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Promoting Air Quality-Related Awareness and Behavioural Change: A Rapid Review of communication interventions integrating behavioural, science communication and socio-ecological perspectives

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Highlights

- We reviewed 79 interventions integrating behavioural and communication frameworks
- AQ communication interventions are needed to promote awareness and behaviour change
- Advancements in air quality (AQ) monitoring can support better public communication
- Top-down persuasive strategies support awareness but have low behavioural impact
- Participatory strategies are growing and foster protective/mitigating behaviours

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1 Title Page

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Abstract

Air pollution (AP) is a global environmental threat to human health and development. Day-to-day behaviours contribute to poor air quality (AQ) but limited public understanding of AQ warrants effective communication strategies to promote awareness and empower positive behavioural change. Through the integration of behavioural, science communication, and socio-ecological frameworks, this rapid review maps existing AQ-related communication interventions and their influence on AQ awareness, protective and/or mitigating behaviours (i.e., avoiding exposure; reducing polluting

activities), and civic engagement. We conducted a comprehensive literature search of peer-reviewed and grey literature, including 79 studies for analysis. Findings were synthesised narratively and assessed for quality with the QuADS tool. Despite high heterogeneity in intervention types, most served a persuasion or enablement function, often utilising dissemination modes such as websites or web applications, and most assessed awareness and/or engagement in protective behaviours. While most interventions focused on individual/household-level actions and interindividual dynamics, only some considered policy-level actions, and very few embedded infrastructural considerations in their communication. Overall, 47 studies reported positive impacts on awareness and/or behaviours, particularly through participatory approaches, although we noted issues associated with promoting meaningful participation and identified influencing psychosocial factors. Evidence of effectiveness for behaviours was often limited by observational designs and the focus on awareness only or self-reported behaviours/intentions. Our findings highlight growing attempts to communicate AQ-related risks and behavioural solutions through empowering approaches that are sensitive to individual and local circumstances, but note the need for further work to foster mitigating behaviours and civic engagement.

Keywords: Air quality communication; interventions effectiveness; air pollution awareness; protective behaviours; polluting behaviours; civic engagement.

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2 Introduction

Breathing clean air is a fundamental human right, as established by the United Nations General Assembly resolution passed in July 2022 [1]. Despite this, 99% of the world's population is exposed to air that exceeds the recommended WHO's [2] air quality (AQ) guideline values, making air pollution (AP), both indoor and ambient (outdoor), a major public health threat. Breathing polluted air has been estimated to cause over 8 million excess deaths globally every year [3] and also has negative health and economic impacts arising from heightened risk of cardiovascular and respiratory diseases, cancer, and poor mental health [4–8]. A recent analysis found that between 3%-9% of the global population are affected by asthma, with higher rates where AQ is poorer [9]. Not everyone is affected by AP equally; children, pregnant women, older people, those with respiratory disorders, and

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those living in socioeconomic disadvantages, face higher risk levels of exposure to polluted air and negative health impacts [2,10]. From a wider environmental perspective, air pollutants are often released with greenhouse gases during combustion; therefore, addressing AP has co-benefits for climate mitigation [2].

There are geographical variations with regards to determinants of AP, yet across almost all regions, important drivers of polluted air include individual and household behaviours related to motor travel and solid fuel burning for home heating. Technical and structural innovations may ameliorate some of the source of AP, yet there remains a need for behavioural solutions to support the adoption of any new innovation, and reduce the current behaviours that contribute to AP [11]. However, the fact that AP is mostly invisible can make it difficult for people to appreciate how their day-to-day activities influence air quality and impact health, and importantly, how to act on the problem [12–14]. Communication interventions are needed to effectively raise awareness, support exposure prevention and empower a reduction in contributing behaviours [11,15]. As proposed by Michie et al.'s [16,17] Capability, Motivation and Opportunity for Behaviour (COM-B) model, behavioural interventions should aim to promote individual capabilities (both physical and psychological) and nudge motivational drivers, while leveraging opportunities in the social and physical environment that may help with tackling social and health inequities.

Building on the COM-B model, Riley and colleagues [15] reviewed research on AQ communication and highlighted the need for engaging and personally-relevant approaches. Based on their findings, the authors suggested that communication using positive emotional framing, fostering self-efficacy and social norms, providing locally-relevant information, and founded on interdisciplinary engagement, could be effective in promoting protective behaviours (i.e., avoiding exposure to AP), while reducing, to a lesser extent, contributing behaviours (i.e., reducing activities that pollute the air) and fostering more civic engagement around the topic of AQ [15]. Since Riley et al.'s [15] review of academic evidence up to 2018, research on AQ communication has increased and warrants an updated assessment of the available evidence.

The present rapid review builds on Riley et al.'s work to synthesise recent evidence of AQ-related communication interventions aimed at individuals and households, and to assess their influence on awareness and AP-related behaviours. We also mapped intervention functions according to the COM-B model [17]. As discussed in Riley et al.'s findings [15], communication interventions that are centred on community involvement can be among the most effective at eliciting positive behavioural responses, possibly because they enable dynamics of empowerment, ownership, and agency among people. These insights were based on a framework integrating the COM-B model with Berlo's Sender-Message-Channel-Receiver (SMCR) model of effective communication [18]. While the SMCR model

offers a linear and streamlined understanding of communication, it has been criticised for being over simplistic and not considering the social complexities of communication [19]. To address this limitation, in this review we opted to map interventions with a consideration of the level of participation and engagement promoted by different communication processes, and their potential power dynamics; we used to this end a science communication framework from Trench [20] and Bucchi and Trench [21,22]. This proposes three approaches to expert-public interaction that can enable different levels of non-expert engagement in the communication (and knowledge production) process:

- *Dissemination* refers to one-way, top-down, communication approaches, also labelled as deficit models [23], where scientist/experts provide information to an audience that is often considered to be lacking knowledge.
- *Dialogue* refers to two-way communicative interactions between scientists/experts and the public, where the latter are actively involved in the communication, but experts are mainly driven by an extractive logic, aimed at consulting to gather information and feedback.
- P*articipation* refers to a multi-directional model of communication, with interactions occurring not only between experts and the public but also among members of the public. In this model, the public plays a co-leading role in the communication process, through the presence of co-creation and deliberation dynamics.

Furthermore, one of the criticisms towards models of behavioural change such as the COM-B model is that they focus primarily on the individual and offer a limited (if at all) understanding of the systemic factors that may influence certain behaviours [24], especially in relation to "wicked" problems such as AP. The term "wicked" refers to complex problems [25,26] that are caused by multiple interconnecting factors and that lack straightforward simple solutions [24,27,28]. Addressing wicked problems requires a combination of solutions across individual, social and infrastructural levels in order to promote both individual and contextual opportunities [24]. However, to the best of our knowledge, a socio-ecological analysis of existing AQ communication interventions has not been carried out to date. To bridge this knowledge gap, this review looked at whether AQ interventions integrated in their communication approach a consideration of interindividual, policy and infrastructural opportunities for behavioural change in addition to focusing on intraindividual opportunities.

With these three frameworks – COM-B, science communication and socio-ecological model – in mind, the present review aimed to update and expand the current knowledge of what AQ-related communication interventions have been used to promote awareness of AP and behavioural change, and assess which of these interventions have been effective, with the goal of identifying knowledge

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gaps and insights to inform further AQ communication, research, and practice. In addition to updating peer-reviewed academic evidence on the topic [as done in 15], our search also included grey literature and non-scholarly sources such as governmental and non-governmental reports. To our knowledge, such sources have not been reviewed to date but can offer an opportunity to uncover good practices of AQ communication interventions or initiatives.

