Title

A public health research agenda for managing infodemics: Methods and results of the first WHO infodemiology conference

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Abstract

Background: An infodemic is an overflow of information of varying quality that surges across digital and physical environments during an acute public health event. It leads to confusion, risk-taking and behaviors that can harm health and lead to erosion of trust in health authorities and public health responses. The global scale and high stakes of the emergency have made responding to the infodemic related to the COVID-19 pandemic particularly urgent. Building on diverse research disciplines and expanding the discipline of infodemiology, more evidence-based interventions are needed to design infodemic management interventions and tools, and implement them by health emergency responders.

Objective: WHO organised the first global infodemiology conference, entirely online during June-July 2020, and a follow up August-October 2020, to review current multidisciplinary evidence, interventions and practices that can be applied to the COVID-19 infodemic response. This resulted in a public health research agenda for managing infodemics.

Methods: As part of the conference, a structured expert judgement synthesis method was used to formulate a public health research agenda. One hundred and ten participants represented diverse scientific disciplines, from over 35 countries and global public health implementing partners. The conference used a laddered discussion sprint methodology by rotating participant teams, and a follow-up managed process to assemble a research agenda based on the discussion and structured expert feedback. This resulted in a five-work-stream frame of the research agenda for infodemic management and 166 suggested research questions. The participants then ranked the questions for feasibility and expected public health impact. The expert consensus was summarised in a public health research agenda which included a list of priority research questions.

Results: The public health research agenda for infodemic management has five work-streams: (i) measuring and continuously monitoring the impact of infodemics during health emergencies; (ii) detecting signals and understanding the spread and risk of infodemics; (iii) responding and deploying interventions that mitigate and protect against infodemics and their harmful effects; (iv) evaluating infodemic interventions and strengthening the resilience of individuals and communities to infodemics; and (v) promoting the development, adaptation and application of interventions and toolkits for infodemic management. Each work-stream identified research questions and highlights 49 high priority research questions.

Conclusions: Public health authorities need to develop, validate, implement and adapt tools and interventions for managing infodemics in acute public health events in ways that are appropriate for their countries and contexts. For that to be possible, infodemiology provides a scientific foundation. This research agenda proposes a structured framework for targeted investment for the scientific community, policymakers, implementing organizations and other stakeholders to consider.

Keywords

Infodemic, infodemiology, infodemic management, research agenda, research policy, COVID-19, SARS-CoV-2, community resilience, knowledge translation, message amplification, misinformation,

disinformation, information-seeking behavior, access to information, information literacy, communications media, internet, risk communication, evidence synthesis, attitudes, beliefs

Introduction

A pneumonia of unknown cause detected in Wuhan, China, was first reported to the World Health Organization (WHO) Country Office in China on 31 December 2019. The disease, caused by a novel coronavirus (SARS-CoV-2), was subsequently named coronavirus disease 2019 (COVID-19) and declared a Public Health Emergency of International Concern (PHEIC) on 30 January 2020. On 11 March 2020, WHO characterized the outbreak as a pandemic. Globally, as of 23 August 2021, there have been 211 373 303 confirmed cases of COVID-19, including 4 424 341 deaths, reported to WHO [1].

On 15 February 2020, WHO Director-General Tedros Adhanom Ghebreyesus raised the concern that the epidemic was accompanied by an infodemic [2]. An infodemic is an overflow of information of varying quality that surges across digital and physical environments during an acute public health event and makes it difficult for people to find information to better protect themselves and their communities [3]. An infodemic can lead to confusion, misunderstanding of health information, risk-taking and behaviors that can both harm health, hinder the public health response and lead to mistrust in health authorities. [4]. Therefore, people need timely, accurate, and accessible information in the right format and amount during epidemics to adopt health-promoting behavior to protect themselves, their families, and communities against the infection.

The International Health Regulations (2005) lists risk communication as one of eight core capacities that WHO Member States need to build and sustain as part of a global agreement to strengthen national and global systems to detect and respond to public health threats [5]. Risk communication and community engagement (RCCE) are important approaches for developing and disseminating accurate information, and have been associated with more successful empowerment of affected local communities in outbreaks [6]. Experiences from HIV, Ebola, Zika and Polio epidemics have demonstrated the cost to public health and health systems when rumors and misinformation are amplified in an environment where there is already a high level of distrust, which is aggravated by a poor public health communications response [7]. In a public health emergency or outbreak, existing service delivery may be disrupted and health authorities may not yet know the facts and have adequate evidence, leading to an information void, causing confusion and anxiety in the affected population [8]. If information voids are not responded to with high quality health information, they can quickly be filled with misinformation and disinformation. Pieces of information of unknown validity can be benign and transient, or they can be false, causing damage if they affect individual and community decision-making. Rumors can be detrimental to health, especially in emergencies and crisis situations [4]. Rumors, unlike misinformation or disinformation, may turn out to be true, and can be either persistent and long-standing, or evolve quickly after an acute event [4].

Overall, health emergencies give rise to information overload, which has been shown to influence people's behavior, risk perception and protective actions during health emergencies [9] and subsequently give rise to information avoidance. In emergencies, affected individuals and populations may have difficulty processing complex information and may retain only some of the early information they receive. In such circumstances, rumors can propagate quickly, challenging emergency responses that rely on the affected population to follow accurate health advice and enacting behaviors to protect individual and community health [8].

Even though rumors and health misinformation have been around just as long as diseases, today's environment is different. What has made the COVID-19 infodemic such an unprecedented challenge is

the fact that we are experiencing an epidemic in a digitized globalized society. Digital tools and technologies have not only changed the way we communicate, but have also changed our lives, the way we live, work, interact and build our social identities and sense of community. For example, rumors and information have travelled across borders very quickly and influenced traditional media news cycles and coverage, emotive misinformation travels much more quickly across the digital media than fact-based health information, and epidemic control decisions or controversy in one country cause debate and comparison with response in other countries [9].

