How to increase and maintain high immunization coverage: Vaccination Demand Resilience (VDR) framework

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ABSTRACT

Background: Resilience in vaccination demand is ever more critical as the COVID-19 pandemic has increased our understanding of the importance of vaccines on health and well-being. Yet timid demand for COVID-19 vaccines where available and reduced uptake of routine immunizations globally further raise the urgent need to build vaccination resilience. We demonstrate the complexity of vaccination demand and resilience in a framework where relevant dimensions are intertwined, fluid, and contextual.

Methods: We developed the Vaccination Demand Resilience (VDR) framework based on a literature review on vaccination demand and expert consultation. The matrix framework builds on three main axes: 1) vaccination attitudes and beliefs; 2) vaccination seeking behavior; and 3) vaccination status. The matrix generated eight quadrants, which can help explain people's levels of vaccination demand and resilience. We selected four scenarios as examples to demonstrate different interventions that could move people across quadrants and build vaccination resilience.

Results: Incongruence between individuals' attitudes and beliefs, vaccination behavior, and vaccination status can arise. For example, an individual can be vaccinated due to mandates but reject vaccination benefits and otherwise avoid seeking vaccination. Such incongruence could be altered by interventions to build resilience in vaccination demand. These interventions include information, education and communication to change individuals' vaccination attitudes and beliefs, incentive programs and reminder-recalls to facilitate vaccination seeking, or by strengthening healthcare provider communications to reduce missed opportunities.

Conclusions: Vaccination decision-making is complex. Individuals can be vaccinated without necessarily accepting the benefits of vaccination or seeking vaccination, threatening resilience in vaccination demand. The VDR framework can provide a useful lens for program managers and policy makers considering interventions and policies to improve vaccination resilience. This would help build and sustain confidence and demand for vaccinations, and help to continue to prevent disease, disability, and death from vaccine-preventable diseases.

1. Introduction

Vaccines are credited as one of the most cost-effective interventions in public health [1–3]. Yet country immunization programs have been facing challenges to reach and maintain vaccine coverage targets, overcome access disparities, and ultimately avert deaths from vaccine-preventable diseases [4,5]. In 2021, 25.0 million infants worldwide, which is 19% of the target population, did not receive three doses of the diphtheria, tetanus and pertussis (DTP) vaccine [6]. Moreover, there were 18.2 million zero-dose children who have not received a single vaccine to prevent illness in 2021 [7]. Vaccination coverage for adolescents, adults, and the elderly substantially lags behind child

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immunization in most countries [8,9]. During the coronavirus disease 2019 (COVID-19) pandemic, continuation of routine immunizations and planned vaccination campaigns was disrupted worldwide [10]. These missed opportunities set the stage for preventable disease outbreaks, disabilities, and deaths [11,12].

Vaccination resilience refers to immunization systems that are able to withstand major shocks and disruptions, to quickly adapt to changing circumstances in order to maintain high vaccine uptake and acceptance over time [13]. Vaccination resilience is more than increasing vaccination coverage. It is about growing and maintaining high coverage over time across various vaccines and age groups, and having communities strongly support routine immunizations. Building vaccination resilience is a mounting challenge as vaccinations have become victims of their own success. The more vaccines effectively prevent vaccine-preventable diseases, the harder it becomes to readily observe and appreciate the value of vaccines, resulting in lowered demand for vaccinations [14,15]. Moreover, vaccination resilience lies within health system resilience, involving the development of strong health systems that can respond to crises, as well as having effective communication strategies [16,17].

The COVID-19 pandemic markedly affected health care systems around the globe. As the pandemic evolved, the instability of routine and COVID-19 vaccination program resilience became very evident as routine vaccinations were halted or deprioritized [10], and demand for COVID-19 vaccines stagnated [18]. The challenges of the COVID-19 vaccination campaign further revealed that vaccination resilience is complex. Reduced levels of COVID-19 vaccine acceptance had serious implications in terms of morbidity, mortality and economic costs [19].

