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Promoting Vaccine Uptake in Epidemics: A Model Emerging From the COVID-19 Pandemic

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Abstract

Background: COVID-19 pandemic exposed both the critical role of vaccines and the challenges to their uptake, such as hesitancy, misinformation, and structural barriers. Existing strategies often lack integration and adaptability during crises. There's a clear need for an evidence-based, expert-informed model that unifies behavioral, structural, and policy approaches to guide vaccination efforts during epidemics.

Aim: This research aimed to develop a multidimensional, consensus-based model for promoting vaccination during epidemics.

Method: A mixed-methods design was conducted in three phases. First, a systematic scoping review identified global strategies for promoting vaccination during epidemics. In the second phase, a three-round Delphi study was carried out with 30 experts. In the third phase, dynamic modeling was employed using Python.

Results: A total of 131 unique strategies were identified and categorized into six domains: Provision, Promotion, Public Awareness, People, Preconditions, and Prizes. Common recommendations included improving access, transparent communication, and culturally tailored campaigns. A Delphi study resulted in consensus on 46 strategies, that 28 received strong agreement. The highest-ranked strategies focused on large-scale promotional campaigns, use of visual media, accurate information dissemination, and prioritizing vulnerable groups. Dynamic modeling identified the Promotion and Provision domains as the highest-priority categories across multiple evaluation scenarios.

Implications for Practice: The proposed model provides a dynamic, evidence-based framework for promoting vaccination during epidemics. By incorporating real-time adaptability, expert consensus, and socio-cultural responsiveness, it addresses limitations of static models and provides a practical tool for policymakers.

Keywords: Vaccination Promotion, Vaccine Hesitancy, Epidemic Response, Delphi Method, Systems Modeling, Health Communication

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Introduction

The COVID-19 pandemic has underscored the critical role of vaccination in mitigating the impact of infectious diseases. While the rapid development and deployment of vaccines have been a landmark achievement, ensuring equitable access and high uptake remains a persistent global challenge (1). Vaccine hesitancy, fueled by misinformation, sociocultural factors, and institutional distrust, continues to hinder immunization efforts, particularly among marginalized populations (2). Addressing these challenges requires evidence-based, context-specific, and adaptable strategies that integrate behavioral, logistical, and policy-driven approaches.

Several theoretical frameworks have been proposed to explain and influence vaccine uptake. The Health Belief Model (HBM) suggests that vaccination decisions are driven by perceived susceptibility, benefits, and barriers (3). However, this model often fails to account for social determinants of health and misinformation dynamics (1). The Rogers' Diffusion of Innovations Theory (DOI) highlights the role of social networks and trusted messengers in vaccine promotion (4), yet its applicability diminishes in populations with limited access to verified health information or systemic distrust in healthcare providers (2). Managerial models such as the C5 Model provide structured approaches for vaccination campaigns but lack real-time adaptability and do not integrate expert consensus into decision-making (5, 6). Beyond theoretical models, practical interventions such as community engagement, digital nudges, and motivational interviewing have shown promise in increasing vaccine uptake. Partnerships with local leaders, religious institutions, and healthcare providers have effectively enhanced vaccine confidence (7, 8). Similarly, text-based nudges and tailored digital communication have increased vaccination rates by 5-20% in various studies (8, 9). While these models and strategies offer valuable insights, they remain fragmented and context-dependent, making it difficult to establish a scalable, adaptable, and integrated decision-support framework for vaccination efforts in epidemics. The lack of a structured, multi-criteria approach to prioritizing interventions limits policymakers' ability to implement data-driven, expert-validated strategies during health crises. Despite extensive research on vaccine promotion strategies, several critical gaps persist:

1-Lack of an integrated, evidence-based model for prioritizing vaccination strategies during epidemics. Most existing approaches focus on individual interventions, rather than a structured multi-criteria decision-making framework.

2-Limited application of expert-driven methodologies such as the Delphi method in refining and validating vaccination strategies. Few studies systematically incorporate expert consensus into real-time policy planning (2, 5).

3-Need for dynamic prioritization frameworks that can adapt to epidemiological shifts and feasibility constraints. Most existing models remain static and context-dependent, reducing their applicability in rapidly evolving public health crises (10).

4-Equity gaps in vaccine promotion models, particularly for migrants, refugees, and underserved populations. While community-based interventions have shown success (11, 12), they remain fragmented and difficult to scale.

To address these gaps, our analysis develops a comprehensive, expert-informed, and dynamically adaptable vaccination promotion model using a three-phase methodological approach:

-Scoping Review: Identifying and categorizing global vaccination strategies based on effectiveness, feasibility, and scalability.

-Delphi Method: Engaging interdisciplinary experts to prioritize the most impactful strategies for real-world implementation.

-Dynamic Modeling: Translating expert insights into a policy-ready decision-support tool, optimizing strategy selection based on real-time constraints.

By integrating expert consensus with evidence-based prioritization, this study introduces a structured, adaptable, and policy-driven framework that overcomes the limitations of previous models. Unlike conventional approaches, which often assess strategies in isolation, this research offers a multi-dimensional decision-making system, ensuring that vaccination interventions are scientifically grounded, operationally feasible, and adaptable to epidemic settings. This framework contributes to global vaccination policy, epidemic preparedness, and health equity by providing a scalable tool for optimizing vaccine promotion efforts. Beyond COVID-19, the proposed model can be applied to future infectious disease outbreaks, enabling policymakers to design more resilient and effective

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vaccination programs**.**

The COVID-19 pandemic has underscored the urgent need for robust strategies to promote vaccine uptake and address vaccine hesitancy, particularly in diverse and vulnerable populations. Existing literature has explored a wide range of approaches, from communication-centered strategies to structural and equity-based interventions, to improve vaccination rates across global contexts.

One dominant theme across the literature is the critical role of communication strategies in influencing public vaccine behavior. Several studies emphasized the importance of transparent, culturally appropriate, and tailored communication in fostering trust and increasing uptake (9, 13). For instance, motivational interviewing was found to reduce hesitancy by enabling empathetic and individualized dialogues between healthcare providers and patients (14). Similarly, text-based nudges and visual content have been shown to enhance vaccine intent, especially when strategically designed and personalized (8, 15). Community engagement and participatory models have emerged as another central pillar in successful vaccination campaigns. Studies from various contexts, including UNICEF-supported interventions, church-based outreach programs, and peer navigator models, highlight the effectiveness of leveraging trusted community figures and co-designed strategies (8, 16, 17). These approaches not only improve communication channels but also empower marginalized communities and foster greater acceptance through trust-building. In parallel, several investigations have examined structural and delivery-related barriers to vaccination, especially among equity-deserving populations. For example, health disparities linked to race, geography, migration status, and socio-economic background have been shown to significantly affect vaccine access and uptake (7, 18, 19). Addressing these barriers requires systemic investment in delivery strategies, including mobile clinics, home visits, and integration of vaccine services into existing healthcare infrastructure (20, 21).