This has put a strain on not just how to communicate the evolving scientific knowledge, but also how public health authorities can implement a more nimble pandemic response that addresses the needs and concerns of local communities. During the COVID-19 response, health authorities have faced full-on the changed information and communication ecosystem [10] and its challenges, such as:

- computational amplification of polarizing messages over factual ones, and use of bots and cyborgs to manipulate the outcome of online petitions, change search engine results and boost certain messages on social media;
- wide-spread micro-targeting of social media users that is enabled by the social media and search engine platform business models, putting individuals into their own personalized "information bubbles"
- changed practices in TV and radio newsrooms that enable dissemination and amplification of poor-quality information that originates online
- weakened local media and collapse of local journalism, which has enabled for mis- and disinformation to take hold

In response to the infodemic, health authorities have needed to build partnerships beyond their usual networks - with fact-checkers; broader groups of media and journalists; social media, search engines and digital interaction platforms; community organizations; civil society; and others. But there is still room for improvement based on experience from COVID-19 response. For example, while factchecking organizations are relatively mature across the world, half of them do not work with health professionals when factchecking and debunking health-related claims, leaving room for better collaboration with health authorities and medical associations [11]. And whereas communication campaigns can raise visibility of a set of messages, they are often not effective at debunking false claims, which require more quantitative and qualitative pretesting of messages and must respond to questions, concerns and narratives that are currently capturing attention of people, in a specific geographical area or a vulnerable community [12]. Mis- and dis- and mal-information (also referred to as information disorder) are major and growing challenges, not only for emergency response but also other societal actions [10].

Because of these challenges, the infodemic is not only a communication challenge, but a challenge of the whole information ecosystem. Already at the beginning of the pandemic in April 2020, WHO crowdsourced a framework for managing infodemics that calls for a whole-of-society involvement and response [3]. This framework recognized that in the digitized society, the harmful effects of the infodemic cannot be managed through the prevailing approaches to communication, community engagement, and messaging alone. Infodemic response must take into account the information ecosystem, the ways we interact within the information ecosystem and how information affects our health behavior. Consequently, this dynamic environment requires interventions across multiple levels such as individual, community, medium, platform, policy, and others. The WHO infodemic management

framework called for a multidisciplinary research agenda that informs the use of evidence-based interventions and surveillance across all phases of an epidemic [13], which led to the convening of this technical conference.

Between June and October 2020, the WHO Information Network for Epidemics (EPI-WIN) organized a global online technical conference followed by an asynchronous expert review exercise to develop a public health research agenda for infodemic management [3, 13-17]. It was a transdisciplinary scientific consultation and review that gathered infodemic insights and approaches from as wide a range of relevant fields to inform and expand frameworks in infodemiology. Along with strengthening the foundations of an expanding infodemiology discipline [18] and creating the research agenda to direct focus and investment in this emerging field, other aims of the conference were to improve understanding of the multidisciplinary nature of infodemic management; identify current examples and tools to understand, measure and control infodemics; and establish a community of practice and research, preparing the ground for sustainable, long term practices for responding to infodemics. The full conference report is available on the WHO website [19]. This paper summarizes the methods and results of the research agenda and development of research questions development.

Methods

The research question prioritization exercise was designed in line with the WHO research agenda development guide for staff [20]. Held in the context of the COVID-19 pandemic and travel restrictions in place, the consultation necessarily took place online via videoconference. The virtual discussions took place over eight meeting days during four weeks in June-July 2020 which resulted in a research agenda frame and a list of priority research questions. This was followed by asynchronous email communication from August to October 2020, during which participants were led through a structured expert opinion exercise to review and prioritise research questions within the set research agenda frame. IRB review was not sought because the work described in this paper was based on observation of discussions at the conference, and focused on synthesis of expert opinion following Chatham House rule [21]. No personal information was collected from the participating experts.

Format of the virtual conference

The 110 invited participants represented over 35 countries across 19 time zones, with a 56% to 44% gender split in favour of women. They were academics selected by the organizers for relevance of their publication record in the past two years for the purpose of this consultation, or practitioners who were working in pandemic response. Additional 60 invited academics were not available to participate. The conference participants represented 20 different academic and professional fields such as digital health, computer science, communications and graphic design, media studies and journalism, history, applied mathematics, information science, data science and computational social sciences, complexity science, social and behavioral sciences, ethics, governance, marketing, user experience and design, and were joined by colleagues from the fields of risk communication and community engagement, epidemiology and public health, as well as global public health implementing partners. Conflicts of interest were reviewed in accordance with WHO procedures for management of declaration of interest for expert

consultations [22]. The conference and follow-up communication were supported by a team of 49 organizers.

The meeting took the format of plenary sessions at the beginning and end of the conference, and an in-between working session with four discussion sprints. Each participant was engaged in the meeting process for 18 hours (10 hours in plenary and 8 hours in topic discussions). Participants were split into four teams, grouped by similar time zone location, but ensuring academic and practitioner diversity of the teams. Each team met four times for two-hour "sprint sessions" of intense discussion on one of four topics, led by dedicated "topic masters" (scientific facilitators). The topic masters were scientists established in their scientific disciplines; seven were academics employed by universities, and one was a WHO staff with an academic affiliation. As the teams rotated from topic to topic, the topic masters facilitated discussions to collect insights from the discussion and validate expert opinion they had collected from discussion with preceding teams. By the end of the process, each team had discussed each topic, and each topic was discussed with four teams in an additive fashion —a total of 32 sprint hours of expert discussion.

The discussion sprints were oriented around four topics, which mirror the epidemiological method for outbreak detection and management across the phases of the epidemic curve, enabling the actions of "preparing, monitoring, detecting, intervening, strengthening and enabling" infodemic management. The topics were: (i) How to measure and monitor digital and physical information environments; (ii) How information originates and spreads; (iii) How information affects individuals and populations, and (iv) What interventions work to protect and mitigate against mis- and disinformation. By the end of the working session, a frame for a research agenda emerged based on the feedback from all the team discussions, seeded with draft research questions that were identified by the discussion facilitators.

