBC, 2021; Thistle, 2021) or a plotted scheme by authorities and pharmaceutical companies for political or financial gains.

In a nationally representative survey of Americans, 19% believed that gaining immunity through contracting the disease is better than vaccination (Stecula et al., 2020). This claim found some scientific support in a large Israeli study (Gazit et al., 2022), which showed people who once had a COVID-19 infection were less likely than never-infected, vaccinated people to contract the Delta variant, develop symptoms from it, or become hospitalized with serious COVID-19 symptoms. In fact, however, data from the same study suggested that previously infected people should still

receive at least one dose of the mRNA vaccine as it provides a much higher protection against reinfection than remaining unvaccinated for those who once had the virus.

Furthermore, data have suggested that there have been relatively few deaths and mild disease in children under the age of 18 years compared to other age groups. The lower likelihood of death, in combination with reports of side effects from receiving the vaccine, has led some physicians (Makary, 2021) and parents to be on the fence about getting their school-age children and teens vaccinated.

The catastrophic impact of the COVID-19 pandemic has contributed to the unprecedented speed of COVID-19 vaccine development. Effective vaccine development usually takes almost 10 years, but several COVID-19 vaccines have been developed and approved for use within a 1-year timeframe. The novelty of the COVID-19 disease as well as the accelerated development and review process of COVID-19 vaccines may have further exacerbated public concerns and heightened risk perception regarding vaccine safety and effectiveness.

Furthermore, the introduction of a new vaccine technology—the mRNA vaccines—during the COVID-19 pandemic has raised concerns about the ability of vaccines to alter the DNA or genetic make-up of humans, and thus contributed to uncertainty around the immediate and long-term adverse reactions or effects of these vaccines. On the other hand, reports of blood clots caused by AstraZeneca-Oxford and Johnson & Johnson vaccines, both of which adopted more traditional vaccine technology, have triggered new waves of vaccine hesitancy across the globe. Governments have suspended the use of these vaccines, temporarily or permanently as public pressure mounted, resulting in a significant blow to Europe's already lagging inoculation drive despite a lack of clear evidence that the vaccine had caused any harm.

Delta and then Omicron, were the most-infectious coronavirus variants to emerge. Mounting evidence has demonstrated that people with Delta or Omicron induced breakthrough infections also may be capable of transmitting the virus, according to a large UK study (Pouwels et al., 2021). Evidence of waning antibody levels have prompted calls to offer a booster dose of a COVID-19 vaccine in countries like Israel and the United States, while simultaneously causing some to lose confidence in the effectiveness of vaccines available in protecting against COVID-19.

5.2 | Contextual factors: Politics and public reactions

It appears increasingly clear that review and approval, distribution, suspension, and booster offering of vaccines have as much to do with politics as science. Negative experiences with healthcare service provision and immunization programs in the past have been linked to distrust in health authorities and governments and have also been identified as driver of COVID-19 vaccine hesitancy. Some believe that the scientific data and information about vaccines published by governments are misleading and unreliable, while others hold the opinion that there has been a lack of transparency in vaccine procurement processes (Goodman & Carmichael, 2020; Islam et al., 2021; Thacker, 2021).