Policy-level strategies and cross-sector collaborations also play a pivotal role. The literature illustrates the value of integrating vaccination efforts into broader public health agendas and leveraging partnerships with NGOs, religious institutions, and civil society organizations (12, 22). In Uganda and Madagascar, adaptive community-based strategies have demonstrated promising results in boosting vaccination rates among prioritized groups (21, 23). Despite these advances, important research gaps remain. Studies consistently report insufficient data on vaccine promotion strategies for refugees, migrants, undocumented individuals, and other hard-to-reach populations (11). Additionally, while many interventions emphasize communication and access, fewer efforts focus on evaluating long-term sustainability, cultural appropriateness, and cost-effectiveness across contexts (24). Notably, some research underscores the importance of co-design and behavioral science methodologies to develop interventions responsive to community-specific needs and sociocultural realities (25). This participatory ethos not only ensures contextual relevance but also enhances scalability and ownership of vaccine promotion efforts.

Taken together, the existing body of evidence demonstrates that no single strategy suffices. Rather, a multifaceted and adaptive model, integrating evidence-based communication tools, community engagement mechanisms, equitable service delivery frameworks, and context-specific policy levers, is necessary to effectively address vaccine hesitancy and ensure equitable access in future epidemic settings. By synthesizing insights from diverse contexts and populations, the present study builds upon this foundation to propose a comprehensive, dynamic, and consensus-based model for vaccination promotion. In doing so, it aims to fill the identified research gaps and contribute to a more inclusive and resilient public health preparedness agenda.

Methods

This mixed-methods study was conducted in three sequential phases to design a comprehensive model for promoting vaccination during epidemics. The methods include a systematic scoping review, a Delphi study with expert panels, and dynamic modeling based on the results of previous phases.

Scoping Review

A systematic scoping review was conducted to identify existing strategies and interventions for promoting vaccination during epidemics. The review followed the PRISMA-ScR guidelines (26). The databases searched included PubMed, Scopus, Web of Science, and Google Scholar. The search strategy included combinations of keywords such as "vaccination promotion", "vaccine hesitancy", "COVID-19", "epidemic", and "health communication" (Table 1).

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Table 1: Search Strategy in Medline Database via PubMed

(("motivate"[All Fields] OR "motivated"[All Fields] OR "motivates"[All Fields] OR "motivating"[All Fields] OR "motivation"[MeSH Terms] OR "motivation"[All Fields] OR "motivations"[All Fields] OR "motive"[All Fields] OR "motivational"[All Fields] OR "motivator"[All Fields] OR "motivators"[All Fields] OR "motives"[All Fields] OR "inducements"[All Fields] OR "motivation"[MeSH Terms] OR "motivation"[All Fields] OR "inducement"[All Fields] OR "encourage"[All Fields] OR "encouraged"[All Fields] OR "encouragement"[All Fields] OR "encouragements"[All Fields] OR "encourager"[All Fields] OR "encouragers"[All Fields] OR "encourages"[All Fields] OR "encouraging"[All Fields] OR "inhalation"[MeSH Terms] OR "inhalation"[All Fields] OR "inspiration"[All Fields] OR "inspirations"[All Fields] OR "inspired"[All Fields] OR "inspirate"[All Fields] OR "inspirates"[All Fields] OR "inspirational"[All Fields] OR "inspire"[All Fields] OR "inspires"[All Fields] OR "inspiring"[All Fields]) AND (((COVID-19) OR (coronav*) OR (*CoV-2) OR (nCoV*)))) AND ((((COVID-19) OR (coronav*) OR (*CoV-2) OR (nCoV*))) AND (((((COVID-19) OR (coronav*) OR (*CoV-2) OR (nCoV*))) OR ((vaccine) AND ((((novel coronavirus) OR wuhan virus) OR 2019-nCoV)))) AND ((vaccine) AND ((((novel coronavirus) OR wuhanvirus) OR 2019-nCoV)))))

Articles published between 2020 and 2022, and a few in 2023 in English were included. Inclusion criteria focused on studies that explored strategies to enhance vaccine uptake during epidemics or pandemics. The process of screening, eligibility assessment, and data extraction was performed by two independent reviewers, with disagreements resolved by a third researcher. A total of 1,728 articles on strategies for promoting COVID-19 vaccination were retrieved through database searches. After screening titles and abstracts and removing duplicates and incomplete texts, 207 articles were selected for full-text review. Of these, 22 articles were excluded due to irrelevance or unclear information regarding target populations, methodologies, or content. Ultimately, 185 research articles relevant to COVID-19 vaccination promotion strategies were analyzed. Additionally, four weekly written reports and eight visual content reports from the Ministry of Health were reviewed to identify vaccination promotion interventions in various countries. In total, 197 documents were selected for final analysis.

Figure 1 presents the PRISMA flow diagram of the screening and study selection process (27). Data were extracted using a structured form tailored to the study objectives. This form included sections such as the first author's name, publication year, study location, data collection method, identified strategies, and strengths and weaknesses of each strategy.

To enhance reliability, 10% of the articles were randomly selected and reviewed by two researchers using the designed form. Qualitative data were analyzed using Braun and Clarke's six-phase thematic analysis method, including familiarization with data, identifying initial codes, searching for themes, reviewing themes, defining themes, and producing the final report to categorize the strategies (28). Patterns and meaningful insights in the data were systematically classified. Data analysis was conducted using Excel version 16.0 (Microsoft Corporation).

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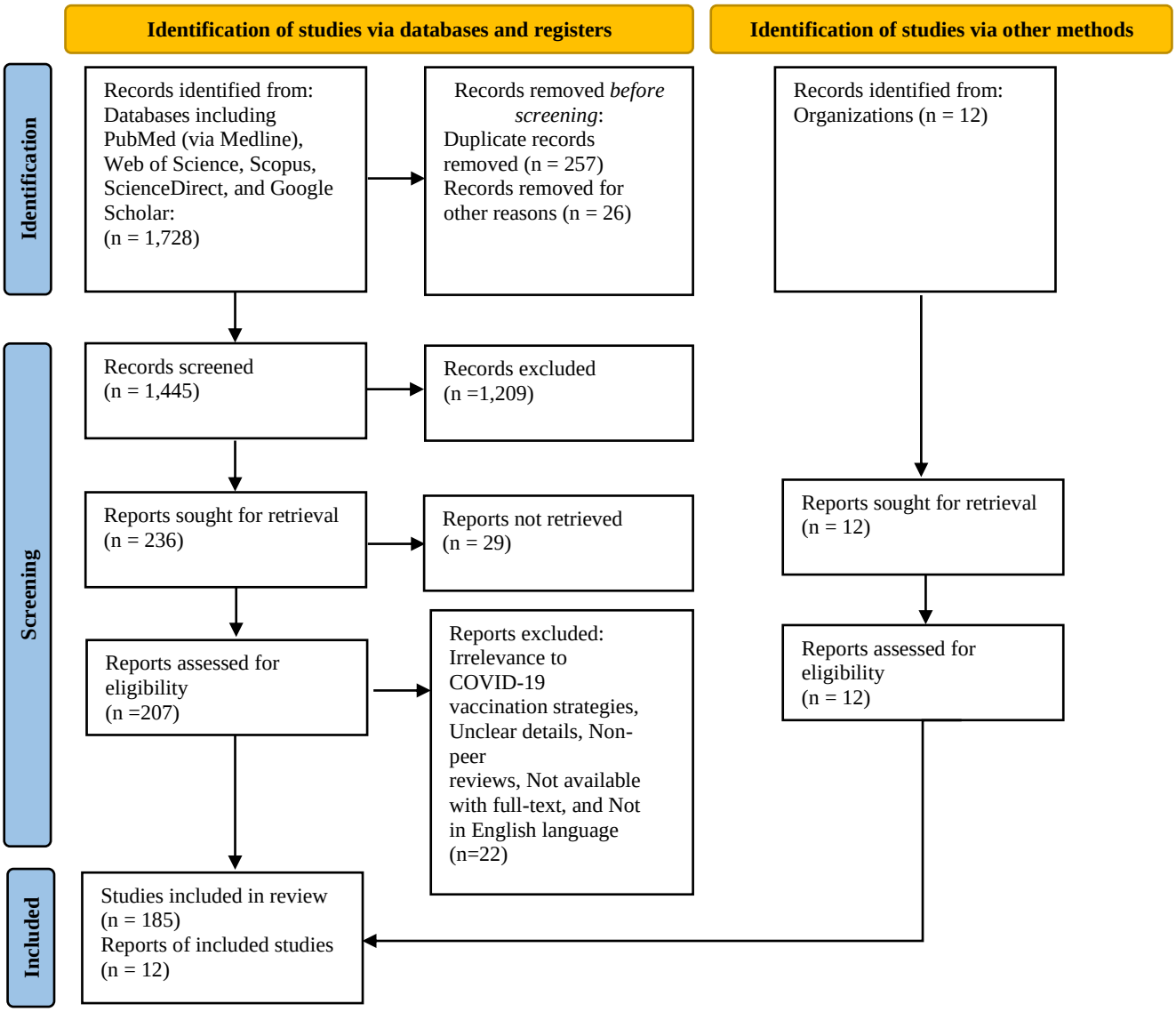