3 Methods

The methods and search strategy for this rapid review were pre-registered and published in a protocol available at [Anonym]. Rapid reviews are a recent approach to quickly synthesising knowledge and provide evidence-based answers [29]. In line with Tricco and colleagues [30], our review can be considered a rapid review in that we employed a systematic approach to our search design and implementation, but our database searches were limited to the timeframe after a previous systematic review [15] rather than covering all sources from inception.

The development of the review protocol integrated multiple guides, in particular [29,31–34], as the methodological characteristics of this approach have not been completely formalized in shared guidelines yet [30]. This report follows the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines [35] and a compiled PRISMA checklist is included in Supplementary File S5.

3.1 Eligibility criteria

We selected our studies following the Population, Interventions, Comparators, Outcomes, and Study designs (PICOS) criteria, as follows:

3.1.1 Population

Studies where AQ communication interventions involved or were aimed at individuals, households, communities or organisations (e.g., hospitals, schools, occupational settings). After a pilot search, we decided to exclude studies focused on industrial or agricultural settings as these would commonly be involved in technical or engineering interventions. We did not apply exclusion criteria based on geographical or social setting (e.g., urban/rural).

3.1.2 Intervention

Communication interventions related to AQ or AP, whether ambient or indoor, i.e., the transmission or exchange of information related to the state of AQ, and/or the causes of AP, and/or the health or environmental consequences of AP, via any channel, ranging from digital media (e.g.,

apps, websites, social media, sensing technology) to traditional media (e.g., radio advisories, TV) to dialogue and discussions between humans (e.g., healthcare visits at home; school interventions).

Interventions could fit any of the behavioural functions suggested within the COM-B model [16,17] and could use any science communication approach within Trench's [20] framework.

We excluded technical or engineering interventions that did not focus on communication (e.g., installing air cleaning technology without communication). No limitations were set for sources of the intervention (for instance, whether it stemmed from a governmental campaign, research project, civic society initiative, or commercial entity).

3.1.3 Comparator(s)/control

Studies were included even if not involving a control group or comparison. Where applicable, the comparator was regarded as a group that was not exposed to the intervention, as defined by the respective studies.

3.1.4 Intervention Outcomes

We included research that investigated three main types of outcomes:

- Awareness and understanding of AP, AQ, associated causes and/or consequences; AND/OR,
- Behaviours related to preventing exposure to or personal contribution to AP (protective and/or contributing behaviours); AND/OR,
- Civic engagement and public mobilization concerning AQ issues, e.g., through community or policy advocacy.

We also considered potential mediating or moderating factors that could impact the effectiveness or ineffectiveness of the interventions, particularly with regards to characteristics of communication such as content, framing, and channel. Additionally, we explored potential variations in the effectiveness of the intervention across different contexts and the experiences of various sociodemographic groups.

3.1.5 Study design

We included any type of study design, as the main aim of the review was to map available evidence on the topic independently of methodological robustness. For instance, interventions such as community-based citizen science projects may not follow strict experimental designs, but nonetheless carry value for further research and practice. Being inclusive with regards to study design enabled an in-depth exploration of the richness and diversity of initiatives currently available, which reflect the complexity of this topic in the real world. Nonetheless, we conducted a quality assessment

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(see Section 3.4) to evaluate the methodological robustness of the included studies and used this to inform our interpretation of the outcomes.

Literature reviews that met the inclusion criteria and that reported on empirical data collection were included in our mapping as they are valuable sources of information on the subject; however, they were considered only within the Discussion section and not in the analysis in the Results section. These literature reviews were also not considered in the final number of the studies included in this review.

3.2 Information sources

We conducted a comprehensive search encompassing peer-reviewed publications and grey literature. We excluded study protocols or other publications with no empirical data collection (e.g., opinion papers or media news).

The database search was performed on EBSCO Databases (Academic Search Complete, CINAHL Plus with Full Text, GreenFILE, MEDLINE, APA PsycInfo); Web of Science Core Collection; ProQuest Central. We identified the databases with the support of an information scientist. We searched academic papers written in English, and published between 2018 (the year when [15] completed their review) and November 2023.

The grey literature search involved working papers/preprints, conference proceedings, dissertations, written work from relevant organizations or institutions, policy reports, and other pertinent non-scholarly sources, following guidance by Adams et al. [36] and Rothstein Hopewell [37]. Through consultation within our research team and AQ experts, we compiled a search list of relevant governmental and non-governmental organisations websites (see Supplementary File S1). No time limitations were applied to the grey literature search, as this type of evidence had not been covered in Riley et al.'s [15] review.

Given the high number of records included in the review, our team made the pragmatic decision not to search reference lists of included studies.

3.3 Search strategy

Building on Riley et al. [15], our search terms and criteria were refined to better adapt to the goals of this review. The comprehensive search string can be found in Supplementary File S2. We

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combined search terms related to (i) population; ii) intervention; (iii) AQ-related topics; and (iv) outcomes.

3.4 Selection process

The Rayyan citation management software [38] was used to import and examine all search results, and eliminate duplicate citations. After a pilot screening carried out by two reviewers (RC and MC) on a random subsample of 15 abstracts, a two-step screening process was implemented: During the initial stage, one independent reviewer (RC) screened titles and abstracts against the inclusion criteria (Table 1), while a second reviewer (MC) independently reviewed a random subsample equal to 10% of records. Full texts of included abstracts were then screened in the second stage by RC and verified by MC. Any screening differences between the two reviewers were reconciled through discussion and agreement. We used the online tool ReCal2 online tool for nominal data with two coders (http://dfreelon.org/recal/recal2.php) to calculate inter-rater reliability for abstract screening via the Krippendorff's alpha coefficient [39]. The returned coefficient was 0.89, which is considered a very good level of agreement based on Krippendorff's [40] suggested cut-off >0.80.

[SPACE FOR TABLE 1]

3.5 Data collection process and data items

We created a customized data extraction form (see Supplementary File S3) to retrieve information from included studies, comprised of bibliographic information, key study characteristics, interventions characteristics, outcomes, and key findings. One reviewer (RC) extracted the data for all included records while consulting with a second reviewer (MC) to address any emerging doubts.

3.6 Quality Assessment

We employed the Quality Assessment with Diverse Studies (QuADS) appraisal tool [41] to evaluate the methodological and reporting quality of included studies (see Supplementary File S4). One reviewer (RC) assessed all included records while the second reviewer independently assessed a random 30% subset of records. The Krippendorff's alpha coefficient [39] for ratio data (based on percentage QuADS composite score) was 0.96, which is considered an excellent level of agreement

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Krippendorff [40]. No thresholds for quality have been established for this too; our assessment considered

3.7 Data Synthesis

Due to the methodological heterogeneity among the included studies, the evidence was analysed and synthesised narratively. No meta-analysis was performed. In our approach to data synthesis, we employed Michie et al.'s [16,17] COM-B model to map interventions functions: education, persuasion, incentivisation, coercion, training, restriction, environmental restructuring, modelling, and enablement. Our mapping along the COM-B intervention functions was integrated with the framework from Trench [20], and later Bucchi and Trench [21,22] to consider the level of participation and engagement promoted by each intervention, through the lens of science communication as a form of expert-public interaction.