In addition, the facilitator leaders of each of the four discussion streams at the conference summarised the discussions they had with all four teams of participants. Their reports summarised discussions about the main suggested research questions for the research agenda, enablers and challenges to researching them. This initial collected set of research questions became the basis for the follow up after the conference.

Asynchronous expert ideation and prioritization exercise

After the virtual conference, the same participants were led through a three-month asynchronous structured exercise which aimed to collect and rank research questions and to guide towards a refined research agenda. The exercise collected structured expert judgement through an adapted Delphi consultation using the Investigate Discuss Estimate Aggregate (IDEA) protocol (11). The method involved asking the participants to devise and submit research questions that were relevant to the topic, answerable in the short or medium term, ideally capable of producing knowledge that could be put to use in the short or medium term, and focused in scope (i.e., an answer to the research question should be provided in a single academic paper). They were also asked to focus on what would be scientifically feasible to answer and that had an expected public health benefit. To improve reach beyond the pool of conference participants, each expert could invite up to two additional experts, based on their expertise and the value of their potential contributions. In total 38 experts submitted additional research questions to the pool of candidate research questions and the following ranking survey. To maximize

transparency in the categorization, experts could themselves choose under which (sub-)category to submit a research question. To identify potential gaps in the overall research agenda, the survey included open-ended questions.

A list of candidate research questions was built by combining the questions that were proposed by the topic facilitators based on the discussions at the conference and those that were collected through the survey round after the conference. The collected candidate research questions were assessed for topic overlap and scope, and edited and merged for clarity by three reviewers. The three experts were present in the discussions during the conference and are co-authors of this paper. Two are staff of health authorities and one is an academic. This reduced the questions down to a consolidated list that was used in the research questions ranking exercise.

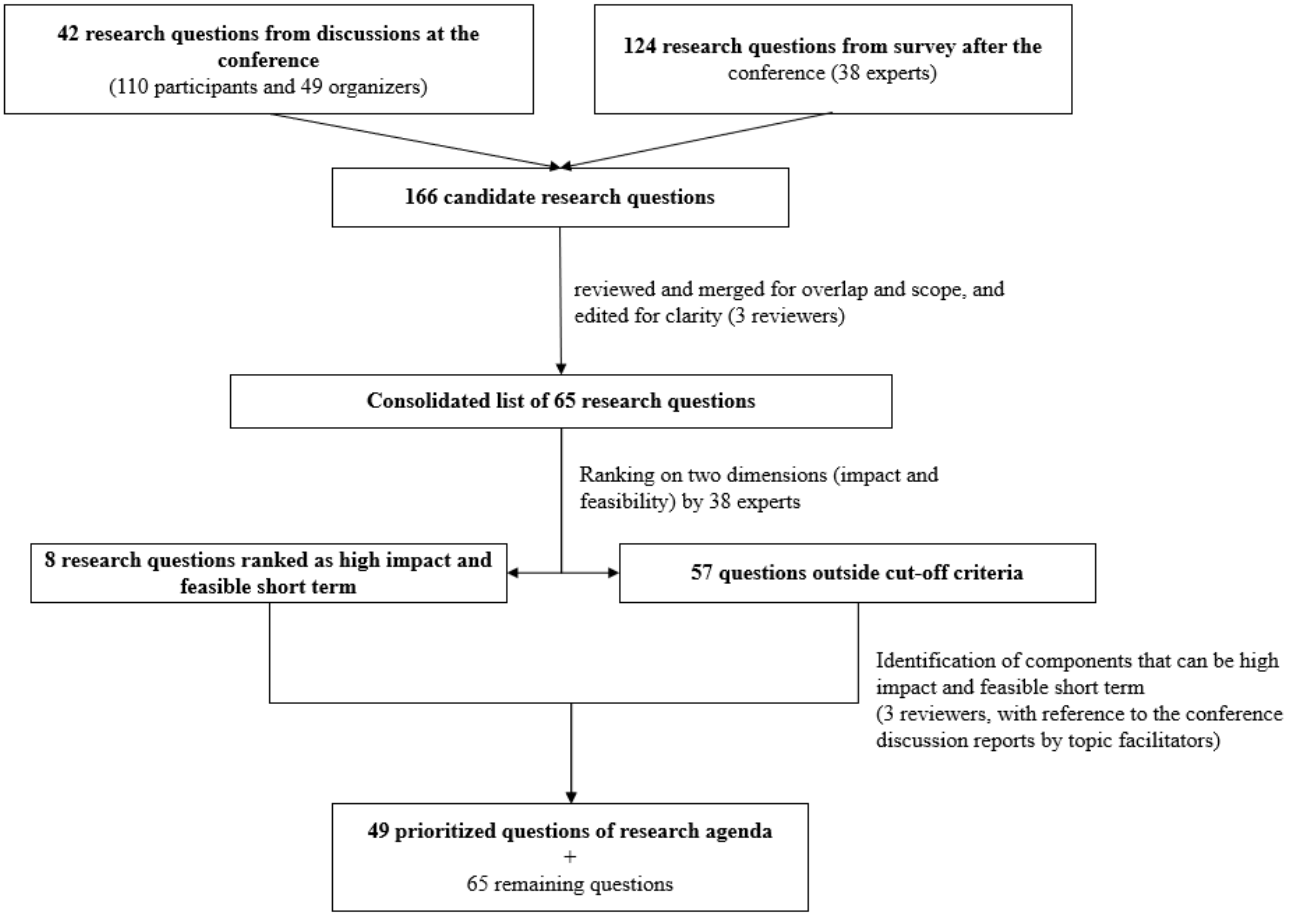
The questions in the consolidated list were then anonymously scored and ranked through another exercise by using the LimeSurvey platform [23]. There, participating experts were asked to rank the research questions based on two dimensions: public health impact and feasibility. These two ranking indicators were selected to point the agenda to evidence that can quickly or with high impact inform COVID-19 infodemic response, anticipating its importance in light of pandemic fatigue, protracted use of public health and social measures to manage the pandemic, and ahead of eventual introduction of COVID-19 vaccines. Public health impact was assessed through the question: Can this research lead individuals or communities to take healthy actions or help understand why and how they do not take healthy actions? Research questions that could lead to meaningful change or adaptation of behaviors would be considered more impactful. Experts were asked to rate each question on a 5-point Likert scale (1 = Very low impact, 2 = Minor impact, 3 = Moderate impact, 4 = High impact, 5 = Very high impact). Feasibility was assessed through answering the question: Can you think of a research project that would answer this specific question in about set number of months? The faster the research project could be initiated and deliver results the higher feasibility and usefulness for the COVID-19 pandemic response. Experts were asked to rate this question on a 5-point Likert scale (1 = 3 months, 2 = 6 months, 3 = 12 months, 4 = 18 months, 5 = 24+ months, based on emergency response planning time periods). A research question was considered high priority when it scored above 3 on impact and below 3 on feasibility.