While challenges of supplying vaccines – including elements of planning, service delivery, training, and supervision – continue to exist, demand-side barriers have increasingly come to the forefront of challenges in building vaccination resilience. Even when vaccines are available or accessible, numerous factors may play a role in preventing people from demanding vaccinations [20–22]. Vaccine hesitancy has been used to describe this complex condition on a continuum ranging from individuals fully accepting all recommended doses of vaccines to outright refusing vaccines [23]. However, this term may oversimplify the myriad of factors at the individual, program, and context levels that can influence vaccine acceptance [24].

Vaccination demand is defined as the actions of groups of individuals and communities to seek, support, and/or advocate for vaccines and immunization services [25]. A variety of factors such as cost, time, place, vaccine type, and immunization services can affect vaccine acceptance and alter the demand for vaccination to no demand, or vice versa. For example, an individual or community may fully accept vaccination but may not demand vaccination or refuse a specific vaccine [23]. Factors such as distrust in the system, religious beliefs, source(s) of vaccine information, lack of awareness of vaccine benefits and recommendations, poverty or low socioeconomic status, lack of time to access available vaccination services, and/or gender-based discrimination may all influence vaccine acceptance and subsequently, vaccination demand and resilience [26,27].

Despite the challenge of building vaccination demand and resilience, there are limited frameworks available to understand how various contextual characteristics relate to and influence vaccination decisions. To help conceptualize vaccination demand and build resilience, we developed a framework that captures these multiple factors that can impact individual and community vaccine acceptance/demand and one that can be used by immunization program managers and policymakers to improve and sustain vaccination uptake.

2. Methods

2.1. Literature review

We first conducted a rapid literature review of vaccine demand in immunization programs in two major databases (PubMed and Scopus) using the following search terms: 'immunization', 'vaccine', 'demand', 'behavior', and 'decision' [28]. In addition, we used articles based on past work on vaccine hesitancy by the World Health Organization's (WHO) Strategic Advisory Group of Experts on immunization (SAGE) vaccine hesitancy working group and concepts related to the Second Strategic Objective (SO2) of the Global Vaccine Action Plan as identified by the Working Group on Vaccine Demand [29–31]. We also used articles on vaccine decision-making and vaccination behavior in previous vaccine demand work [31]. Evidence came from peer-reviewed behavioral, epidemiological, social, anthropological, operational, and systems science literature as well as economics and closely related fields in the medical humanities. We included articles that described one or more factors affecting vaccine demand, but excluded those that focused on supply-side factors, did not examine human vaccination, or did not provide insights on why people demand vaccines. For each article, we abstracted the title, author, year, journal, type of manuscript, factors discussed affecting vaccine demand, and relevant themes. We assessed article content for thematic contributions to understanding factors associated with vaccine demand. Two investigators reviewed articles and met to discuss underlying themes found in each article. These themes were used to abstract examples from the literature and grouped characteristics of vaccination seekers and their behaviors. The findings also helped us identify the scenarios to illustrate our framework.

2.2. Framework development

A framework on vaccine hesitancy was used to guide the initial development of a diagram to represent the dynamics of vaccine demand. We then used literature-based vaccine demand themes to further modify this diagram and develop a matrix for vaccination resilience. We examined individual decision-making processes, decision environments, inter-personal relationships, individual and household characteristics, epidemiologic environment, and immunization program readiness to deliver vaccination services including responsiveness, adaptability, and functionality. We also looked at the strength of the country's health system and community health care, especially when the literature was based on low-limited resource settings. These themes were categorized together to provide insights on linkages between factors. The authors discussed and iterated numerous times on the development of the framework.

The matrix framework was built based on three analytical dimensions: 1) an attitudinal/belief axis, ranging from the extent to which an individual's attitude/belief in vaccination is strongly positive and accepting, versus negative and rejecting; 2) a behavioral axis, ranging from active seeking of vaccination services to active avoiding of vaccination services; and 3) an outcome of vaccination status axis which captures outcome measures such as immunization coverage estimates, ranging from completely vaccinated to completely unvaccinated status. We utilized examples abstracted from the literature to refine the framework and ensure that it captures various perspectives. This framework was circulated to the Working Group on Vaccine Demand and incorporated with the experts' feedback for finalization.