Furthermore, we considered the systemic levels at which different interventions operated. Following Nguyen-Trung et al. [24], we mapped interventions based on whether they acted on any of the following systems: (1) *intraindividual* capability and/or motivation; (2) *interindividual* (social) opportunities in the proximal network (e.g., friends and family) or community; (3) *infrastructural* opportunities in the local environment; (4) *policy* opportunities at the local or national level.

In our synthesis, the notation "*k*" refers to the number of records.

4 Results

4.1 Study selection

Figure 1 displays the PRISMA flowchart for study selection [35]. In total, 79 studies were included in the review (73 from databases and 6 from other sources). Database searches yielded 2,843 records; after removing 1,442 duplicates, 1,261 records were excluded during abstract screening, and 62 during full-text screening due to ineligibility or inaccessibility. Four review studies [42–45] were excluded from analysis but considered in the Discussion. Of 17 studies identified from grey literature; 11 were excluded, and 2 reviews (46,47) included only in the Discussion, leaving 6 for the review.

[*SPACE FOR FIGURE 1*]

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4.2 Studies characteristics

Supplementary File S3 details the 79 included studies, predominantly from the United States (k=18), China (k=14), and the United Kingdom (k=10), with further contributions from Africa (k=6), Oceania (k=3), and Central-South America (k=3). Most records were journal articles (k=64), with fewer working papers/reports (k=7), conference papers/abstracts (k=5), dissertations/theses (k=2), and preprints (k=1). Study designs included observational cross-sectional (k=37), quasi-experimental (k=22), experimental (k=19), and observational longitudinal (k=1). Sample sizes ranged from a single participant in an autoethnography [46] to 375,672 people [47], totalling 455,304 observations.

Target populations included general adults (k=37), app users, citizen scientists, or transport users (k=12), socio-economic groups (k=7), health-vulnerable individuals (k=4), antenatal/postnatal women (k=3), and children or students (k=12). Interventions varied in duration and complexity, including brief exposures under one hour (k=8), short-term workshops (k=8), participatory activities (k=4), school/community monitoring (k=5), long-term public monitoring or educational programmes (k=22), and large-scale awareness campaigns (k=24).

4.3 Interventions functions and communication approaches

Table 2 summarises intervention types (see Supplementary File S3 for full details). The dominant function was persuasion (k=35), primarily through dissemination (k=33). Other common functions were education (k=21) and enablement (k=19), incorporating diverse science communication methods. Less frequent were modelling (k=2), restriction (k=1), and training (k=2). No studies addressed incentivisation, coercion, or environmental restructuring. Where multiple functions were present, categorisation was based on the primary function described.

[*SPACE FOR TABLE 2*]

4.3.1 System Levels

Most interventions operated at the intraindividual level, targeting personal capability and motivation. Others addressed interindividual (k=46), infrastructural (k=5), and policy levels (k=31) (see Table 3; Supplementary File S3).

Top-down communication interventions, such as persuasive or educational initiatives, aimed to influence interindividual networks and AQ behaviours in home or educational settings. Interindividual opportunities were often enhanced through dialogue and participatory methods, such as citizen science and participatory research, in two contexts: grassroots AQ monitoring for local

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communities or engagement with healthcare providers to change practices. In these initiatives, AQ monitoring tools were used as "boundary objects" [48], facilitating cross-sector communication and, in some instances, policy influence.

Policy-level interventions (k=31) primarily utilised persuasive dissemination, particularly public AQ monitoring or educational campaigns. Some studies, particularly in China, analysed public disclosure of AQ information and its impact over the past decade. Community engagement efforts also aimed to gather AQ data to influence policy and agenda-setting, with some studies examining citizens' willingness to support actions like paying taxes or using sustainable fuels.

Lastly, five initiatives targeted local infrastructure through citizen science, where community groups monitored AQ and participated in discussions about transportation and home heating systems' impact on public health.

[*SPACE FOR TABLE 3*]

4.4 Quality Assessment Findings

Detailed scorings from the quality assessment are provided in Supplementary File S4. The assessment s revealed that the average percentage score for the included studies was 75% (SD = ±16%; median = 79%), suggesting overall appropriate methodological/reporting quality as falling in the third quartile of ranked scores. However, quality scores ranged considerably across studies, from 21% to 97%. Across studies, the criteria with the highest scores included description of research setting and target population (criterion3 – 96%), the data collection procedure (criterion8 - 92%) and the statement of research aim/s (criterion2 – 91%). Conversely, several studies lacked a comprehensive discussion of strengths and limitations (criterion13 – 61%) or justification for the chosen analytical method (criterion10 – 55%). The criterion with the lowest average score regarded the consideration of research stakeholders in the design and implementation of the research (criterion12 - 36%), which was discussed only in studies with participatory approaches. We did not identify any clear patterns with regards to methodological/reporting robustness based on communication approach or behavioural function, although the studies that scored over 90% (k=8) included mainly citizen science or community engaged efforts in which research questions, sampling, data collection, analysis and interpretation were carefully justified and reported.

4.5 Overview of outcomes

Figure 2 presents measured outcomes. In this section, we provide a high-level summary of key outcomes, while a more in-depth review of findings is provided in the following sections. Most

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studies focused on raising AP awareness (k=57) and promoting protective behaviours (k=56). Many studies measured or discussed multiple outcomes. Mitigation behaviours, such as sustainable home heating and mobility choices, were assessed in 31 studies, particularly in persuasion-focused interventions. Civic engagement was the least investigated outcome (k=16), mostly appearing in enablement interventions, especially those adopting a participatory approach. Outcome measurement methods varied widely, including surveys, secondary data analysis, workshops, focus groups, and interviews, limiting cross-study comparisons.

[SPACE FOR FIGURE 2]

Figure 3 categorises interventions across positive, negative, no effects, or partial effects. We observed considerable variability in outcomes, even within the same intervention type. 59% of studies (k=47) found positive effects on awareness and/or behaviours, primarily in education, enablement, and persuasion interventions. 32% (k=25) reported partial context-specific positive effects, such as with certain demographic groups. Negative or null effects were reported in 9% (k=7), with three studies identifying adverse effects, including increased anxiety, mental burden during poor AQ conditions, reduced self-efficacy, or over-privatization of AQ issues [49–51]. It was unclear whether the absence of negative effects in other studies was due to lack of reporting or actual absence.

[SPACE FOR FIGURE 3]

Key findings on intervention effects are discussed in subsequent sections across intervention types and communication approaches. More details about each study are provided in the data extraction table in Supplementary File S3. We note that a full evaluation of impact was limited in many studies due to observational or cross-sectional designs, as well as other issues with methodological robustness identified in the quality assessment described in section 3.4. Furthermore, 27 studies offered only general statements about increased awareness or knowledge among participants, lacking specific data to demonstrate these changes.

4.6 Persuasion: Communicating AQ data and information

In line with Michie et al. [16,17], 35 interventions focused on persuasion, aiming to change motivation through affective and cognitive mechanisms. Most of these (k=33) employed dissemination methods, using websites, portals, apps, or mainstream media to provide real-time or forecasted AQ information. Two used, respectively, a dialogue approach with a qualitative investigation of AQ personal monitoring experiences [52], and participation through auto-ethnographical analysis of the experience of routinely monitoring personal exposure to AP [46].

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Beyond the intraindividual level, 16 interventions addressed policy opportunities, and 6 focused on the interindividual level.