Figure 1. Database search and screening procedure

Delphi Method

To validate and prioritize the strategies identified in the scoping review, a Delphi study was conducted with experts in public health, epidemiology, and health policy. The Delphi method is used not only to achieve consensus among experts in a specific field but also to develop innovative perspectives in emerging areas of research, such as achieving vaccination coverage during the COVID-19 pandemic, which presents a complex and novel challenge (29). The Delphi process consisted of three rounds:

Round 1: Experts (n=30) were asked to rate the importance of each strategy using a five-point Likert scale. The questionnaire included two parts. Part one, included 8 general and demographic questions and part two included 131 vaccination strategy items categorized into six main groups: Provision, Promotion, Public Awareness, People, Preconditions, and Prizes.

Round 2: Participants received feedback on group responses and were asked to re-evaluate items that demonstrated moderate to high levels of consensus (Kendall's $W \geq 0.60$) and recommended items from round 1.

Round 3: Experts were asked to rate 8 extra questions on the effectiveness of the final model in addition to re-evaluating final items with moderate to high consensus. Final prioritization was conducted. Kendall's coefficient of concordance was calculated to assess agreement.

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Participants were selected through purposive sampling to ensure diversity in expertise, which included fields such as medicine, healthcare management, health policy, nursing, health education and promotion, public health, health economics, immunology, medical virology, epidemiology, biology, and vector control. Initially, a list of key managers and decision-makers in the national healthcare system involved in COVID-19 vaccination management and policymaking was compiled. Detailed information about the research objectives and methods was shared with 43 experts, of whom 30 agreed to participate and completed rounds. The characteristics of the participants are presented in Table 2.

Table 2 - Demographic Characteristics of Experts

Characteristic	Number of Panel Members
Gender	
Male	15
Female	15
Graduation	
Undergraduate	1
Master's Degree	6
PhD	20
MD	3
Age	
20–30 years old	4
31–40 years old	12
41–50 years old	11
More than 50	3
Position	
Junior roles	11
Senior roles	19

Data were collected through a structured questionnaire distributed to experts in all Delphi rounds. Participants were asked to evaluate each strategy based on the following four criteria (FAME):
Feasibility, Appropriateness and stakeholder support, Meaningfulness (including timeliness of implementation), and Effectiveness
Responses were scored on a Likert scale ranging from 1 (lowest) to 5 (highest). A sample question from the questionnaire is as follows: "Please rate the following strategy in terms of feasibility, stakeholder support, timeliness, and cost-effectiveness on a scale of 1 (very low) to 5 (very high):
Strategy 1: 'Improving public access to vaccines.' How effective is this strategy in promoting vaccination?" To facilitate data collection, an online questionnaire was designed using Google Forms and distributed via WhatsApp and email. Content validity and test-retest reliability were assessed to ensure the accuracy and reliability of the findings (29). The questionnaire was refined after each round to clarify ambiguities and improve its comprehensibility. Throughout the Delphi process, three key principles were maintained: anonymity among panel members, provision of feedback, and iterative rounds (30). Participants were unaware of the identity of other panel members (anonymity). After each round, the mean scores for each strategy were calculated and shared with participants without identifying individual responses (feedback). This process continued until consensus was reached (iteration).

Consensus Levels

A significant challenge in the Delphi method is determining the level of consensus among panel members. Many researchers neglect to establish consensus levels before beginning the Delphi process, relying instead on post-hoc interpretations. To address this, the Kendall's coefficient of concordance used in the analysis to determine strong consensus among panel members (31). If the coefficient showed little or no change over two consecutive rounds, the process was halted, indicating that further rounds were unlikely to yield increased agreement (Table 3).

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Table 3 - Interpretation of Various Kendall's Coefficient Values

Coefficient Value	Interpretation	Confidence in Ranking Strategies
0.1	Very weak consensus	None
0.3	Weak consensus	Low
0.5	Moderate consensus	Moderate
0.7	Strong consensus	High
0.9	Very strong consensus	Very high

In the present investigation, a consensus level of 70% was used as the benchmark for strong agreement, while 60% to 70% indicated moderate agreement. Strategies achieving at least 60% to 70% of the maximum possible score (90–105 points) were deemed moderately valid, while those surpassing 70% (105 points or more) were considered strongly valid. This approach ensured the inclusion of strategies with moderate agreement, avoiding the loss of potentially impactful solutions.

Dynamic Modeling

In the third phase, a structured mathematical modeling approach was employed to support evidence-informed health policymaking and strategic prioritization of vaccination promotion interventions during epidemics. Mathematical modeling has become an established approach in health policy analysis, enabling systematic evaluation of complex interventions under varying epidemiological conditions (32). Building upon the results of the Delphi method, four key decision-making criteria were extracted from expert evaluations: Feasibility, Appropriateness, Meaningfulness, and Effectiveness. These criteria reflect both operational and policy-relevant dimensions of strategy implementation. The visual output of this scoring process was later presented as a heatmap to enhance interpretability (Figure 2). The distribution of consensus levels across these categories was subsequently visualized using a radar chart (Figure 3), providing an intuitive overview of expert agreement patterns.