To reduce potential survey fatigue and to avoid systematic missingness in the rankings (i.e., due to respondents ranking only the first few questions within each stream), the order of the research questions to rank was randomized within each research stream. The randomization was carried out via the LimeSurvey platform. Following the ranking exercise, four experts reviewed the questions that fell outside the prioritization area – below the 3.5 consensus impact rank and with feasibility of over a year. The four experts were three that previously reviewed the submitted research questions, with an additional staff of a health authority who is not co-author on this paper. The fourth health authority staff was added because the research agenda questions were to be feasible in short time frame or highly important to health authority response to the infodemic. The experts reviewed the questions outside the cut off and on consensus identified prerequisites or parts of these research questions that could be delivered with quicker feasibility and high public health impact. These research components were added into research agenda as research questions.

This exercise whittled the questions down to a shortlist of top priority and second tier priority questions per work steam, totalling 49 priority research questions. The remaining set of questions that were part of the exercise and did not make the prioritization cut-off was retained for reference and they can be

used for future reviews. The results of the recursive refinement of research questions through structured expert judgement exercise is summarised in Figure 1.

Figure 1: Research question refinement through structured expert judgement process.



Results

Themes that emerged during the discussion sprints

The discussion at the virtual conference reflected the complexity of the information ecosystem and the way it influences the strategies for managing the COVID-19 and other infodemics to support health behaviors and the management of epidemic risk. Several themes surfaced in topic discussion sprints. as follows.

A common theme across discussions was that it is necessary to identify reproducible patterns and cross-disciplinary metrics for the science of infodemiology. Because access to full data sets from social media is rare and they do not represent the engagement of all populations, and because metrics vary from

platform to platform, it is difficult to produce generalizable or comparable results. Mathematical modelling, such as epidemiological modelling, does not necessarily take human behavior into account, which can limit its efficacy to predict future human behavior and impact on an outbreak; however, modelling can help develop hypotheses for how information/infection flows, how networks might respond, and how to design interventions to test them. There are also limits to applying the epidemiological framework as a way to monitor and measure spread, especially if we assume that the unit we are working with is information, instead of a virus, because viruses do not have an agenda and they infect opportunistically. Detangling the differences between rumors, misinformation and disinformation requires a common taxonomy of information classification, some of which may be labelled as more harmful or less harmful. This could inform identification of the "tipping points" or when action needs to be taken to address more harmful misinformation by offering a more tailored and effective response.

While it is important to describe the flow of health information, there needs to be a balance between a system-level understanding that washes over details and a case-study understanding that which captures details but may miss the bigger picture. There is an ocean of social and behavioral and health data available, however, determining which data sources and types of analyses would improve a response needs a clearer definition. The degree of detail is needed to understand the infodemic whilst balancing privacy and ethical concerns and managing limited analytic capacity in short time-frames should be discussed. Amidst of a pandemic, speed is of the essence, and balancing rapid data collection and analysis methods with the desire for rigor may mean prioritizing specific kinds of data for short term operational use versus longer term, longitudinal trend analysis and use. Understanding the diffusion of information through certain networks may require other data collection approaches, and discuss how closed messaging apps and offline networks challenge this.

One area of research that needs further research is the extent to which offline behavior is being influenced by online behavior (and vice versa). There is limited research on how exposure to information or misinformation affects behavior because behavioral processes can be quite complex. Amidst a crisis, people might end up using cognitive shortcuts, rely on the first information they hear and may be less adept at processing more complex information. At the same time, there is little known about the longitudinal effects of the exposure to false claims that may not seem harmful at any one point in time, but could have a cumulative harmful effect over time. In addition, when misinformation is easy to spread, this can create a harmful mixture. Anecdotal evidence suggests that people can exhibit negative health behaviors because of misinformation they heard during the COVID-19 outbreak, however, we need better measures of how knowledge connects to intent and behavior, both online and offline. For example, does increased exposure to misinformation make it more likely that someone will exhibit a behavior detrimental to their health? Further research is needed to develop better monitoring metrics, in addition to consolidated and validated indicators that predict behaviors or serve as proxies for specific behaviors.

The participants also emphasised that there is an interplay between the information ecosystem actors and the resilience of the communities and individuals. It was agreed that trust is a key element of building resilient communities. This leads to the need to establish and maintain trustworthy information sources. Some work must be done on identifying these sources of information and ensuring easy and equal access. The discussions also highlighted the urgent need to empower communities to manage

infodemics and build resilient communities, through co-designed interventions. This would be possible by understanding the context where infodemics occur and spray. Community engagement goes along with building self-efficacy and self-capability, through practice. It should focus on the "middle-ground", the majority of "silent lurkers" – those who have not yet formed strong opinions. Besides individuals and communities and states, the private sector should be regarded as actors as well. The internet platforms can be active vectors or targets of campaigns and are partly also influential members of the communities.