Providing AQ data was associated with higher awareness and, in some cases, increased protective behaviours. For instance, public disclosure of AQ information in China was linked to greater awareness and behaviours like purchasing air purifiers [53] or reducing outdoor activities when AQ was poor [51]. Du [54] suggested that AQ information availability may be associated with university choices among prospective students. Similarly, AQ-related alerts were found to be effective in encouraging protective behaviours among the general public, [55,56] and in specific groups such as pregnant women [57] and asthma patients [58].

Some studies explored how manipulating the AQ message content or framing might influence awareness or behaviours. In the UK, D'Antoni et al. [58] found that a hypothetical AQ alert with behaviourally enhanced messages promoted higher levels of protective intentions compared to using an AQ index alone, both among healthy and at-risk individuals. However, at-risk participants reported more protective behaviours during a real moderate AQ alert than healthy individuals did. Bosone et al. [59] found that narrative AP risk messages promoted higher levels of perceived effectiveness of pro-environmental behaviours than statistical messages, particularly for people in the pre-action stages of behavioural change. Delmas and Kohli [60] found that AQ messages most effective in increasing engagement were actionable, combining positive and negative framing, and targeted to the user. However, these effects were not observed in a subsequent field experiment, where demographic characteristic and health concern were the most important predictors of interaction with messages.

Both the content accessibility and media of AQ communication can influence engagement with, and the behavioural impact of, persuasive dissemination strategies [61,62]. A qualitative analysis on public AQ information in the US found it to be overly technical and lacking health context, making that information ineffective [63]. Furthermore, mass media and digital communication tools could exclude people from low socioeconomic groups, who are disproportionately affected by AP [64], and who are most in need of accessing real-time AQ data and related health advice, such as people affected with asthma, pre-existing health conditions, personal symptoms, or women [60,65]. Schulte and Hudson [66] underline that engagement with AQ information and behavioural change are more likely among people who regularly use digital sources, have higher education, or care for someone with health conditions. In line with this, a communication campaign in Hong Kong aimed at older people using an AQ index [47] was shown to only partially influence outdoor activities during peaks of poor air, potentially due to limited understanding of the index implications. Similarly, in an

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experiment in China, receiving text warnings the day before a severe AP event did not encourage protective behaviours due to incorrect subjective perceptions or work demands [67]. In an experimental study in Canada, receiving prerecorded AQ phone warnings increased risk information sharing and adherence to recommendations from authorities but did not affect AP risk awareness or reduce the use of health system services [64,68]. Even when health circumstances promote awareness and use of AQ indexes, an in-depth understanding of issues and solutions may be better promoted by direct interactions with healthcare providers as opposed to publicly-available information [61].

Some studies showed that embedding AQ information in public messages could influence transportation choices and encourage non-car travel modes [69,70], longer but less trafficked walking routes [71], or use of electric motorcycles over petrol ones [72]. However, these positive results were not replicated in other studies considering micromobility (i.e., scooter or e-scooter) use [73], which suggested socio-demographic and/or financial circumstances as important factors for behavioural change.

Some studies showed that cost was a barrier to engage in protective AQ-related behaviours, especially amongst more financially and/or socially vulnerable groups. An experimental study in Chile [74], found that providing suggestions on the health benefits of using stove dampers for wood burning at home increased the frequency of selecting less polluting stove settings. However, another study in Cambodia showed that this type of information-based interventions aimed at incentivising the purchase of better stoves may not be sufficient to overcome financial constraints [75].

Therefore, while dissemination-based interventions, such as AQ indexes and alerts, can provide a means to increase awareness and influence some behaviours at a large scale, their effectiveness may be limited by the top-down, one-way communication approach, which can hinder engagement and understanding, or limit motivation for behaviour. In addition, the persuasion potential can be influenced by several factors such as accessibility, health relevance, message content, individual characteristics and external barriers.

4.7 Education interventions related to AQ and AP health risks

We grouped under “education” 21 interventions that, in line with Michie et al. [16,17], aimed to increase “knowledge or understanding of a behaviour by informing, explaining, showing and correcting” [17], thus supporting both capability and motivation. Of these, 11 adopted a top-down dissemination approach, 7 used dialogue, and 3 used participation. Most (k=18) operated both at the

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intraindividual and interindividual levels, while six addressed policy opportunities and only two considered infrastructures.

4.7.1 Educating through dissemination of AP health risks

Educational dissemination approaches included various strategies, with several studies investigating efforts by public authorities or other organisations to educate people about the health risks of AP. A study in South Korea [76] found that the WHO's release in 2013 of educational resources about AP health risks increased public awareness regarding AQ and health, and influenced outdoor activities, to a greater extent than national AQ information provision services did. In New Zealand, Harrison et al. [41] reported that a communication campaign by the Otago Regional Council using consistent messaging across different channels to educate on the use and replacement of wood burners was associated with higher awareness and subsidy uptake, although achieving behavioural compliance was challenging. This finding resonated with studies in the Global South [77,78] whereby education programmes for women about the health risks associated with burning solid fuel for home cooking promoted awareness and some changes in intensity of solid fuel use; however, behavioural changes were limited by financial barriers. On the other hand, interpersonal dynamics were shown to influence the impact of education in a controlled study aimed at reducing household AP from cooking via education and ventilation improvement for women and children in low socio-economic circumstances in Sudan [79]; this study reported improved cooking behaviours in both the intervention and the control group, possibly due to sharing of information between the two groups.

Some studies (*k*=3) focused on using AQ monitors and sensors in households to provide personalised data on indoor AP and educate on the related health risks. An experimental study in France found that the use of generic AP-related health information through home devices supported increased risk awareness, but a comparison group who received personalised indoor AQ data were found to engage in more protective behaviours such as ventilation [80]. On the other hand, Boso and colleagues [49] showed that providing personalised indoor AQ data increased participants' awareness but did not contribute to a change in the AQ levels in the households, with some participants leaving the study due to low self-efficacy and feelings of anxiety about what action to take. To counteract this risk, strategies such as behavioural feedback and tracking of changes over time may support agency, as demonstrated in a COM-B informed citizen science study by Kureshi et al. [81] in the UK, which used a home digital platform with information and visualisation from AQ monitors.

Some educational interventions showed positive results in schools. For instance, an observational study in China showed that the use of 3D animated posters in primary schools can promote children's awareness of AP, although parents in this study expressed conflicting opinions

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about the effectiveness of this strategy [82]. A qualitative study in Canada focused instead on an educational outreach program with university and grade school students and teachers and showed how the use of quizzes and a digital dashboard can support engagement among students [13].

4.7.2 Education through dialogue

Some interventions (*k*=7) attempted to educate people about AQ issues using dialogical approaches, with a two-way communication process where users were engaged by experts in the creation of the tools aimed at sharing information and results related to AQ monitoring. Three studies described how users' involvement in the design of AQ-related information documents fostered the creation of more grounded materials and more awareness among participants [83–85]. Jiang and colleagues [86] found increased awareness and decreased hostility towards institutions associated with a deliberative approach to inform citizens on AQ decision making. Johnston and colleagues [87] reported increased awareness of AP risks as a result of using an app to collect AQ data, track real-time symptoms from users and provide information and notifications. Golumbic and colleagues [88], described a citizen science process which enabled an inclusive identification of communication preferences for a user-centred design of an AQ platform; the authors found that while the platform was recurrently used by very few participants, those who used it found it useful and kept engaging with it for a long time. While dialogue can promote higher levels of engagement with AQ topics, some of the included studies suggested that the choice of communication tools can limit its reach. For instance, a study in South Africa [89] investigated the benefits of using social media to foster communication between the local authority and the public around AQ, and indicated that, while this strategy can enhance feedback sharing from the community, it can exclude people with limited digital literacy and/or access.