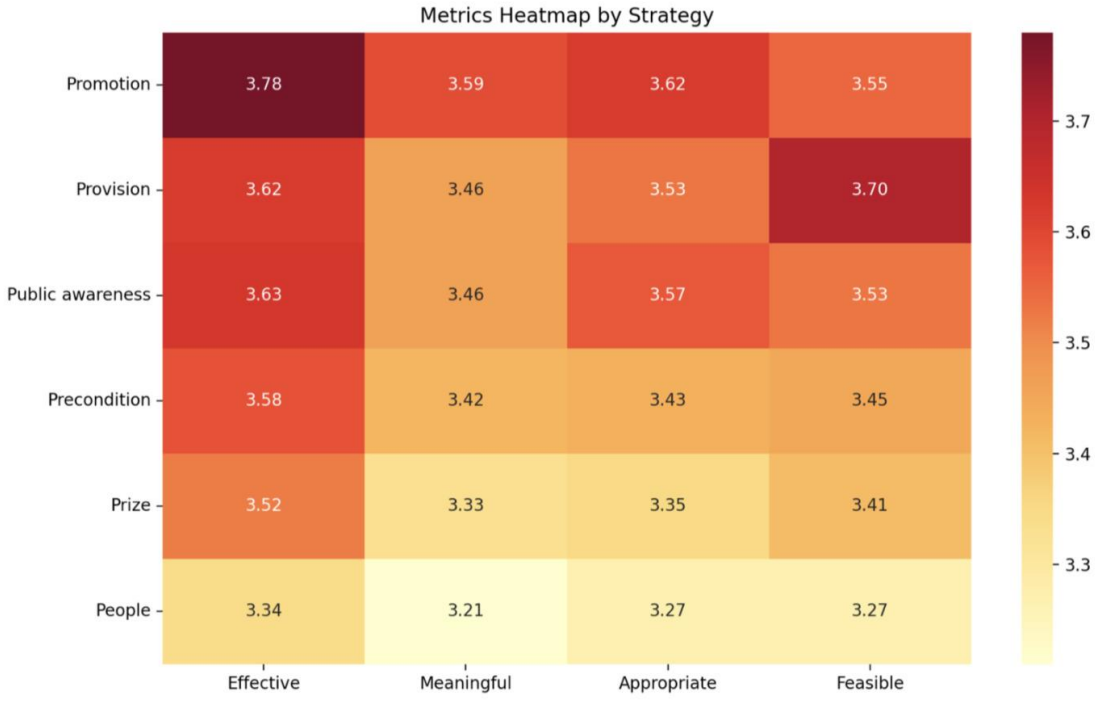

Figure 2. Comparative heatmap of Feasibility, Appropriateness, Meaningfulness, and Effectiveness across strategies

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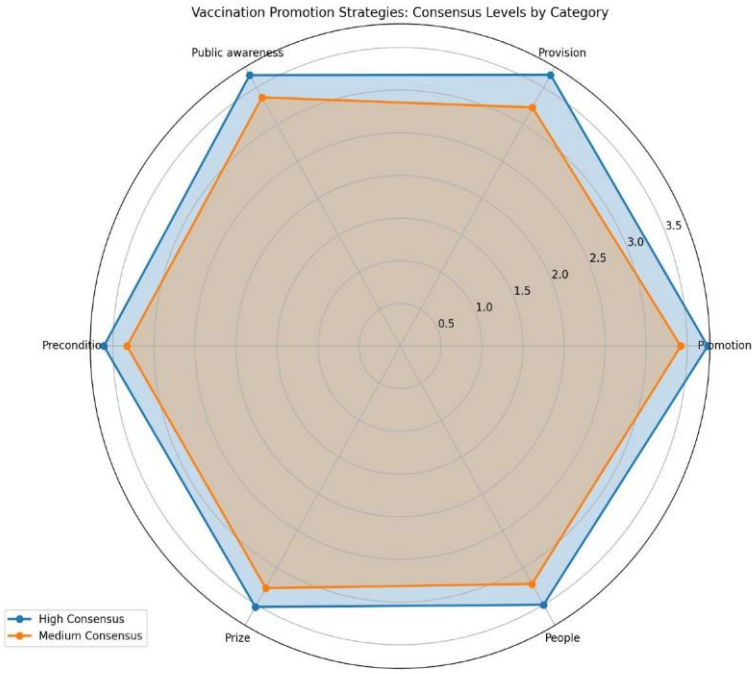

Figure 3. Consensus levels for vaccination promotion strategies by category

This radar chart illustrates the level of expert consensus (high vs. medium) on six categories of strategies proposed for promoting vaccination during epidemics. These categories include Promotion, Provision, People, Prize, Preconditions, and Public awareness. The chart helps visualize which areas reached strong expert agreement and where moderate consensus was observed during the Delphi study.

A dynamic modeling framework was designed to quantify the relative value of each strategy. Strategies with strong or moderate consensus were selected and scored across the four criteria. A weighted scoring system was then applied to account for the shifting priorities that typically characterize epidemic response planning. For example, Feasibility may be weighted more heavily during early outbreak phases, while Effectiveness and Meaningfulness may gain priority in later phases of policymaking (33, 34). The final calculated priority scores were used to generate a dynamic radar model that integrates weighted scores with consensus levels for each strategy (Figure 4), enabling a more comprehensive policy analysis.

The model calculates the overall priority score of each strategy using the following weighted summation formula:

$$R_S = \sum_{m \in M} w_m \cdot r_{s,m}$$

Formula 1

Where:

- R_S is the final score of strategy s,
- w_m represents the weight of criterion m,
- $r_{s,m}$ is the score of strategy s in criterion m.

To enhance the transparency and applicability of this model in public health decision-making, a set of visualization tools was integrated. Python-based tools (such as Matplotlib and Pandas libraries) were utilized to generate dynamic radar charts that visually represent the strategic profile of each intervention across the scoring criteria (Berman, 2010 ; Kumar, 2018).

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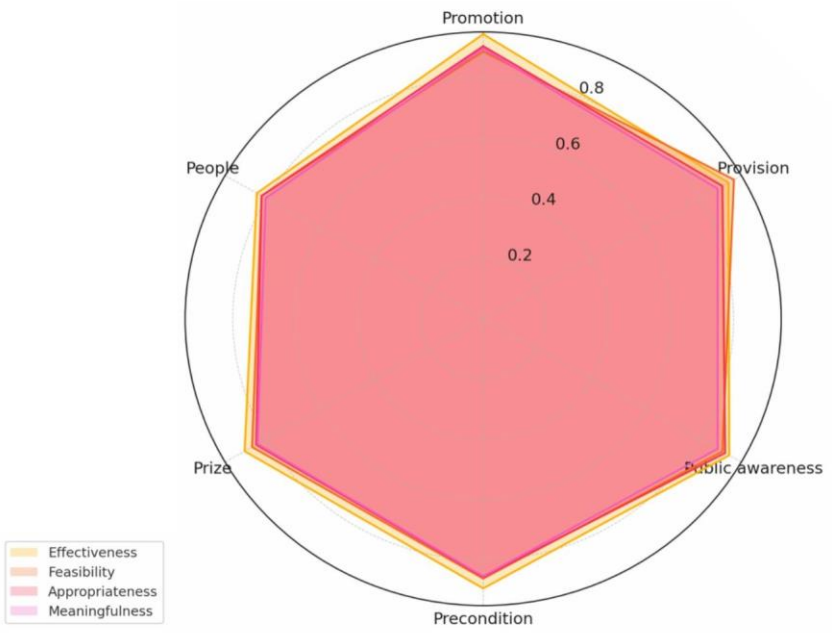

Figure 4. Dynamic prioritization of vaccination promotion strategies by evaluation criteria

This radar chart presents a dynamic model evaluating vaccination promotion strategies across four key criteria: Effectiveness, Feasibility, Appropriateness, and Meaningfulness. Strategies were scored using a weighted system that reflects shifting priorities during different phases of an epidemic. The model integrates expert consensus with multi-criteria analysis to support adaptive, evidence-based policymaking. In addition, a hybrid chart was developed to simultaneously depict expert consensus levels alongside weighted scores. This dual visualization approach provides policymakers with an intuitive framework for assessing strategy suitability and alignment with epidemic-specific policy goals. The final outcome of this phase was a data-driven and context-sensitive prioritization model, offering a robust foundation for adaptive and evidence-based vaccination promotion policies. By integrating expert opinion with quantitative modeling techniques, the framework serves as a practical decision support tool for health systems under epidemic pressure.