2.3. Scenario identification

To help us illustrate the framework, we explored the existing literature to identify scenarios related to individuals' vaccine attitudes/beliefs, vaccine behavior, and vaccination outcomes. We developed four types of scenarios from the perspectives of each analytical dimension and interpreted them alongside our framework. These scenarios encompassed interventions to change attitudes and beliefs, vaccine-seeking behavior, vaccination status outcome, and strengthen patient provider communication. We reviewed factual examples and categorized them into scenarios, as well as identified relevant interventions for each quadrant of the framework. We selected examples across countries with different income levels and geographic regions. Identified scenarios

represent the dynamics of individuals' shifts in demand, related factors in vaccination decision-making, and interventions to increase and maintain vaccination demand.

3. Results

We developed the Vaccination Demand Resilience (VDR) framework (Fig. 1) to conceptualize the resilience of vaccination demand and its complexity. The three axes in the framework denote individuals' attitudes and beliefs about vaccinations (x axis), their behaviors around seeking or avoiding vaccinations (y axis), as well as vaccination outcomes (z axis). Attitudes and beliefs lie on a continuum from acceptance (right) to rejection (left). Vaccination behaviors can range from actively seeking vaccinations (top) to avoiding vaccinations (bottom). Finally, vaccination outcomes denote whether individuals actually get vaccinated (front, in purple) or remain unvaccinated (back, in blue). This framework can be applied across the age span from infancy to older adults by considering whose behaviors, attitudes/beliefs, and vaccination status is most relevant to each vaccination. For example, for childhood vaccines, mothers', fathers' or caregivers' attitudes and beliefs about vaccinations and their vaccination seeking behaviors would impact children's vaccination status. This framework could also be applied for vaccine-specific or dose-specific differences in individuals' attitudes and beliefs, behaviors, and vaccination outcomes.

The three axes generated eight quadrants which can explain people's levels of vaccination demand (Table 1). Each quadrant represents individuals' attitudes and beliefs about vaccinations, vaccination behaviors, and vaccination status, generating combinations that demonstrate their level of resilience toward vaccination demand. For example, quadrant 1 (Q1) represents individuals who fully accept the benefits of vaccinations, actively seek vaccinations, and are vaccinated. On the other hand, individuals in quadrant 8 (Q8) reject the benefits of vaccination, actively avoid vaccinations, and remain unvaccinated. The quadrants in between (Q2-Q7) demonstrate the challenge of vaccination demand resilience, where mismatches between individuals' attitudes and beliefs, behaviors, and vaccination outcomes, can challenge individuals' vaccination demand resilience.

To aid interpretation, this framework can be subdivided and viewed in two parts based on vaccination status in Fig. 2: one that explores the attitudinal/belief and behavioral dynamics of vaccinated populations (left, in pink) and the other focused on unvaccinated populations (right, in blue). Quadrants 1 through 4 (Q1-Q4) describe attitudes and beliefs, as well as behaviors of vaccinated populations, where these could be incongruent with their vaccination outcomes (Q2-Q4). For instance, individuals may be vaccinated and accept the benefits of vaccination but not actively seek vaccination, demonstrating complacency (Q2). Individuals in Q2 may miss future vaccinations without demand-generation interventions. Other individuals may not believe in the benefits of vaccination but seek vaccination and become vaccinated because of requirements (Q3). Furthermore, some individuals may neither believe in nor seek vaccinations but be vaccinated only because of mandates or expectations through schooling or employment (Q4). These individuals (Q3 and Q4) could miss future vaccinations when requirements are relaxed or circumventable, demonstrating weak vaccination demand resilience.