Recent surveys have shown that trust in governments and COVID-19 vaccines among healthcare professionals (HCPs) is low in many countries. While HCPs are widely considered the most trusted source of information on vaccine-related topics, studies have shown that some HCPs are reporting their own hesitancy around certain vaccines, influencing their intention to vaccinate themselves as well as influencing their recommendations to their patients and target population (Luo et al., 2021; Maltezou et al., 2021; Shekhar et al., 2021; Razzaghi et al., 2021). In Germany (Aertzeblatt, 2020), half of surveyed nurses and a quarter of surveyed doctors did not want to be vaccinated, citing fears of side effects and long-term damage. In a five-country survey in West Africa only 31% of respondents said they trusted their governments enough to take the vaccine (Seydou, 2021). In a Thailand hospital, one-fifth of physicians surveyed were not willing to recommend the vaccine to their family members or patients despite expressing willingness to receive a COVID-19 vaccine themselves (Sirikalyanpaiboon et al., 2021). In the United States, a survey by the Kaiser Family Foundation (KFF), a health think-tank, found that 29% of US healthcare workers would probably or definitely not get a vaccine (Hamel et al., 2020). This lack of confidence in vaccination among HCPs and their possible refusal of vaccination could pose important challenges in controlling the spread of the virus, especially among those with close and regular contact with COVID-19 patients. Their hesitancy could also create controversies and weaken public confidence in vaccination. For example, in Italy 13 cases of doctors sharing anti-vaccination content or playing down the severity of the virus are currently being investigated (Solomon et al., 2021).

In the era of the COVID-19 pandemic, vaccine politicization has reached new levels of intensity. The surveys led by the Kaiser Family Foundation have consistently found partisanship to be one of the main factors driving differences in COVID-19 vaccination rates across the United States where Democrats are much more likely to report having been vaccinated than Republicans, and Republicans are much more likely to say that they definitely do not want to get vaccinated (Kates et al., 2021). Not surprisingly, such divisions are consistent with the resistance to the adoption of other containment measures such as face covering and social distancing, that had been introduced before the COVID-19 vaccines became available. The controversies around COVID-19 vaccines have been amplified by the broader controversies around the COVID-19 disease itself. Some political leaders, too, have played a role in creating and sustaining polarized views.

Possibilities for creating or countering a vaccine mandate have appeared as potent triggering events in the social amplification, driving COVID-19 vaccine hesitancy as illustrated in Figure 3 in section 6. Although partly aligned with political identity, the debate over the fairness of demanding

vaccination passports or vaccine mandates raises difficult ethical questions about how to balance public welfare against individual liberty. Is the emphasis on risks to the public or should people be able to decide whether or not to be vaccinated without the fear of losing jobs, being denied entry, or facing other socioeconomical consequences? Some view vaccination passports as completely unethical or inequitable, or as a part of a government agenda to place citizens under illegal surveillance and manipulate society (Medical Ethics Advisor, 2021). Some argue that the concept of a mandate is unethical because it will inevitably further widen societal divisions between groups and/or because it presents a risk of profiling certain groups based on individual's membership in a racial, religious, or social group that has lower rates of vaccination (Jecker, 2021). The heated discussion about the potential violation of liberty is happening in many countries. In the United Kingdom, 34% of respondents in a survey of 2000 adults expressed concern that vaccination passports would be a breach of human rights, as they could discriminate against groups who are waiting for, delaying, not wanting, or ineligible for the vaccine, though the remaining two-thirds support the idea despite legal and ethical concerns (Hearn, 2021).

5.3 | Communication

Misinformation through social media platforms has been identified as a key driver of COVID-19 vaccine hesitancy (Gabarron et al., 2021; Himelein-Wachowiak et al., 2021). Inaccurate perceptions of the risks presented by COVID-19 diseases and vaccines have been further amplified on mass and social media platforms, often through the circulation of myths, misinformation, fake news, and rumors. If not promptly addressed, such misinformation can reverse the gains made in combating the COVID-19 pandemic. Uncertainty, a lack of complete information, and infodemic (too much information) around the disease and vaccines have presented an environment in which myths, misinformation, fake news, and rumors can brew and proliferate. Misinformation can create a public sentiment of doubt and hesitancy about accepting vaccines. Unfortunately, some of the public figures, health officials, scientists, or researchers who disagree with scientific evidence about COVID-19 disease and the vaccines have also contributed to the creation and dissemination of misinformation and false claims around COVID-19 disease and vaccines, and they have attracted a widespread following. Opponents of vaccine passports have been using social media platforms to drive resistance to vaccination.