Ethical Consideration

Ethical approval was obtained from the Iran National Committee for Ethics in Biomedical Research, Iran University of Medical Sciences, Tehran. Iran (Ethical Code: IR.IUMS.REC.1401.373). All participants provided informed consent prior to participation. Participants' confidentiality and privacy were fully protected throughout the research process.

Results

The findings of the study are presented in three sections corresponding to each methodological phase.

Results of Scoping Review

The scoping review identified 197 eligible studies that proposed diverse strategies to enhance COVID-19 vaccination. In the initial phase, 1034 subthemes, including 131 strategies for promoting vaccination, were identified. Thematic analysis led to categorization of strategies into six main domains: Provision, Promotion, Public Awareness, People, Preconditions, and Prizes. While some articles proposed a single strategy or a combination of strategies based on identified barriers to vaccination, others assessed their effectiveness through clinical trials. Given the nature of the scoping review, all proposed strategies were included in the analysis. Additionally, 12 studies focused on archival reports from health ministries, detailing strategies implemented in various countries.

The frequency of strategies across different articles was examined by group and target country.

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Results indicated that the most frequently recommended strategies for increasing vaccine uptake pertained to the Promotion and Provision groups. Studies were conducted in various regions, including China, Taiwan, African nations, and European countries, with the highest number focusing on vaccine uptake in the United States (Figure 5).

To further highlight key insights, a word cloud (Figure 6) was generated to visualize the central terms and phrases identified across the reviewed studies. Terms such as 'healthcare providers,' 'public trust,' and 'transparent communication' emerged as the most influential, reflecting the importance of credible sources, clear messaging, and targeted outreach in fostering trust and vaccine uptake. Frequently recommended strategies included transparent discussions about vaccine safety and benefits, improving accessibility, enhancing safety and efficacy, and organizing culturally tailored campaigns at religious and public gatherings. Additional approaches involved implementing conditional regulations (e.g., requiring vaccination certificates for employment), disseminating evidence-based intervention results, correcting misconceptions (e.g., conspiracy theories and misinformation) through health expert education, utilizing social media for extensive outreach, and engaging social leaders to advocate for vaccination. These findings provide actionable guidance for enhancing vaccine uptake and ensuring equitable access across diverse populations.

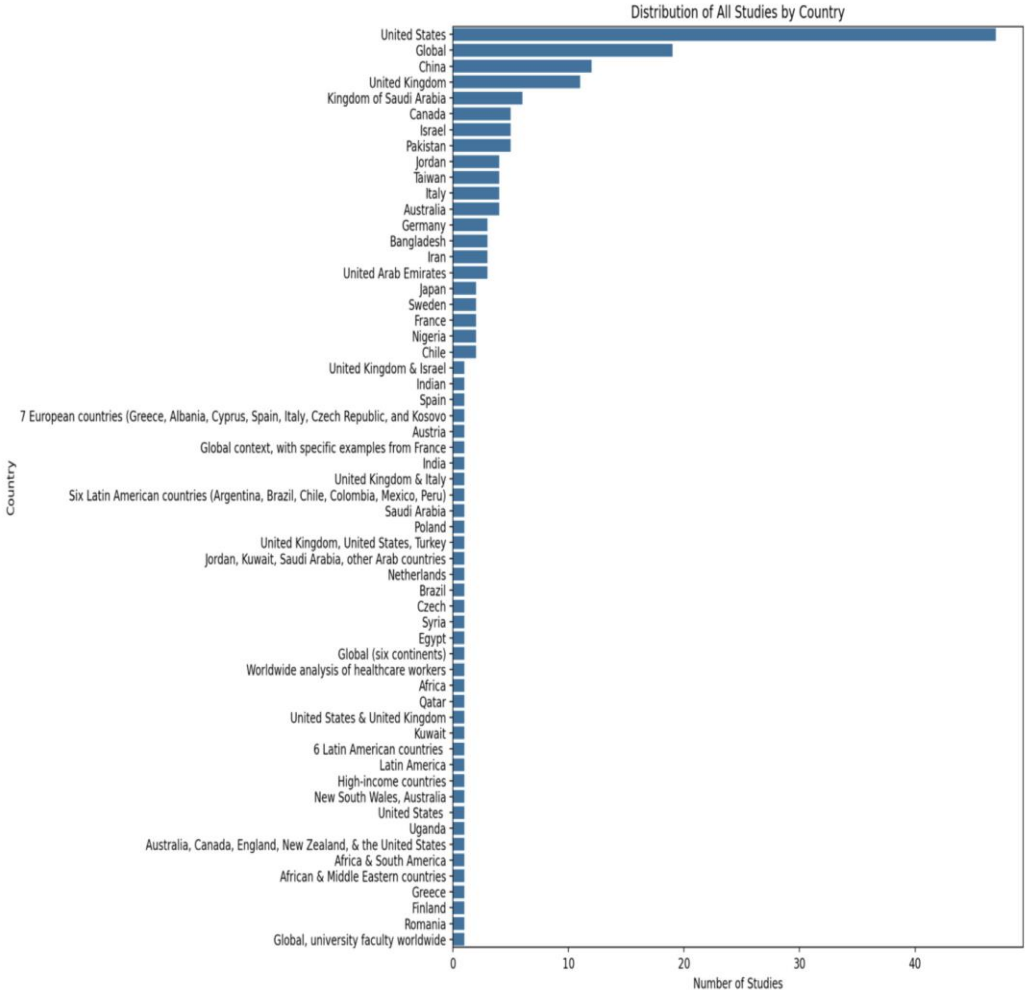

Figure 5. Frequency distribution of studies on COVID-19 vaccination strategies by research setting

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Figure 6. Word Cloud of Key COVID-19 Vaccine Promotion Strategies Across Studies

Results of Delphi Study

Results of round 1: In round 1, all 131 strategies for promoting COVID-19 vaccination were presented to experts for evaluation. Of these, 48 strategies achieved the desired level of consensus (consensus ≥60%). The most strongly agreed-upon strategies included:

-Effective prioritization of vaccination for vulnerable groups (e.g., the elderly, uninsured individuals, and low-income populations) within a specific timeframe, scoring 114.5 (76.33% of the possible score).

-Disseminating accurate and reliable information about vaccines, scoring 114 (76%).

-Conducting widespread and informed vaccine promotion campaigns, scoring 113 (75.33%).

-Improving public access to vaccines, scoring 112.5 (75%).

-Integrating COVID-19 vaccination into the national vaccination program and other health initiatives, scoring 110 (73.33%).

Three other strategies with lower scores included:

-Offering incentivized health insurance premiums for unvaccinated individuals who receive the vaccine, scoring 93 (62%).

-Utilizing volunteer ambassadors within families to promote vaccination, scoring 92.5 (61.67%).

-Removing political factors that negatively impact public trust in vaccine development, scoring 90 (60%).

Based on expert feedback, 10 new strategies were added to the list of vaccination promotion strategies.