Fig. 3 focuses on unvaccinated populations, where quadrants 5 through 8 (Q5-Q8) illustrate vaccine hesitant attitudes and beliefs, behaviors, as well as supply-side barriers. Incongruence between individuals' beliefs, behaviors, and their unvaccinated status are observed in Q5-Q7. Individuals in Q5 accept and seek vaccination but are not vaccinated due to supply-side barriers such as vaccine unavailability or missed opportunities. This demonstrates the link between the demand and supply, where vaccination relies on there being supply of and access to vaccines. In Q6, individuals accept the benefits of vaccination but do not actively seek vaccination and remain unvaccinated, and these individuals may benefit from a nudge to seek vaccination. For example, Q6 may include children whose parents delay vaccines or seek an alternative vaccination schedule. In Q7, individuals seek vaccinations but reject the benefits and remain unvaccinated. Q7 demonstrates a breakdown in the immunization system where regulations may prompt individuals to seek vaccinations, but they remain unvaccinated because of bottlenecks at the point-of-service.

Incongruence between individuals' attitudes and beliefs, vaccination behavior, and vaccination status could be altered by interventions,

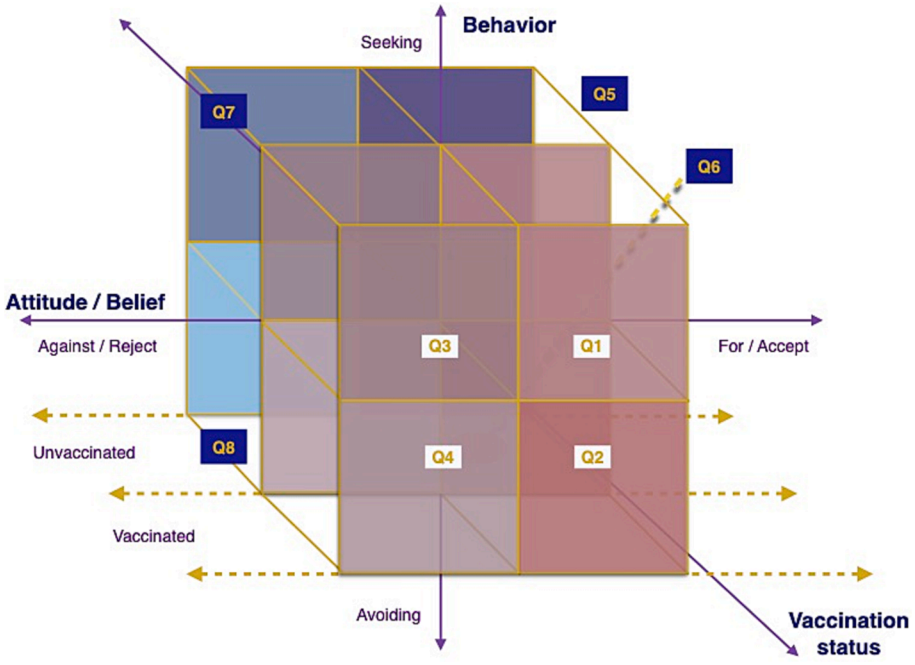

Fig. 1. The Vaccine Demand Resilience (VDR) framework. Developed to conceptualize the resilience of vaccination demand and its complexity using three axes to denote individuals' attitudes and beliefs about vaccination (x axis), their behaviors around seeking or avoiding vaccinations (y axis), as well as vaccination outcomes (z axis).

Table 1
The Vaccination Demand Resilience (VDR) framework components and relevant interventions.