When considering long term interventions, critical thinking and literacy (e.g., health, information, digital, media) play an important role as a basis for interventions to address infodemics. Health literacy is a major topic in health communication research and practice. It includes critical literacy as the ability to evaluate and apply health information, and is considered a major asset in managing an infodemic. Similarly, information, news, digital, and media literacies contribute to individuals' ability to distinguish high from low quality information, especially online, and the ability to improve offline lives from digital technology use. Research into each type of literacy has developed in isolation, and questions remain on how to empower populations in thinking critically, what normative models of thinking are most appropriate for an infodemic, who is responsible for building literacy, and how literacy efforts can be integrated into existing societal systems (e.g., school education) and be adapted to reach populations outside of the traditional educational settings.

To help prioritise interventions and actions, it is also necessary to identify priority populations based on key vulnerabilities. Population studies need to be carried out to identify specific individuals and groups of individuals at the greatest risk of not being able to critically assess misinformation and spreading it. This should include studying people's perceptions, beliefs, knowledge and the barriers, and facilitators that can affect the access to and the evaluation of credible health information, and its use in offline life. Additionally, the alignment of information vulnerabilities with disease vulnerabilities should be considered.

Public health research agenda for managing infodemics

In addition to reviewing the current evidence and research gaps across different scientific fields, the conference sought to identify a research frame that could structure a public health research agenda for infodemic management. The aforementioned themes that emerged converged to broader research gaps landscaping (such as: the need for better monitoring and metrics; localized and systems level characterization of infodemics; understanding the components of the information ecosystem, individuals, communities, states, private social media platforms), and also focused on some specific areas of knowledge gaps or promising interventions (such as: understanding the linkage between online and offline behavior; the role of critical thinking and health literacy; and identification of priority populations). A research agenda frame would need to facilitate bridging the gap between the evidence and gaps that will be filled, and the public health practice in health authorities. Therefore, conference participants agreed to frame the research agenda frame analogous to the lens of epidemic management, and fit the themes, issues and gaps identified to this epidemiological frame (see Figure 2). The framework's streams were built on the activities of a health authority that support outbreak response along the phases of an epidemic curve [24] - prepare and monitor, detect, intervene, strengthen and enable infodemic response:

- Stream 1 supports the preparedness and monitoring of infodemics through measurement and monitoring of impact of infodemics. Standardised metrics and measurement tools can help characterise infodemics online and offline, identify absence of information where misinformation can gain more traction, and can help recognize tipping points when detailed investigations need to take place. Lastly, evaluation of infodemic management interventions need more elaboration.
- Stream 2 addresses the need to detect and understand the spread and impact of infodemics. In the context of infodemics, communities and vulnerable groups are not defined anymore only in terms of geographies, but can also be formed through shared values, goals or motivations. Development of interventions therefore needs localised contextualised understanding of the infodemic, how misinformation affects behaviors in vulnerable groups, and understanding of what are the ethical and regulatory approaches for mitigating the spread of misinformation.
- Stream 3 addresses the response and deployment of interventions that protect and mitigate the infodemic and its harmful effects. Thinking about implementation of interventions needs to be built into the infodemic management activities and research, so that the research is linked to what health authorities need to respond. To achieve this, behaviour/change models relevant to infodemic management needs to be developed, and interventions need to be designed
- Stream 4 aims at research that strengthens infodemic management by development of common frames to improve interventions development and programmatic response to infodemics. Using the continuum of community engagement, local cultural context, and building resilience to infodemics and misinformation at individual, community, platform and societal levels are addressed.
- Stream 5 supports the overarching aim to strengthen infodemic management practice by enhancing transferability of lessons learned and evidence-based interventions between contexts, countries and infodemics. The information ecosystem and socio-economic determinants of access and use of health information differ across countries; we therefore need to understand how interventions can be successfully transferred across countries and what impact they would have in other settings.

Figure 2: The frame of the research agenda mapped onto the phases of epidemic preparedness and response.

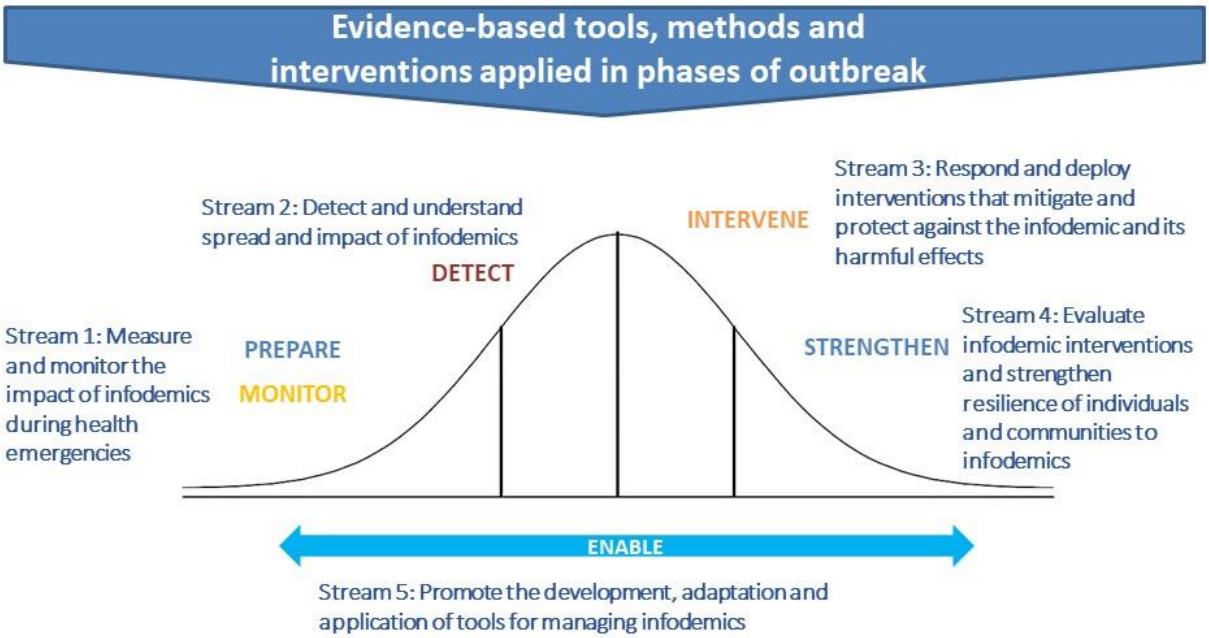


Table 1: Framework of the public health research agenda for managing infodemics.