Results of round 2: In the second round, panel members were asked to reevaluate their responses. The questionnaire included the scores from the first round alongside each strategy for context. In addition to the 48 original strategies, feedback was sought on the 10 newly proposed strategies from the first round, resulting in a total of 58 strategies in the second round. By the end of the second round, 46 strategies had achieved at least 60% of the possible scores. Among these, 28 strategies (scoring 60%–70%) were classified as having moderate consensus, while 18 strategies (scoring 70% or higher) were categorized as having strong consensus and proceeded to the third round. The largest number of

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strategies belonged to the "Improving Vaccine Accessibility" and "Widespread Promotion" groups, each with 14 strategies. The highest-ranked strategies in the round 2 included:

-Effective prioritization of vaccination for vulnerable groups (e.g., the elderly, uninsured individuals, and low-income populations) within a specific timeframe, scoring 113.75 (75.83% of the possible score).

-Utilizing visual content (e.g., video clips, animations, and advertisements) instead of textual content (e.g., SMS), scoring 113.5 (75.67%).

-Conducting widespread and informed vaccine promotion campaigns, scoring 112 (74.67%).

-Improving public access to vaccines, scoring 111.25 (74.17%).

-Broadcasting advertisements highlighting the benefits of vaccination on media platforms and urban billboards, scoring 110.75 (73.83%).

Other strategies, such as "offering incentivized health insurance premiums for vaccination," "advocating vaccination through religious leaders," "removing political factors from vaccine development processes," and "conducting door-to-door vaccinations during epidemics," scored 92.25, 92, 90.75, and 90.75, respectively, ranking lower on the validated strategies list. In total, 12 strategies with scores below the threshold (60%) were excluded from further analysis. These included "offering academic scholarships in exchange for vaccination," "forming political alliances to promote vaccination," and "imposing escalating penalties, from mandatory leave to work suspension and license revocation for unvaccinated individuals," which scored 73.25, 79.75, and 81.25, respectively. These findings reflected the iterative review and analysis process and helped identify the most effective strategies for promoting COVID-19 vaccination across different approaches.

Table 4: Comparison of Expert Ratings in Rounds 2 and 3 by Category

Category Title	Rank in Category	Strategy Title	AES, R3	TES, R3	EC, R3	TE, R2	EC, R2	Overall Rank
Promotion	1	Widespread and informed promotion of the vaccine	4.04	121.25	H	112	H	1
	2	Use of visual content (such as videos, animations, and teasers) instead of text-based content (like SMS)	3.88	116.5	H	113.5	H	2
	3	Broadcasting and sharing accurate and credible vaccine news	3.87	116	H	105.75	H	3
	4	Launching public health campaigns to promote vaccines in schools, neighborhoods, and urban/rural areas	3.83	114.75	H	107.75	H	6
	5	Sending SMS messages encouraging vaccine uptake	3.73	112	H	106.25	H	8
	6	Advertising the benefits of vaccination in media and city billboards	3.68	110.5	H	110.75	H	13
	7	Promotion of the vaccine by social media influencers	3.68	110.25	H	107.5	H	14
	8	Launching cultural campaigns promoting vaccination in neighborhoods, religious places, and public gatherings	3.54	106.25	H	108	H	24
	9	Medical group campaigns to promote vaccination among other groups of doctors who are opposed	3.51	105.25*	H	100.75	M	26
	10	Online debates with various stakeholders, e.g., vaccine manufacturer, vaccine importer, Ministry of Health representatives	3.49	104.75*	M	102	M	29
	11	Announcing the number of unvaccinated deaths in official news	3.46	103.75	M	102.75	M	31
	12	Promoting vaccination in various social groups (age, gender, ethnicity, profession, etc.)	3.43	102.75	M	98.25	M	32
	13	Real interviews with COVID patients in hospitals or relatives of deceased due to the disease	3.40	102	M	103	M	33
	14	Extensive and continuous advertisements in newspapers and magazines	3.34	100.25	M	101	M	36
Provision	1	Effective prioritization of vaccination for vulnerable groups (elderly, uninsured, low-income individuals)	3.86	115.75	H	113.75	H	4
	2	Allocation of specific and special budget to vaccination processes and increased monitoring	3.83	115*	H	103.25	M	5

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	3	Improving public access to the vaccine	3.73	112	H	111.25	H	7
	4	Improving the safety and effectiveness of the vaccine	3.73	111.75*	H	100	M	10
	5	Fair and non-discriminatory distribution of the vaccine through improved logistics	3.67	110*	H	98.75	M	15
	6	Control of vaccine pricing and reduction of access costs	3.63	109*	H	99.75	M	16
	7	Color-coding regions based on vaccination rates in relation to COVID intensity	3.63	109	H	105.75	H	17
	8	Integration of COVID vaccination into existing health programs	3.61	108.25	H	110.25	H	18
	9	Establishing vaccination policies for specific occupational groups	3.58	107.5	H	105.5	H	19
	10	Expanding vaccination centers to organizations, parks, and major city shopping centers	3.56	106.75	H	105.5	H	20
	11	Open and transparent dialogue, providing clear information about vaccine safety and effectiveness backed by valid scientific data	3.55	106.5*	H	104.5	M	23
	12	Removal of political factors (policies harming public trust) from the vaccine development process	3.35	100.5	M	92	M	35
	13	Effective vaccination prioritization based on demographic characteristics	3.33	99.75	M	103	M	38
	14	Conducting house-to-house vaccination campaigns during an epidemic	3.02	90.5	M	90.75	M	46
Public Awareness	1	Presenting research results on vaccination and evidence-based interventions in an accessible manner for the public (e.g., infographics and animations)	3.73	112	H	107.5	H	9
	2	Disseminating scientific findings widely and creatively via popular social media networks	3.71	111.25	H	107.75	H	11
	3	Correcting misconceptions about vaccines (e.g., vaccines are deadly, vaccinated individuals can be tracked geographically, they want to infect us with the vaccine) by health professionals	3.56	106.75*	H	102.5	M	21
	4	Using family doctors to raise public awareness about vaccines	3.48	104.25	M	101.25	M	30
	5	Organizing scientific competitions about vaccines as a tool for promoting correct information	3.26	97.75	M	96	M	41
Precondition	1	Requiring health insurance organizations to pay for COVID patients' treatment only upon presentation of a vaccination card	3.69	110.75	H	107.25	H	12
	2	Making travel contingent on presenting a vaccination card	3.53	105.75	H	106.5	H	25
	3	Making non-urgent surgeries contingent on vaccination	3.33	100	M	94.5	M	37
	4	Making contract renewals contingent on possessing a vaccination card	3.33	99.75	M	103.5	M	39
Prize	1	Government recognition for public participation in vaccination	3.56	106.75*	H	104.5	M	22
	2	Encouraging voluntary vaccination	3.50	105*	H	100.5	M	27
	3	Offering paid leave as an incentive for employees to get vaccinated	3.37	101	M	98.5	M	34
	4	Increasing health insurance premiums as an incentive for those who have not yet been vaccinated	3.18	95.5	M	92.25	M	44
People	1	Promoting vaccination by popular and trusted social leaders	3.50	105*	H	102.25	M	28
	2	Promoting hope, positive emotions, and social norms as effective tools	3.32	99.5	M	102	M	40
	3	Promoting vaccination within families by a family member as a vaccine ambassador	3.23	97	M	94.75	M	42
	4	Promoting vaccination by leaders of different religions influencing their followers	3.22	96.5	M	92.25	M	43
	5	Using vaccination promotion working groups with trusted community representatives in neighborhoods	3.11	93.25	M	93	M	45