4.7.3 Education through participation

Education interventions using participatory communication models included three initiatives involving children and schools, where participants were offered access to information while having decision-making capacity in part of the process of knowledge production and communication. These interventions were positively associated with enhanced knowledge. For instance, a citizen science initiative that involved around 30 primary schools in Norway [90] provided pupils with an AQ toolbox that allowed students to make their own AQ experiments and analysis. The researchers found that these activities supported increased knowledge about AQ and decreased misconceptions among students. Another data monitoring process in Norway [91] involved high school students both in the

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data collection and in handling the technical aspects of setting up and programming sensors, as well as research activities (e.g., hypothesis formulation and results description). The initiative enhanced favourable perceptions of science, improved skill acquisition, and raised awareness about AP. In the UK, a participatory process of AQ data collection [92] involved primary school children, their families and teachers not only in the data monitoring but also in process planning and in the dissemination of results, leading to an increase in awareness and AP avoidance behaviours. Against this backdrop of positive results, these studies warned against the risk of placing too much of the AQ analysis process on the shoulders of the public, since previous studies have shown that it can create anxiety if not accompanied by feasible solutions [92]. In addition, the bottom-up initiatives often risk attracting people that are already environmentally involved and who can find the solutions proposed as not innovative or effective [91].

4.8 Enabling behavioural change through dialogue and participation

We categorised under "enablement" those interventions (*k*=19) focused on supporting the capability of individuals or communities with regards to AQ-related behaviours. These included dialogue (*k*=10) and participation (*k*=9) approaches.

Dialogue-based interventions included citizen science initiatives in which groups of people (e.g., students, community representatives) were usually provided with devices to collect indoor or outdoor AQ data in their community. The collected information was then analysed and presented by experts to the citizen scientists during a collective event. The results of these studies usually indicate that these collective monitoring processes have the effect of raising awareness on AQ, creating more confidence on the topic and motivation toward healthy behaviours [93–100]. Incorporating local knowledge from participants also contributed to collecting more precise pollution exposure data by considering particular situated dynamics [96]. As for other interventions described above, enablement initiatives such as citizen science appeared to contribute to increased awareness, but not necessarily promote in-depth knowledge or behavioural change [98,101]. Collier and colleagues [94] stressed that consumer-grade AQ sensors used for citizen science monitoring still need some sort of guidance to be used autonomously by the public and effectively promote understanding of AP. On the other hand, in their study on participatory monitoring, Haddad and de Nazelle [102] found no changes in awareness and behaviour due to self-selection from participants who were already familiar with the topic and had already adopted the relevant sustainable behaviours.

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Enablement interventions with a participation model were mostly bottom-up initiatives created by civil society organizations that involved, or collaborated with, professional researchers. The participants of these initiatives were provided with tools and decision-making power to influence knowledge production and communication processes related to AQ data collection. The interventions focused mainly on building networks within communities in order to monitor AQ 'bottom-up' [103–106]. In some cases, the goal was the creation of policy recommendations on the topic [e.g., 107] or evidence for advocacy campaigns [e.g., 104,108,109]. For instance, West and colleagues [109] described a community AQ monitoring campaign with workshops in an informal settlement in Nairobi, Kenya, involving citizens, policy makers and experts, which led to higher awareness of AP-related issues and the creation of a cross-sectoral network for AQ improvement. The results of these interventions were in many cases narratively described as positive, insofar as they offered participants the opportunity of increasing their awareness and knowledge of the issues discussed, reducing personal exposure, facilitating dialogue between stakeholders, and the possibility to work with groups that are usually seldom involved in decision-making [104]. However, some studies [e.g., 50] showed that these processes do not necessarily support collaboration among communities, but they can have the effect of internalising and privatising the issue of AP, where people collect data only with a focus on their home space and immediate environment. In addition, some studies underlined the lack of diversity among participants due to different constraints (time, language, confidence, digital divide etc.) as a barrier to true participation and to achieve positive behavioural changes where they are most needed [103,107].

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4.8.1 Other types of interventions

Among the remaining studies, two [110,111] used surveys to independently evaluate the impact on awareness and behavioural intentions of a documentary about AP released in China in 2015; we categorised this as a dissemination by modelling intervention, as the documentary used personal stories to "model" appropriate behaviours for good AQ. Both studies found increased AP-related risk perception among the general public, as well as information seeking. While Qin et al. [111] did not find any influences on mitigating or protective behaviours, Huang & Yang [110] reported positive engagement in mitigation, although this was higher for participants who were younger, more educated and with higher income. Furthermore, this study found higher support for AQ policies among those who watched the documentary, particularly if older and more highly educated.

Further two studies focused on AQ-related training. In a qualitative study, Ekman [112] found that taking part in an online AQ citizen science initiative focused on training promoted engagement with the topic and informal learning beyond the focus of the initiative itself. Madrigal et al. [113] involved high school students in a 10-week programme training on AQ science and monitoring, health impacts, and related policies. The initiative promoted knowledge about AQ policies and monitoring techniques, as well as self-efficacy for behaviour change.

Lastly, Zhao et al. [114] used a survey to explore residents' perceptions of two red AQ warnings (the most severe category of four AP warning signals) that occurred in Beijing in 2015. The actions following the warnings included mainly restrictions to reduce exposure, e.g., school closures and driving restrictions. While the restrictions were effective in triggering protective behaviours, acceptance of the warning measures varied among respondents based on age (older people more supportive of school closures), gender and socio-economic status (men and more wealthy respondents were less supportive of driving restrictions).

5 Discussion

5.1 Summary of findings and implications

Since the review conducted by Riley and colleagues [15], interest in AQ communication appears to be increasing. Their review, which synthesised academic evidence up to 2018, encompassed 37 studies. In contrast, our review (2018-2023), included 79 studies. Although part of this increase may be attributed to our inclusion of more databases and the grey literature, the substantial rise in the number of studies suggests a significantly greater productivity on this topic within a much shorter timeframe.

In their paper, Riley and colleagues [15] concluded that communication on AQ issues predominantly relied on top-down, information-based approaches, which failed to effectively engage a broader audience. Our review supports the observation that expert-to-public information dissemination remains prevalent in AQ communication, largely relying on disseminating data and persuasive messages to encourage self-protection or reduced pollution. However, when combining interventions that utilised dialogue-oriented communication with those that incorporated public participation, we found that 40% of the mapped interventions involved active public engagement. These interventions primarily aimed to educate people on AQ issues or empower them to address these issues effectively. Thus, it is encouraging to see a pattern towards more engaging interventions, given the overall finding in this review that they are more likely to better address individual or

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community information needs, empower people through increased ownership and agency, and create more trusted information [e.g., 15,115–118].