In a recent WHO technical consultation on responding to the infodemic (and misinformation) related to the COVID-19 pandemic, experts called for swift, regular, systematic, and coordinated action from multiple sectors of society and government (Tangcharoensathien et al., 2020); they recognized that promoting trusted information and countering misinformation about COVID-19 vaccines is as crucial as providing vaccines to saving lives.

What is often overlooked in the focus on misinformation and rumors, and the role of technology platforms in their spread, is the new opportunities for those sharing common beliefs and perceptions to self-organize online and recruit others to join their echo chambers.

6 | DISCUSSION: UPDATING THE SOCIAL AMPLIFICATION OF RISK FRAMEWORK

As we described above, Figure 1 works well for describing the few years immediately following the Wakefield report. However, the subsequent persistence of resistance to MMR and the broad influence this resistance has had for other vaccines require attention to other considerations.

The original proposers of the SARF did not, and perhaps could not, anticipate the powerful role digital social media would play in social amplification. Social media have special features for influencing perceptions: they circulate news, rumors, and opinions very rapidly; they are interactive which can enhance engagement; they facilitate closed circles of information processing with mutual reinforcement. There is much still to learn about how social media function in the various processes described in the SARF; the prominent role that social media have played in public perceptions of vaccines is a fertile opportunity for study.

The original authors did observe that various events and messages could acquire symbolic meanings and that these could influence amplification processes; they also observed that politics and political symbolism could be significant contributors to social amplification processes. However, they did not anticipate the recent extreme levels of political polarization around the world, nor did they anticipate how political identity could dominate other considerations in perceptions and behavior relating to health risks. While it is easy to deplore the "politicization" of what many believe should be nonpolitical choices, it is more difficult, but potentially more useful to better understand such "politicization" and to understand its implications for how individuals and institutions make choices. The debates about public health measures for controlling the COVID-19 pandemic, including debates about COVID-19 vaccines, have exposed many complexities in people's ideas about individual liberty and group welfare; these complexities also appeared in earlier debates about other vaccines, and they are different in different countries and cultures.

The challenges in coping with risks in complex systems were only partially addressed in the formulation of the SARF. The SARF was an early and significant contribution to understanding systemic risks: it emphasized ripple effects, ways in which risks can be linked to and influence each other; it also drew attention to the importance of human connections, that communication, perceptions, and behavioral response were powerful links among risks. However, the original SARF perspective was primarily expansive, looking downstream from an initiating event. An event could serve as a signal like a rock