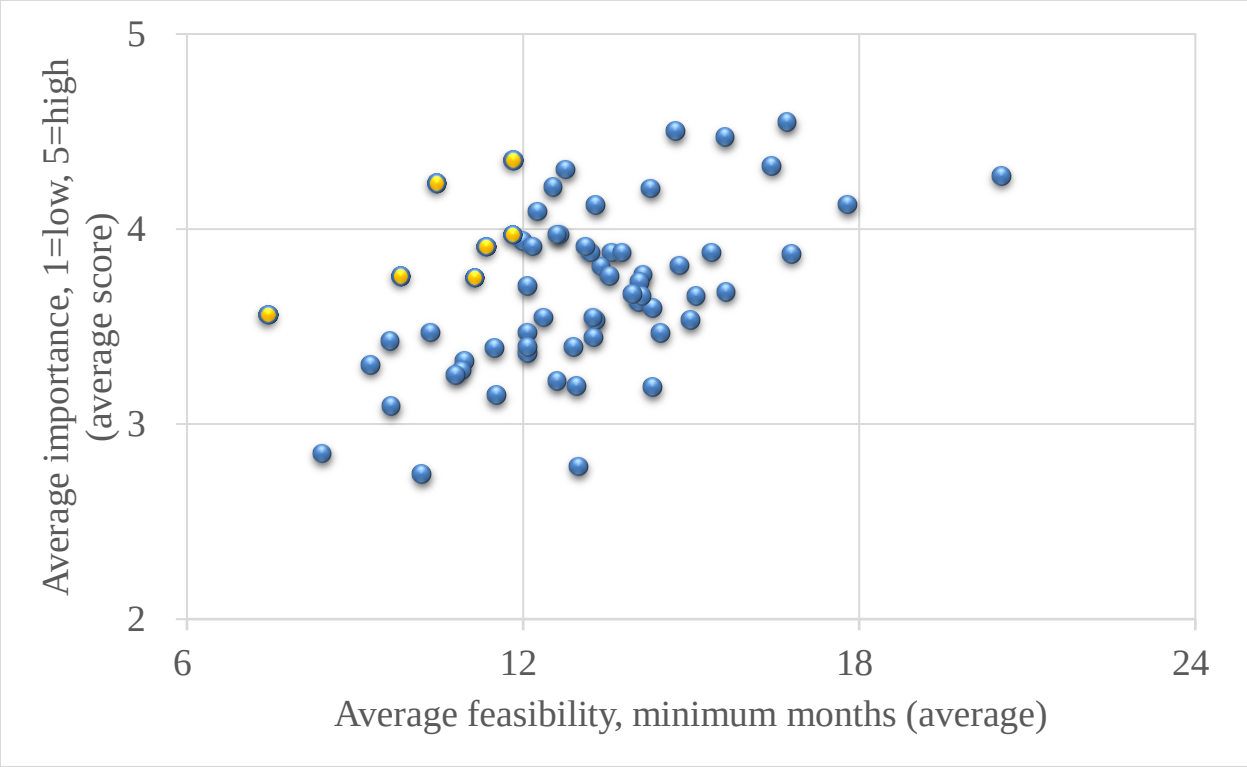
Stream	Subtopic
Stream 1: Measure and monitor the impact of infodemics during health emergencies	1.1. Standardize taxonomies and classifications 1.2. Develop new metrics to measure and quantify infodemics 1.3. Analyse and triangulate data from multiple sources 1.4. Improve evaluation approaches for infodemic interventions
Stream 2: Detect and understand the spread and impact of infodemics	2.1. Understand how information originates, evolves and spreads on different platforms and channels 2.2. Assess the role of actors, influencers, platforms and channels 2.3. Understand how misinformation affects behavior in different populations 2.4. Develop regulatory and ethical principles to mitigate the spread and propagation of harmful health information
Stream 3: Respond and deploy interventions that mitigate and protect against the infodemic and its harmful effects	3.1 Design behavioral/change model applicable to infodemic management 3.2. Design interventions for different levels of action to mitigate the infodemics
Stream 4: Evaluate infodemic interventions and strengthen the resilience of individuals	4.1. Develop interventions that address individual, community, cultural and societal-level factors affecting trust and resilience to misinformation

and communities to infodemics	4.2. Understand and learn from how misinformation has affected behavior among different populations and in different contexts for specific infodemics 4.3. Identify factors associated with successful infodemic management by health authorities, the media, civil society, the private sector, and other stakeholders
Stream 5: Promote the development, adaptation and application of tools for managing infodemics	5.1. Use implementation research evidence in programme improvement and policy development 5.2. Promote evidence-based interventions and approaches among countries 5.3. Improve effectiveness and response times to the infodemic during acute health events

At the conclusion of the conference, 42 research questions were collected from the topic discussions, curated by the scientific topic facilitators. During the follow up research question generation exercise, 38 experts had submitted an additional 124 research questions, across five research streams and 16 subcategories. This added up to 166 candidate research questions. These research questions were reviewed and merged for repetition, overlap and scope; they were then edited for clarity by three reviewers. Suggestions that were not formulated as research questions were excluded. This review identified a high degree of overlap and repetition, pointing to a saturation of topics submitted for the ranking exercise. It resulted in a consolidated list of 65 questions that underwent the ranking exercise.

The research questions to be ranked were evenly distributed, with at least 10 questions included for ranking in each of the five research streams (18 in stream 1, 16 in stream 2, 10 in streams 3 and 4, and 11 in stream 5). The ranking exercise results for these questions are depicted in Figure 3.

Figure 3: Ranking of surveyed research questions across two indicators, public health impact and feasibility.