Abbreviations: AES, R3: Average Expert Score in Round 3; TES, R3: Total Expert Score in Round 3; ECL, R3: Expert Consensus Level in Round 3; TES, R2: Total Expert Score in Round 2; ECL, R2: Expert Consensus Level in Round 2; Consensus levels are denoted as H (High/Strong consensus) and M (Moderate consensus)

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Results of round 3: In the third round of the Delphi process, 46 vaccination promotion strategies were evaluated based on their scores from round 2. As in the previous round, strategies achieving moderate consensus (60%–70% of the possible scores) and strong consensus (above 70% of the possible scores) were presented to panel members for final agreement. All 30 distributed questionnaires were completed and returned, and ultimately, all 46 strategies achieved at least 60% of the possible scores. Among these, 18 strategies with scores between 60% and 70% were classified as having moderate consensus, while 28 strategies with scores of 70% or higher were classified as having strong consensus. Table 4 provides a detailed comparison of the scores for the strategies across Delphi rounds 2 and 3. The analysis showed that the highest mean score belonged to the "Promotion" category, with an average score of 3.63. This was followed by "Provision" (3.57), "Public Awareness" (3.55), "Preconditions" (3.53), and "Prizes" (3.40). The lowest overall mean score was observed in the "People" category (3.28). Table 4 compares expert ratings of strategies in Round 2 and Round 3, ordered by the highest scores in Round 3 within each strategy category. Strategies marked with an asterisk (*) had moderate consensus in Round 2, which increased to strong consensus in Round 3.

Among the selected strategies in the third round, the top five strategies with the highest scores were:

-Conducting widespread and informed vaccine promotion campaigns: 121.25 points (80.83% of the possible score).

-Using visual content (e.g., video clips, animations, teasers) instead of textual content (e.g., SMS): 116.5 points (77.67%).

-Disseminating accurate and reliable information about vaccines: 116 points (77.33%).

-Effective prioritization of vaccination for vulnerable groups (e.g., the elderly, uninsured, low-income populations) within a specified timeframe: 115.75 points (77.17%).

-Allocating dedicated funding for vaccination processes and enhancing oversight: 115 points (76.67%).

The three strategies with the lowest scores included:

-Offering incentivized health insurance premiums for individuals who had not yet been vaccinated: 95.5 points (63.67%).

-Forming vaccination promotion task forces in collaboration with trusted community representatives: 93.25 points (62.17%).

-Conducting door-to-door vaccination campaigns during epidemics: 90.5 points (60.33%).

After round 3, all 46 strategies reached either moderate or strong consensus levels. Of these, 10 strategies, including "Improving vaccine safety and efficacy" and "Controlling vaccine prices and reducing access costs," achieved strong consensus in this round. In the final analysis, based on four key criteria—Feasibility, Appropriateness, Meaningfulness, and Effectiveness—the strategy of "conducting widespread and informed vaccine promotion campaigns" ranked highest. This strategy received widespread approval for its feasibility, effectiveness, and appropriateness, demonstrating its potential for implementation and impact. Figure 4 presents a heatmap comparison of the four metrics across all strategies. Strategies that scored highly across all four criteria (highlighted in darker colors) were considered promising candidates for promoting vaccination in future epidemics. Strategies with higher scores for Feasibility and Effectiveness were expected to be implemented more rapidly and potentially achieve greater vaccine uptake. Conversely, strategies with higher scores for Meaningfulness and Appropriateness were more closely aligned with cultural and social needs and may contribute to greater public acceptance. According to expert opinions, the five most feasible strategies for promoting vaccination were:

1. Conducting widespread and informed vaccine promotion campaigns.
2. Sending SMS reminders encouraging vaccine uptake.

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3. Using visual content (e.g., videos, animations, teasers) instead of textual content (e.g., SMS).
4. Launching public health campaigns to promote vaccination in schools, neighborhoods, and urban and rural areas.
5. Broadcasting advertisements highlighting the benefits of vaccination on media platforms and urban billboards.

Experts also identified the five strategies most likely to gain stakeholder support:

1. Conducting widespread and informed vaccine promotion campaigns.
2. Disseminating accurate and reliable information about vaccines.
3. Using visual content instead of textual content for vaccine messaging.
4. Launching public health campaigns for vaccine promotion in schools and neighborhoods.
5. Effective prioritization of vaccination for vulnerable groups within a specified timeframe.

The five most time-sensitive strategies were identified as:

1. Conducting widespread and informed vaccine promotion campaigns.
2. Disseminating accurate and reliable information about vaccines.
3. Effective prioritization of vaccination for vulnerable groups within a specified timeframe.
4. Sending SMS reminders encouraging vaccine uptake.
5. Presenting research findings and evidence-based interventions in an accessible format (e.g., infographics, animations).

Finally, the five most cost-effective strategies included:

1. Conducting widespread and informed vaccine promotion campaigns.
2. Allocating dedicated funding for vaccination processes and enhancing oversight.
3. Effective prioritization of vaccination for vulnerable groups within a specified timeframe.
4. Improving vaccine safety and efficacy.
5. Using visual content for vaccine promotion.

Results of Dynamic Modeling

The radar-based dynamic model provided a visual and analytical framework for prioritizing vaccination promotion strategies based on expert consensus. Figure 5 illustrates the radar chart designed based on the panel members' ratings of the vaccination promotion strategies. This model categorizes different strategies based on the level of agreement among the panel members, highlighting strategies with high consensus and medium consensus for each category. Each axis of the radar chart represents a category of strategies, such as Public Awareness, Provision, Promotion, etc. Strategies falling under categories like Provision and Promotion tend to have higher consensus, while categories such as Prize or Precondition might show lower levels of agreement.

Categories with a clear high consensus (such as Public Awareness and Provision) could be considered as priorities when planning vaccination promotion programs. Strategies with medium consensus indicate a need for further review or additional research to improve and achieve higher agreement. The radar structure of the model provides a comprehensive, comparative view of all categories, which is highly beneficial when designing a systematic vaccination promotion model. The final prioritization of strategies was conducted using a weighted multi-criterion scoring model. In a simulated scenario, greater weights were assigned to Feasibility (0.3) and Meaningfulness (0.3), reflecting a high-urgency epidemic context. Table 5 presents the comparative final scores of two strategies under this scenario: Promotion (3.86) and Provision (3.83), using following calculations for each strategy. The slight difference illustrates the model's capacity to reflect contextual prioritization nuances.

$$R_{Promotion} = (0.3 \times 4.0) + (0.2 \times 3.5) + (0.3 \times 4.0) + (0.2 \times 3.8) = 1.2 + 0.7 + 1.2 + 0.76 = 3.86$$

$$R_{Provision} = (0.3 \times 3.8) + (0.2 \times 3.6) + (0.3 \times 4.1) + (0.2 \times 3.7) = 1.14 + 0.72 + 1.23 + 0.74 = 3.83$$

Figure 6 integrates weighted scores and consensus levels in a hybrid chart, offering a comprehensive visualization to support evidence-based decision-making. This model enables policymakers to

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systematically adapt strategy prioritization based on epidemic-specific needs and stakeholder perspectives.