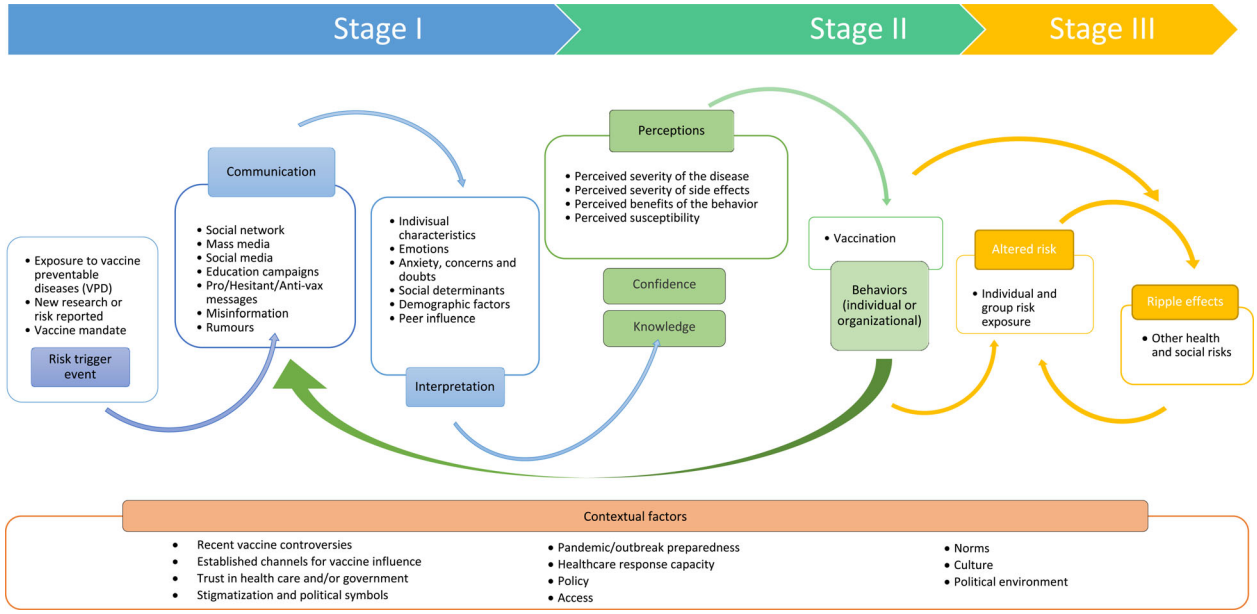

FIGURE 3 Updated social amplification of risk framework for vaccination

dropping into a pool. The ripples travel outward from direct to secondary and tertiary impacts. The challenge, posed at that time to the risk community, was to learn how such signals get transmitted and interpreted under different conditions in different settings. The further challenge was to consider the implications of the resulting signals. Users of the framework have devoted considerable attention to issues of trust and legitimacy (Kasperson et al., 2003). The SARF has also been used to gain insight into the phenomenon of stigmatization (Kasperson et al., 2001; Flynn et al., 2001; Kasperson et al., 2003). Trust, legitimacy, and stigmatization are all critical concerns for vaccine hesitancy (Larson & Haymann, 2010; Larson et al., 2012).

However, today's situation with the MMR legacy and its impact on other vaccines is even more complex. Still using the ripple analogy, you can imagine instead of a pristine pool with neat borders, a swampy pond with tree stumps and fallen branches and some rocks and muddy islands. Ripples will travel complex paths and create reflected ripples. But that is not the only shift your imagination should make: we rarely deal only with single events and their ripple pathways; other events creating other ripple patterns, will occur in the swamp at roughly the same time, and the ripples that we will see will be from the interacting patterns (Schweizer et al., 2021).

The implications of such a mental shift are significant. Already established conditions will strongly affect what happens after a triggering event. The influence of a new rumor will depend on the surrounding circumstances and the nature of previous rumors and responses. Just as significant will be the degree of trust in health authorities and other relevant institutions. Proactive gathering of information on these conditions and, when appropriate, proactive engagement with vulnerable communities are critical capabilities for an effective response.

We illustrate the use of an augmented SARF by considering reactions to vaccine mandates. We continue to consider three stages for analysis, but we also explicitly identify a need for analysis of the context in which events, communications, perceptual and behavioral changes occur. In the three stages we give prominence to social media and the networks created within them. Because vaccine mandates can evoke considerations of political authority and personal liberty, political polarization will also feature in the analyses.

Stage 1: Triggering event: a vaccine mandate or new piece of research is promulgated or disputed: comments about health implications, peoples' liberties, their duty to others, and political authority surge on twitter, Facebook, and other social media; stories about people's reactions and legal and political arguments appear in newspapers and on tv; people form perceptions within their social and political networks or on their own. Perceptions can have many aspects: some will focus on vaccines and the disease—from perceptions that vaccines are foreign substances with unknown effects or that they are unnecessary, to confidence that they are safe and well understood, that they are life-saving, that they can end other harms the disease causes. Other perceptions will focus on the role of the state and its institutions and on employers: what are the limits of authority; who is trustworthy? Some perceptions will focus on mandates and their implications: will I feel safer if those around are vaccinated? Do I fear losing my job? Some perceptions will be about other people's perceptions: will people follow the mandate? Will there be protests or boycotts? Should there be concerns about other efforts at controlling disease?