Note: Research questions that were within the cut-off limit of minimum 3.5 impact and less than 12 months feasibility are marked yellow. Questions that were ranked outside the cut off limits were reviewed and broken up into additional smaller component questions that were of high value.

Following the ranking exercise, four experts reviewed the results. Based on the ranking exercise, only eight research questions covering streams 1, 2, and 3 were prioritized with a consensus rank greater than 3.5 and feasibility of under a year. Therefore, the experts reviewed the 8 ranked and the remaining 57 questions that fell outside the cut-off limit. Based on their expert judgement and guidance from the reports of topic discussions during the conference, they identified precursor questions or components of these research questions that could be delivered with quicker feasibility and/or higher public health impact. The experts worked with the goal to use the questions and the feedback collected in the ranking exercise and used them as a guide to formulate research questions that can be their precursor. They worked on consensus and formulated the final list of 49 research questions, and retained the additional 65 questions for future reference.

Expert review of the results of the ranking exercise identified three top research questions per work stream, resulting in a list of 15 top priority research questions for the public health research agenda for infodemic management (Table 2). Further, a second tier of important research questions was set for each sub-topic, totalling 34 questions. The multimedia appendix shows prioritized research questions and agenda in more detail, as well as the additional 65 other research questions that were not identified as a high priority in the short-term [see Additional file 1]. These can be used to map further evidence gaps on the topics and for reference and guidance in subsequent research agenda reviews [19].

Table 2: Top 15 research questions across five streams of the research agenda.

Stream	Top three questions per stream

Stream 1: Measure and monitor the impact of infodemics during health emergencies	• What are ways to score health-related misinformation according to its potential for harm (to people's health and behaviors; social cohesion; trust in health service delivery, government, communities, media, etc.)? • How do the infodemic curve and measures of spread and impact change over time during the phases of a disease outbreak? • What are the potential indicators or their proxies for measuring trust, resilience, behavior change, exposure to misinformation, susceptibility to misinformation, social cohesion, depth of community engagement, etc.?
Stream 2: Detect and understand the spread and impact of infodemics	• How does misinformation mutate, adapt or get remixed between infodemics and within infodemics? • What are the strategies used to reduce misinformation's potential harmfulness in closed networks (online and offline)? • How do different types of health misinformation affect online and offline behavior and what are some measures that can help forecast the impact of the health misinformation types on behavior?
Stream 3: Respond and deploy interventions that mitigate and protect against the infodemic and its harmful effects	• What behavioral or process models can inform the development of an infodemic strategy and measure its impact at the individual, community, platform or societal level? • What are the promising interventions at the (societal/community/individual/health systems) to address and mitigate health misinformation? • What types of participatory or human-centered design approaches can be used to produce more tailored and more effective infodemic management interventions?
Stream 4: Evaluate infodemic interventions and strengthen the resilience of individuals and communities to infodemics	• How might we define and measure the gradient of community engagement, trust and empowerment at the individual and community level as they relate to infodemic management and reduction of harm from health misinformation? • What are the socio-behavioral, mental heuristics, and design hierarchies that need to be considered when developing an intervention at the individual and community level? • What are the "best buy interventions" to be used by different types of actors of the society, to maximize the impact on the infodemic at a lower marginal cost?
Stream 5: Promote the development, adaptation and application of tools for managing infodemics	• What considerations should be included in the assessment of risk, harms and opportunities during the design and implementation of research and infodemic management interventions? • What would a readiness assessment look like for infodemic preparedness for a new COVID-19 health intervention?

	• What recommendations can be made to update International Health Regulations to incorporate infodemic management more strongly as a core capacity of Member States?

Discussion

Throughout the consultation, discussions built progressively; participants shared a wealth of experience, discussed the challenges and benefits of various approaches, clarified the initial topics, and ultimately achieved a high degree of consensus about the needs that the research agenda would have to meet. The overarching conclusion was the need to complete and implement the research agenda, along with the framework for action [3, 13]. The takeaway action points from the conference are as follows.

Information, misinformation, and public health are intertwined by nature: WHO has dealt with issues at the intersection of misinformation, trust, and demand for health services since it was founded. Lessons from this experience have evolved epidemic response methods, tools and the global response community over time. WHO and other partners who work in the field of public health communication, risk communication and community engagement have been challenged by the scale of the COVID-19 infodemic, which has been amplified by the global digitized information ecosystem. In a new century, addressing new types of outbreaks requires innovative and precise public health tools [25]. Different populations have different information needs, channels, and barriers. Evidence-based interventions are needed at all levels, for individuals, communities, platforms, health systems and societies, to reduce the transmission and impact of the disease. Coordination, connection and integration across disciplines and sectors must be central to expanding the scientific discipline of infodemiology. For the science to be applied quickly in the COVID-19 pandemic, it needs (a) sustained integration across the various disciplines of research; (b) integration between research, practice, and lived experience; (c) to inclusion of representation and voices from different sociocultural contexts in practice and lived experience.

At the same time, infodemic management must broaden its tools beyond communication and consider all components of the information ecosystem [7, 26, 27]. Because the information ecosystem spans both online and offline environments, it is harder to detect and respond to the infodemic in communities, as well as work proactively to build resilience and a healthier information ecosystem overall. Media, policy-makers and the private sector influence the information ecosystem where individuals, interest groups, civil society, academia, factcheckers and others also interact. Partnerships between health authorities, factcheckers, media organizations and other global public health partners, such as the Africa Infodemic Response Alliance [28] are critical to effectively promoting high quality health information and countering health misinformation at local level. RCCE collective service [29] was started in June 2020 to concentrate the RCCE capacities across global RCCE partners. Strengthened partnerships at local levels are also needed to focus on community engagement in offline communities. On the other hand, regulatory interventions could help standardize access to social platform data, ensuring that the data we do have access to is comprehensive and regular. Access to regular and better data/metadata would increase accountability for how a healthier online information ecosystem is built. Based on data availability, it could also facilitate the design of research and interventions to give us a better

understanding of which interventions work online, and the conduct of independent analysis of information provided by the platforms.