Our mapping exercise revealed great variability in types and durations of AQ communication interventions, as well as in populations involved and outcomes assessed. This makes an evaluation of effectiveness quite challenging without considering specific contexts and the variability in data and information used, consistent with recommendations made elsewhere [119]. Nonetheless, through our mapping of interventions in light of COM-B functions and science communication models, we identified some interesting patterns in terms of mechanisms and outcomes of impact. Top-down communications with persuasive or educational functions, such as data dissemination, messages, alerts, and mobility information, (which were the majority of the included interventions) were found overall to enhance AQ-related awareness levels, with some indication that narrative formats and personalised information may foster higher levels of engagement with the issue and understanding. However, the impact of these interventions on behaviour change remains questionable, aligning with the literature on awareness-behaviour gaps [61,62,80,120–122]. Notably, the main type of behaviour change observed in the included studies involved protective behaviours, particularly when these interventions provide personalized information tailored to individuals directly affected by the issue. Furthermore, psychological and socio-demographic factors were found to influence these outcomes, with concern, education and income playing an important role for behavioural impact [e.g., 72,81,110,123]. While top-down communication strategies can reach wider audiences and support public understanding of AP-related risks, a key criticism emerged from this review is that they may create barriers for certain groups due to overly complex language or over-reliance on digital media of communication [63,e.g., 64]. Additionally, efforts to educate by explaining risks and solutions can be controversial, as they may induce anxiety related to fears of inadequate self-efficacy [e.g., 49,62]. The very few studies that considered training or modelling interventions suggest the possibility of positive effects, potentially superior to education/persuasion. However, the paucity of evidence limits the ability to make firm conclusions on this and more research in this area is needed.

In contrast, when communication is rooted on dialogue or participation, it can open avenues for influencing the personal narratives of individuals and communities through AQ data, and potentially promoting impact at different socio-ecological levels. We observed interventions where dialogue between experts and the community allowed the creation of educational tools tailored to the concerns of stakeholders affected by these issues and increased awareness and understanding. Dialogue also served as a means for certain communities to establish scientific evidence regarding AP, particularly when engaging with institutional bodies. Interventions aimed at encouraging community participation in the communication process reported higher levels of stakeholder agency. These

interventions, whether aimed at educating or enabling, were primarily conducted within school ecosystems or civil society organizations to monitor local AQ and contribute to knowledge production and sharing. As discussed by several authors [e.g., 15,115,116,118], the use of community-based approaches in AQ communication allows the empowerment of local people, increasing ownership and agency while avoiding considering the public in a paternalistic or extractivist manner. However, several issues are associated with this form of "engaging" communication. The studies on communicative interventions based on dialogue or participation included in our review frequently risk conflating the process with the outcome. There is often an implicit assumption that merely involving the public in research and communication activities will increase awareness or lead to behavioural changes regarding AQ. This assumption aligns with Ward et al. [45] and Rawat and Kumar [44], who, in their recent reviews on community and students' involvement in addressing AQ, argue the need for more evidence linking involvement to tangible health or environmental outcomes. Additionally, delegating the responsibility for monitoring, analysing, and communicating AQ to individuals and communities can risk privatizing the issue or framing it as an individual effort to protect one's own and one's family's health [50]. Another critique concerns the resource requirements for participation in such processes—resources such as time, language, and skills—which may exclude those from vulnerable groups who are often more affected by pollution.

Our analysis of studies through the lens of the socio-ecological COM-B model [24] identified the interplay between communicating AQ and health risks and the necessity of fostering opportunities for change across various systemic levels. Some interventions in our review, particularly those with an enabling function and more dialogical/participatory formats, worked in fostering interindividual opportunities, and, to a lesser extent, in considering opportunities or issues at policy level. This type of approach can stimulate positive social norms that may result in new behavioural practices beyond individual actions [15,124]. However, infrastructural issues and opportunities remain insufficiently addressed in the communication interventions included in this review. As discussed in Riley et al. [15], and as found in other community-engaged works [125,126], discounting systemic barriers in AQ communication interventions can put unrealistic responsibility on individuals and negatively impact engagement or acceptance. We also noted in this review that financial barriers were especially felt by more at-risk groups such as mothers and households with low socio-economic status, which further warrants work to design equitable interventions.

Therefore, our review aligns with previous work [15], in supporting the potential benefits of AQ communication interventions that are sensitive to both individual and local circumstances, that are empowering and accessible, and that are built on meaningful participation. However, through our integrated mapping along behavioural functions and science communication approaches, we

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identified challenges associated with participatory approaches such as citizen science, and the predominance of dissemination approaches, which warrant a critical and careful approach to the design of engaged interventions that are truly inclusive and multi-systemic, as well as systematic evaluations of these across different contexts and populations. The question on whether AQ communication can promote mitigating behaviours (i.e., less polluting activities) or civic engagement appears to have not been systematically or robustly investigated by current interventions or initiatives; this may reflect systemic, cultural, infrastructural constraints for behaviours that require a more holistic approach to behavioural interventions, as increasingly acknowledged in the literature [24]. Multi-system approaches are challenging and time/resource intensive but may play a key role in incentivizing positive practices at individual and social levels.

5.2 Strengths and Limitations

This rapid review offers a novel integrated lens to synthesise AQ communication interventions based on their functions, the science communication approach and the addressed system levels, which can help to map behavioural interventions while considering the social complexities of communication. This work hoped to broaden the scope of reflection on AQ communication through an interdisciplinary approach informed by experts in the field and the inclusion of literature beyond traditional academic sources. Our systematic search and screening approach across academic and grey literature, together with our broad inclusion criteria, maximised our ability to capture available evidence. The quality assessment enables us to evaluate both methodological and reporting standards in a structured and consistent manner. While the mapping carried out in this review is mainly descriptive, it provides a structured approach to synthesise a rapidly growing field of research and practice that is trying to address the key societal challenge of promoting healthy air.

Nonetheless, this work is not without limitations. In our extensive literature search, we attempted a systematic approach to grey literature search; however, it is likely that relevant case studies or initiatives were left out due to the absence of structured databases for grey literature. We hope that the list of organisations and websites created for this review could form the basis for a comprehensive database for future reviews. Using broad inclusion criteria meant that multiple designs, outcome measurements and data collection approaches were included in the review; this, together with the lack of controlled conditions (dictated in most cases by the nature of the AQ communication interventions or initiatives) limited our ability to estimate effectiveness or carry out a meta-analysis. Thus, our interpretations of outcomes should be taken with due caution and with consideration given to the methodological issues highlighted in the quality assessment. Despite these

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limitations, the review offers narrative insights into the forms of communication and behavioural functions that may support enhanced AQ-related awareness and behavioural change, outlining key recommendations for future research in this area. While our quality assessment revealed overall appropriate reporting standards, we cannot exclude the risk for publication or reporting bias within the available evidence, as many of the included studies tended to report positive results, but a number of them did not necessarily provide rigorous assessments. Our search was conducted in 2023, and we acknowledge that there is growing evidence in the area of AQ communication interventions which may warrant an updated review in the near future. Our review remains valuable in providing a comprehensive search and identifying key trends and needs for future research in this area.

5.3 Recommendation for future research and practice

The majority of included studies in this review limited their assessment of intervention impacts to awareness levels or behavioural self-reports or intentions. While this evidence provides important insights for promoting AQ-related behavioural changes, it limits the ability to identify truly effective interventions; an issue already raised, for instance, by Howell [127] in connection with communication focusing on climate change. Future research should prioritize an assessment of the long-term impact of these communication processes by observing actual changes in people's behaviour and the duration of those changes. This would require a deeper investigation into the interaction between different types of scientific communication and the functions of interventions. Such an approach will help identify which communication strategies are most effective for various system levels and situations, enabling the design of more targeted communication campaigns. Importantly, more attention must also be paid to studying the negative consequences of specific interventions, e.g. by observing how an increase in protective behaviour affects the performance of outdoor sports activities.