Table 5: Weighted Scores of Strategies by Four Evaluation Criteria

Strategy	Feasibility (w=0.3)	Appropriateness (w=0.2)	Meaningfulness (w=0.3)	Effectiveness (w=0.2)
Promotion	4.0	3.5	4.0	3.8
Provision	3.8	3.6	4.1	3.7

This table presents the weighted scores of vaccination strategies (Promotion and Provision) evaluated across four criteria: Feasibility, Appropriateness, Meaningfulness, and Effectiveness. Scores are based on an example scenario presented during an outbreak to assess the potential impact and applicability of each strategy.

Discussion

This work aimed to develop a dynamic and adaptable model for promoting vaccination during epidemics, addressing the limitations of existing static models. Unlike traditional approaches, the proposed model leverages participatory methods and real-time data integration to enhance responsiveness and effectiveness, using insights gained from the Covid-19 experience. The scoping review phase identified six main categories of strategies: Provision, Promotion, Public Awareness, People, Preconditions, and Prizes. Among these, the Promotion and Provision categories showed the highest levels of agreement and effectiveness, aligning with prior studies that emphasize the importance of accessibility and effective communication in improving vaccine uptake (35-37). For instance, clear and accurate information regarding vaccine safety and efficacy significantly reduces public hesitation (38, 39). The Delphi method further classified strategies into high- and moderate-agreement groups, offering a structured prioritization framework. Building on high-agreement strategies, especially those related to promotion, evidence suggests that targeted campaigns enhance public trust. Studies from Jordan, Brazil, South Korea, Georgia, Malaysia, and Arab countries reveal how misinformation hinders uptake, underlining the need for credible messaging (40-42). These findings emphasize the necessity of evidence-based public messaging that directly counters vaccine misinformation. Similarly, Health Belief Model constructs such as perceived benefits and cues to action play a vital role in motivating acceptance in China (6, 35). Research from Canada supports community-centered interventions, demonstrating how localized trust-building measures significantly impact vaccine uptake (43, 44).

Cross-cultural findings highlight the need for tailored strategies. In countries like China and Taiwan, culturally resonant campaigns outperformed generic ones, while in the US, leveraging social media within national programs has proven effective (45, 46). Studies from Sub-Saharan Africa highlight the importance of aligning vaccination strategies with local infrastructure and sociopolitical norms. This includes approaches such as supply chain redesign, outsourcing logistics to local providers, and strengthening trust in government and society, all of which have been shown to improve vaccine availability, reduce distribution costs, and lower vaccine hesitancy (47, 48). These insights affirm the importance of adaptable models that can be calibrated across regions. Future studies are recommended to test the proposed model in diverse contexts, including non-epidemic settings.

The Delphi method underscored the value of evidence-based, targeted interventions, such as dedicated funding and reliable information campaigns, in guiding vaccination strategies (49, 50). Moreover, the use of social influencers and healthcare professionals as trusted sources was identified as a key element in combating vaccine misinformation (41, 51). Research highlights the influence of both healthcare professionals (HCPs) and social media influencers (SMIs) in shaping public attitudes toward vaccination. Healthcare workers are often seen as trusted messengers in Europe (52), while influencers have been shown to significantly affect health-related behaviors, both positively and negatively, through online platforms (53). To ground the model in theory, frameworks like the Health Belief Model (HBM) and Diffusion of Innovations (DOI) were applied. HBM helps address personal motivation through perceived risk and benefit framing, though it is limited in accounting for social dynamics. Hence, incorporating strategies like peer influence and community trust offers a more

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holistic approach (35, 54). The DOI model complements this by emphasizing the spread of innovation through networks. Recent studies have applied this framework to digital environments, using dynamic scoring and user segmentation to monitor the adoption trajectory and inform targeted outreach strategies (4, 55, 56).

The dynamic scoring system enables real-time prioritization of strategies based on evolving conditions. Unlike rigid models, this one adjusts feasibility and effectiveness criteria to accommodate local contexts—an approach validated in India and South Africa (57). By incorporating cultural, economic, and social indices, the model offers a more comprehensive and context-aware framework, aligning with the emphasis on regional specificity and equity identified in research agendas for health, particularly in the context of global and regional health responses (58). To illustrate, in a scenario with regional disparities in vaccine uptake, the model could prioritize awareness campaigns in resistant communities while deploying mass vaccination in dense urban areas. Such flexibility ensures that intervention strategies are both data-informed and context-sensitive. A notable strength of this model is its inclusive, participatory decision-making structure, involving healthcare experts and stakeholders at every stage. This aligns with findings highlighting the effectiveness of co-designed strategies in improving vaccine uptake. Tools like radar charts simplify complex outcomes, supporting decision-makers in formulating timely responses (38, 59, 60). The Delphi method was instrumental in reaching expert consensus, consolidating interdisciplinary insights into a coherent framework. Its application here supports its value in strategic planning and reinforces its relevance for addressing similar public health challenges.

In sum, the proposed model addresses critical gaps in static vaccination frameworks by offering a dynamic, data-driven, and participatory solution. It stands out by integrating real-time feedback, expert consensus, and socio-cultural adaptability. By promoting trust and engagement at the community level, it offers a promising approach for future vaccination efforts. Further research should examine its utility across diverse settings and explore its potential in broader public health interventions. While the proposed model offers valuable insights into vaccination promotion during epidemics, several limitations must be acknowledged. First, the reliance on expert consensus may introduce bias due to the limited diversity of perspectives among panelists. Future studies could benefit from involving a wider range of stakeholders, including local communities and frontline health workers, to capture a broader spectrum of vaccination challenges and solutions. Another limitation concerns the regional focus of the Delphi panel, which primarily consisted of experts from Iran. Although the scoping review encompassed countries across different income levels, the limited geographic diversity of Delphi participants may affect the generalizability of findings. Future research should explore the model's applicability in varied socioeconomic and cultural contexts, particularly in low- and middle-income countries where healthcare infrastructures and social determinants differ significantly. While the Delphi method is a robust tool for achieving expert consensus, the model's effectiveness in real-world settings remains to be empirically validated. Field trials in diverse epidemic contexts, as well as longitudinal studies assessing its long-term impact, are essential to refine and validate the model further.

Implications for practice

The practical implications of the proposed model are substantial. Policymakers can use the model to guide the allocation of resources and tailor vaccination campaigns based on real-time data and socio-cultural context, ensuring more efficient and equitable vaccination efforts. This model can serve as a blueprint for future vaccination campaigns, not only in epidemic contexts but also for routine vaccination programs. Its adaptability to different regions and healthcare systems makes it a versatile tool for global health improvement. The proposed model provides a dynamic, evidence-informed framework for promoting vaccination during epidemics. By integrating real-time data, socio-cultural insights, and expert knowledge, it provides a flexible and responsive framework adaptable to various public health settings. As health systems evolve to face new infectious threats, this model offers a promising path toward more resilient and inclusive vaccination strategies.

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Conflicts of interest
The authors declare that they have no competing interests.

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Authors' Contributions
S.T, M.A, and M.S contributed to the conceptualization and design of the study. Z.A, L.E, F.K, and AJA were responsible for data curation. M.A, S.T, and M.S contributed to methodology, statistical analysis, and manuscript review and editing. M.A and S.T prepared the original draft. All authors read and approved the final manuscript.

Artificial Intelligence statement
The authors used Grammarly to assist with grammar checking.

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