Addressing the harms of infodemics is important because they impact health behaviors and are barriers to healthy life and well-being. It is important to better understand proactive strategies that apply social inoculation theory or literacies theory in building resilience. Developing health literacy is critical and includes access to health services literacy and it is dependent on digital nativity/technological skills, access to information, and media literacy/interrogative skills. The reasons why mis- and disinformation spread are complex and, therefore, it is important not to reduce that complexity by framing infodemic management as simply a battle against misinformation [7, 30-34]. It is equally important to reinforce and accelerate health-enhancing behaviors and generate information to help people develop resilience to the information disorder. In the long term, this will help people build trust, make informed decisions and access essential health services, and will have impact much beyond the COVID-19 pandemic.

Given the urgency of pandemic response, the new transdisciplinary practice will have to learn from practice and iteration even as it develops, reporting experience gained through implementation to provide a more evidence on what works and what does not [35]. Ultimately, health authorities need to identify and allocate the necessary capacity to manage infodemics. This is a programmatic and process issue. Once that capacity is in place, decision makers and the private sector need to develop, validate, implement and adapt tools for infodemic management during acute public health events in culturally- and contextually-appropriate ways. The issue of connecting this evolving practice and research is not trivial: the community that implements the research agenda must be, and must remain, a community of practice *and* research that prioritizes questions to inform operations and improve contemporary practice, foregrounding the pragmatic needs of people in the field and on the ground.

We also need to think about how to build systems for social listening and signals detection, and the analysis of infodemic and misinformation. For example, investment is needed to develop a shared, open reference database for characterizing misinformation (including examples) to identify appropriate interventions and when and how to deploy them [36]. Effectively, the content would be re-contexualised to enable characterization and use in the analysis. This database could include different types and source(s) of misinformation, the intent of those creating or sharing misinformation, the degree of inaccuracy (based on the level of expert consensus and scientific evidence that exists), its impact on attitudes or behaviors, the likely audience, its virality, or its alignment with politics. This reference database could be populated with specific examples of misinformation that fall into each domain, which could then be aligned with interventions based on best practices shown to be effective for that type of misinformation. Such a reference database would help to answer questions about differences between the content people will merely share online and content that will affect their decision-making and offline behavior. It would also help investigate whether we can predict from content characteristics the likelihood of spreading a piece of content in different ways.

The community of research and practice could also develop and use a shared “living systematic review” for interventions measured in terms of effectiveness on a set range of criteria, strength of evidence, generalizability, and likely contexts for application. Interventions across disciplines could be collected, with a rubric describing the outcomes against which the intervention has been tested, its generalizability or application to specific populations, the contexts in which it has been tested, its feasibility and costs, and confidence in the findings. This could include determining the consistent metrics appropriate to

evaluating the success of an intervention to prioritize efforts. However, it is unlikely that only one intervention will be successful; a toolkit of different approaches will likely be appropriate. This living systematic review could be aligned with the misinformation reference database to identify gaps where good evidence-based research does not exist to address certain types of misinformation.

Conclusions

The resulting public health research agenda for infodemic management will be maintained on the WHO website as a living document; its implementation and priorities will be reviewed and adjusted on a regularly.

Infodemics impact people including health professionals, globally. Albeit not new, addressing infodemics in the new digitized society is a different and centrally important challenge in responding to the COVID-19 pandemic as well as future pandemics. The research agenda that emerged from this consultation crystallizes themes that can inform initiatives to build the foundations of effective infodemic management in all countries. The main target audience for these research questions are the researchers and practitioners. They will also be of interest to public health experts, NGOs, the media and other stakeholders.

There is a large gap between infodemiology research and evidence that has been generated by the academic disciplines and the response to the infodemics. Tools and interventions, grounded in this evidence, are sorely needed by the health authorities around the world. This is partially because scientific disciplines have worked mostly disconnected on tackling the challenge of information overload, communication, design, media studies, socio-behavioral factors, misinformation, and the ethics and the regulation of information ecosystem. WHO, Member States and partners must close this gap by developing and adopting evidence-based tools that are appropriate for their local contexts. This consultation and the previous infodemic management meeting [3, 13] may have been among the first opportunities for many people working towards this goal to hear about the expertise and activities of others, and to frame the entirety of this activity within the problems of disease control and public health.

Following the conference, WHO partnered with five scientific journals in a joint call for papers for special issues on infodemiology [37], two of which have already been published [38, 39]. The WHO EPI-WIN team has used the outcomes of this conference as the input in the third and fourth WHO infodemic management conferences [40, 41], and the upcoming fifth WHO infodemic management conference which will focus on development of measurement and metrics for infodemic management. The research gaps that were identified have also guided WHO in the review of the COVID-19 research blueprint [42], and in the development of partnerships that foster filling the research gaps and for translation of evidence into use by health authorities and other partners [28, 43]. WHO has also applied evidence and infoveillance methods to inform its own work and contribute to metrics development for health authorities [18, 44, 45].

The challenge of a novel pandemic pathogen intertwined with an infodemic is a double burden that demands action-oriented research to inform public health response. The new research agenda will strengthen the scientific understanding of how infodemics impact populations and their health, but also serve as a basis for action and learning for future preparedness, strengthened through cross-sectoral

pilot projects and continuous after-action reviews to build capacity. After the acute phase of the COVID-19 pandemic, we need to shift the focus to strengthening longer-term capacities and advocating for the inclusion of new tools and indicators. When applied to acute health events, the evolving research discipline of infodemiology can provide crucial evidence and facilitate multidisciplinary expertise and coordination.

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Conflicts of interest

None declared.

Abbreviations

COVID-19: Coronavirus disease 2019
EPI-WIN: WHO Information Network for Epidemics
PHEIC: Public Health Emergency of International Concern
IDEA: Investigate Discuss Estimate Aggregate protocol
RCCE: risk communication and community engagement
WHO: World Health Organization

Multimedia appendix 1

Public health research agenda for managing infodemics (all prioritised and collected research questions)

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