Stage 2: Changed perceptions may change individual behavior: will previously unvaccinated people become vaccinated? Will they develop greater resistance? Will people try to influence others in their networks, or protest, or

initiate legal action? Will other vaccination efforts be affected? Institutional behavior may change as well: mandates may be changed or canceled, or new mandates may be introduced; communication efforts may be altered.

Stage 3: Altered decisions to vaccinate will alter risks. Altered mandates and communications may alter decisions and lead to further changes in risk. Spillover effects may occur in other vaccine situations and other vaccine-controlled diseases. Such spillovers may involve new communications that further alter behaviors.

Feedback: Individual and organizational behavioral responses may influence further communications as communicators react to the responses of their audience and attempt to encourage or discourage vaccine acceptance. Influences may propagate broadly and very rapidly through social media facilitated by media algorithms

Context: What has been the recent history with health care policy and response to the disease? To other diseases? How has the rollout of various vaccines proceeded? Is there a legacy of controversy? Are there active anti-vaccine efforts already underway? To what extent are various institutions trusted? How completely are social groups and their communication channels separated from each other? What is the political environment? What religious attitudes are prominent? What is the economic and social environment? What populations are particularly vulnerable or have limited access to health care?

This example is illustrated in Figure 3. As with Figure 1, a complete analysis would fill in considerable detail.

7 | RECOMMENDATIONS AND CONCLUSIONS

It is fair to conclude from the examples we have presented, both recent and old, and from the associated analysis, that as vaccine hesitancy has increased, the study of vaccine hesitancy is entering a new and more mature stage. The social amplification of risk framework can still provide needed guidance, but the framework must be revisited to be responsive to new conditions. Two critical aspects that require deeper study are: (1) the complex characteristics and dynamics of the digital landscape through which much communication now occurs, and (2) the characteristics of the complex social systems that form the context in which information and misinformation about vaccines influence vulnerability to hesitancy or rejection of these and other medical interventions. A better understanding of approaches to reduce potentially harmful hesitancy is emerging. However, a critical aspect which needs more attention is to bring in more risk assessment and anticipatory measures in place of reactive responses devoted to debunking misinformation rather than addressing the fertile ground which fuels its spread.

In its original formulation little attention was given to how SARF could have practical application to risk assessment and risk management beyond its use in risk characterization. That was a reasonable choice at the time, since there was little actual experience using the SARF. Thirty some years later, however, considerable experience has accumulated; the vaccine and recent COVID-19 experience show that there is a great need for SARF applications that can help in mitigating some of the undesirable consequences associated with social amplification.

The SARF, in an updated configuration, should offer guidance in developing four critical aspects of a robust approach to alleviate harmful hesitancy:

1. Identify and characterize deep pockets of harmful misinformation or efforts to undermine public trust with a view toward developing effective interventions to build confidence in science.
2. Develop better approaches and messages that can be deployed more quickly in response to potentially harmful messaging.
3. Identify appropriate efforts that will enhance capabilities of communicative and interpretive processes to create resilience against the amplification of harmful messaging and influencing.
4. Develop better diagnostic capabilities for identifying locations, population groups, and situations that are vulnerable to harm with the goal of finding approaches to reduce such vulnerability.

Vaccine hesitancy is a still growing phenomenon. It is a prime example of the social amplification of risk, and it points to the need to further develop the social amplification of risk framework. The digital revolution has profoundly altered communication and the development of new forms of social networks and their influence; the framework must take better account of these new dimensions and their role in the amplification of risk. The dramatic change in the landscape has brought into prominence the systemic nature of the realms in which social amplification occurs. It is not sufficient to consider how messages and perceptions can be amplified, suppressed, or distorted in isolation: a complex context is almost always salient and other concerns and messages will be important considerations in identifying potential vulnerabilities. For the social amplification of risk framework to better inform risk management and risk governance, attention to uncertainty and to changes in context will be aids to adaptive approaches; again, a critical aspect will be achieving an appropriate balance between proactive and reactive efforts.

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