Greater differentiation is needed not only in the study of various types of interventions, but also in the consideration of the diverse socio-demographic and contextual factors with which these interventions interact. For instance, a particular communication strategy aimed at reducing emissions may yield different outcomes depending on the context (e.g., a campaign outside a school versus one on a city-centre street), the broader socio-economic conditions (e.g., lower versus higher fuel costs), or the specific behaviour targeted (e.g., car use versus wood stove use). More robust evidence on what works where and for whom can have invaluable positive impact for policy and practice. While we attempted a comprehensive mapping across three integrated frameworks to capture the

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complexities of AQ communication, future studies are encouraged to account for such dynamics by providing more nuanced accounts of individuals and context-specific factors of impact.Furthermore, we observed that the duration of interventions varied strongly depending on the function of the interventions and the type of scientific communication used. For example, years are taken to disseminate information related to AQ indices and persuade the public to protect themselves, months to create relationships within participatory processes, hours to get certain content through digital media. We did not find certain types of duration to be more effective than others, and this may suggest that duration per se may not be as much a factor of impact as the communication format and style of the intervention, and/or potential intervening factors such as socio-demographic characteristics or contextual circumstances. This further warrants the need for more robust assessment of both the process and outcomes of AQ communication interventions to better understand what communication formats may be more effective in which contexts [e.g., 128,129].

Lastly, while evidence in this field is rapidly growing, we found that most evidence in this review came from studies focusing on specific areas of the world (e.g. U.S. and China). A recent systematic review [130] identified considerable geographical (and related methodological) biases in the available evidence on climate change communication, and our review supports the need for future studies on less represented areas to further capture contextual inequities in participation and local opportunities or barriers to behavioural change.

5.4 Conclusion

This rapid review mapped the available academic evidence and grey literature on AQ communication interventions and their influence on public awareness of AP-related risks and solutions, protective or mitigating AP-related behaviours, or civic engagement. Our synthesis was informed by an integration of behavioural, science communication, and socio-ecological frameworks. While evidence on this topic is rapidly growing, there is high methodological heterogeneity that limits the ability to make conclusions on effectiveness. Most available interventions used a top-down dissemination approach with mainly persuasive or educational functions; these can have a positive influence on awareness, but the potential impact on behaviours is uncertain. Participatory or dialogical approaches with enablement/educational functions may promote enhanced public engagement with AQ topics, but fostering meaningful participation and acceptance requires a careful multi-system approach to communication, cognisant of individual-level and contextual factors may influence the impact of AQ communication. More robust and geographically diversified research is needed to assess the behavioural impact of communication strategies, with attention to potential negative effects.

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Tables

Table 1 Criteria for inclusion/exclusion of records

Criterion #	Criterion type	Rule
C1	Does the document refer to “air pollution” or “air quality” or an air pollutant type or smog?	Yes: include
C2	Does the document comply with Criteria 1 deal with ambient or indoor air pollution in domestic, community or occupational settings (not industrial or agricultural)?	Yes: include
C3	Does the document complying with Criteria 1 AND 2 deal with messaging interventions? or informing individuals or a communication instrument/tool (e.g., Air Quality Indices), digital or of other type, or public engagement/involvement, campaign, citizen science or awareness raising about ambient air pollution? (not technical or engineering interventions)	Yes: include
C4	Does the document complying with Criteria 1 AND 2 AND 3 include an assessment of an outcome related to awareness or behaviour or "behaviour change"	Yes: include

Table 2 Intervention functions and science communication approaches

	Intervention function									
Science comm. model	Education	Enablement	Modelling	Persuasion	Restriction	Training	Incentivisation	Coercion	Env. restructuring	**Total**
dissemination	11	0	2	33	1	1	0	0	0	**48**
dialogue	7	10	0	1	0	0	0	0	0	**18**
participation	3	8	0	1	0	1	0	0	0	**13**
Total	**21**	**18**	**2**	**35**	**1**	**2**	**0**	**0**	**0**	**79**

Notes: The coloured cells indicate the frequency of records for each sub-category of intervention on a spectrum from the most frequent category in dark blue to categories with no records in light blue.

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Table 3 Map of system levels addressed for different intervention functions and science communication approaches.

	Dissemination		**Dialogue**		**Participation**	
	Persuasion	*Education*	*Education*	*Enablement*	*Education*	*Enablement*
Policy	16	3	0	3	0	4
Infrastructural	0	2	3	1	0	2
Interindividual	7	8	7	8	3	8

Notes: The coloured cells indicate the frequency of records for each sub-category of intervention on a spectrum from the most frequent category in dark green to categories with no records in white.

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Supplementary information:

Supplementary File S1 "SupplFileS1_ListGreyLiterature": Search list of relevant governmental and non-governmental organisations websites used to map grey literature on the topic.

Supplementary File S2 "SupplFileS2_SearchString": Comprehensive search string.

Supplementary File S3 "SupplFileS3_DataExtractionForm": Customized data extraction form to retrieve information from included studies.

Supplementary File S4 "SupplFileS4_QUADS": Evaluation of the methodological and reporting quality of included studies through the Quality Assessment with Diverse Studies (QuADS) appraisal tool (Harrison et al., 2021).

Supplementary File S5 "SupplFileS5_PRISMA_2020_checklist": Compiled Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) checklist (Page et al., 2021).

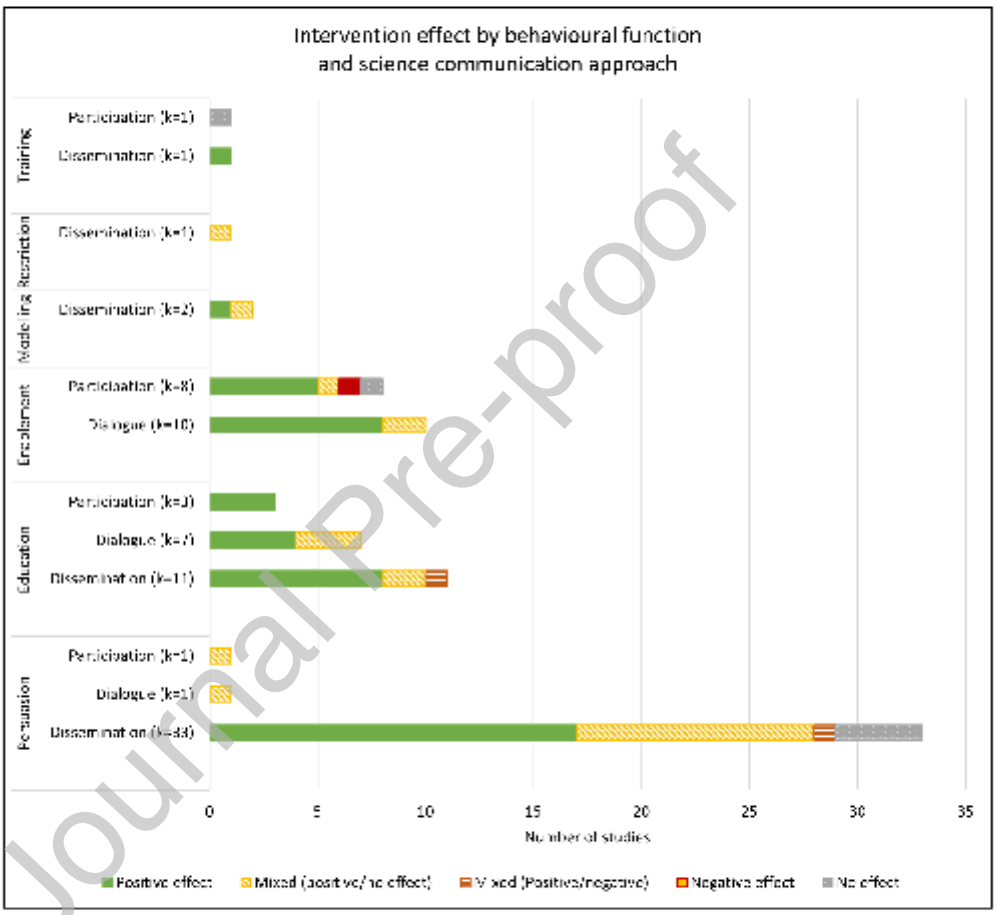
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Figures Captions:

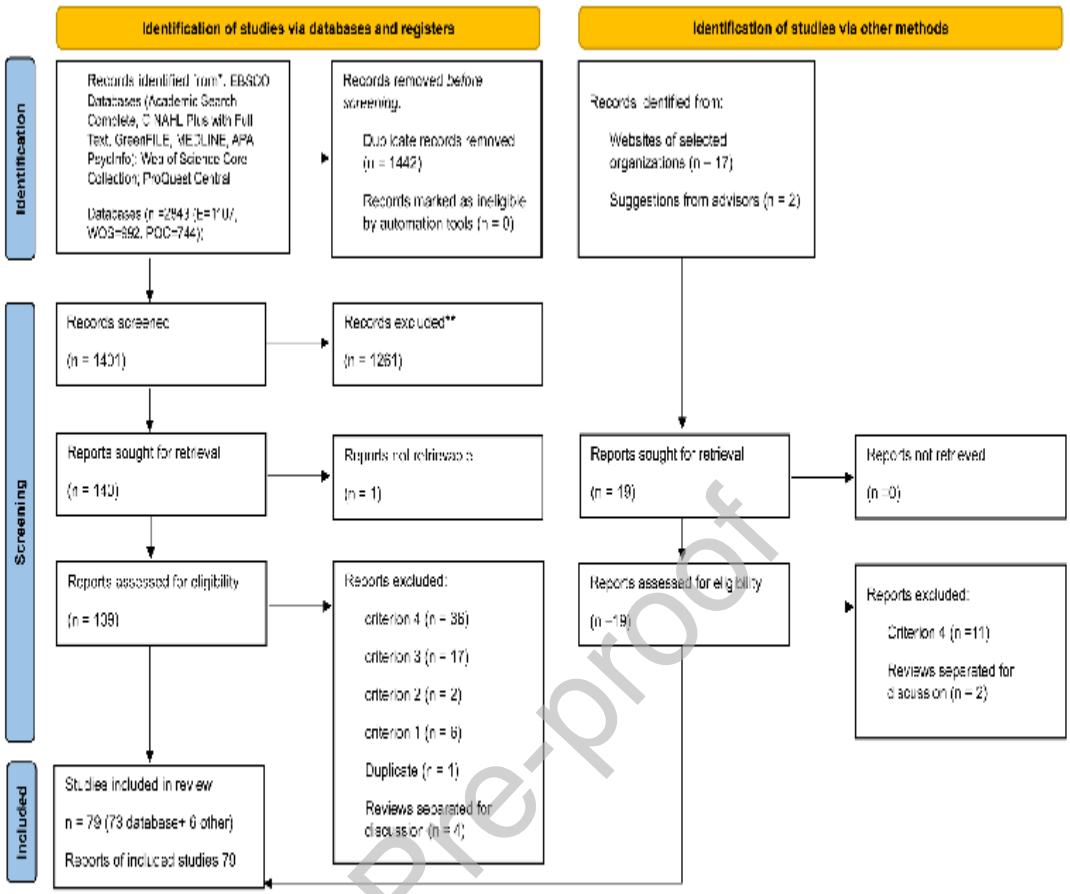
Figure 1: PRISMA flowchart for the process of study selection

Figure 2: Overview of outcome measurements by intervention behavioural function and science communication approach. Note: Some studies assessed or considered more than one outcome.

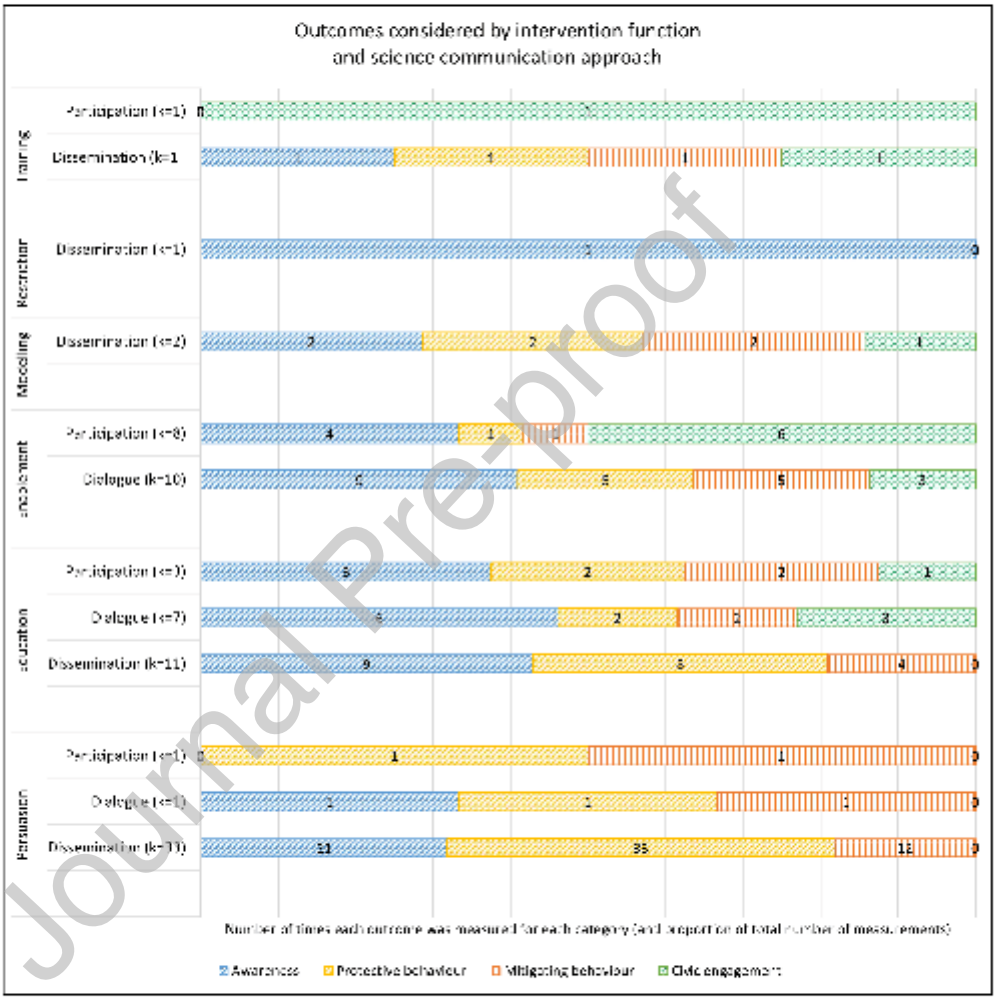
Figure 3: Overview of intervention effects, based on intervention behavioural function and science communication approach.



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Declaration of interests

☐ The authors declare that they have no known competing financial interests or personal

relationships that could have appeared to influence the work reported in this paper.

☒ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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