Quadrant	Accepting*	Seeking*	Vaccinated*	Definition	Description	Relevant Interventions
Q1	+	+	+	Individual accepts the benefits of vaccination, seeks vaccination, and is vaccinated	Individuals who fully accept the benefits of vaccination and actively seek vaccination until they are vaccinated. Their demand for vaccination is resilient.	• Interventions to reinforce and maintain vaccine acceptance and seeking behavior, such as reminders
Q2	+	−	+	Individual accepts the benefits of vaccination, but avoids seeking vaccination, yet is vaccinated	Individuals who accept the benefits of vaccination and are vaccinated but face barriers that prevent them from fully seeking vaccination. These individuals are at risk of being unvaccinated, having partial compliance to immunization schedules, or not receiving all doses.	• Interventions to facilitate or induce seeking behavior, by increasing convenience and affordability, such as incentive programs and reminder-recall interventions
Q3	−	+	+	Individual rejects the benefits of vaccination, but seeks vaccination, and is vaccinated	Individuals who seek vaccination due to mandates or due to decision environments that default to vaccination, such as for schooling or employment, but do not accept the benefits of vaccination.	• Knowledge, education, and awareness interventions tailored to reasons for lack of acceptance of vaccination • Interventions to strengthen mandates/ sanctions for non-vaccination, such as narrowing exemptions
Q4	−	−	+	Individual rejects the benefits of vaccination, and avoids seeking vaccination, yet is vaccinated	Individuals who are vaccinated because of mandates or due to decision environments that default to vaccination, such as for schooling or employment, but do not accept the benefits of vaccination. Individual would not seek vaccination in the absence of mandate and may actively seek exemptions where possible.	• Knowledge, education, and awareness interventions tailored to reasons for lack of acceptance of vaccination • Interventions to strengthen mandates/ sanctions for non-vaccination, such as narrowing exemptions • Interventions to facilitate or induce seeking behavior, by increasing convenience and affordability, such as incentive programs and reminder-recall interventions
Q5	+	+	−	Individual accepts the benefits of vaccination, and seeks vaccination, but is not vaccinated	Individuals who accept the benefits of vaccination and seek vaccination but are unvaccinated due to supply factors, such as vaccine unavailability or missed opportunities for vaccination.	• Interventions to improve vaccination supply • Interventions to strengthen patient provider communication • Intervention to reduce missed opportunities for vaccination at health facilities
Q6	+	−	−	Individual accepts the benefits of vaccination, but avoids seeking vaccination, and is not vaccinated	Individuals who accept the benefits of vaccination but avoid seeking vaccination and remain unvaccinated, due to factors such as inconvenience and time constraints.	• Interventions to facilitate or induce seeking behavior, by increasing convenience and affordability, such as incentive programs and reminder-recall interventions
Q7	−	+	−	Individual rejects the benefits of vaccination, but seeks vaccination, yet is not vaccinated	Individuals who seek vaccination because of mandates, even while rejecting the benefits of vaccination; however, they are unvaccinated because of supply factors or missed opportunities for vaccination.	• Knowledge, education, and awareness interventions tailored to reasons for lack of acceptance of vaccination • Interventions to improve vaccine availability, supply and ease of access, such as vaccine outreach programs
Q8	−	−	−	Individual rejects the benefits of vaccination, and avoids seeking vaccination, and is not vaccinated	Individuals who are anti-vaccination, rejecting the benefits of vaccination, actively avoiding seeking vaccination and remain unvaccinated. Individuals may have a strong ideological or belief systems for rejecting vaccinations.	• Knowledge, education, and awareness interventions tailored to reasons for lack of acceptance of vaccination • Interventions that engage religious leaders and social influencers and are contextualized to beliefs and ideologies driving vaccine hesitancy and rejection • Interventions to facilitate or induce seeking behavior, by increasing convenience and affordability, such as incentive programs and reminder-recall interventions • Interventions to strengthen mandates/ sanctions for non-vaccination, such as narrowing exemptions

Note: * Denotes individuals' continuum on the VDR framework for attitudes/beliefs (+for accepting, − for rejecting), behavior (+for seeking, − for avoiding), and vaccination status (+for vaccinated, − for unvaccinated).

involving changes in policies, programs or practices. These interventions could make it easier for individuals to move between quadrants, urging individuals to become more resilient in their vaccination demand. Below, we describe four types of interventions following the main axes of the framework.

3.1. Scenario 1. Interventions to change vaccination attitudes and beliefs

Immunization program managers and policy makers can utilize the VDR framework to target populations that reject the benefits of vaccination (Q3, Q4, Q7, and Q8) and implement interventions to change individuals' attitudes and beliefs toward acceptance. These interventions may include information, education on media literacy and ability to recognize and resist disinformation, and communication interventions that aim to change negative attitudes and beliefs about vaccination through improved knowledge and awareness about vaccines [19,32,33]. Such interventions can be tailored to the specific reasons and context behind lack of vaccine acceptance, including a focus on

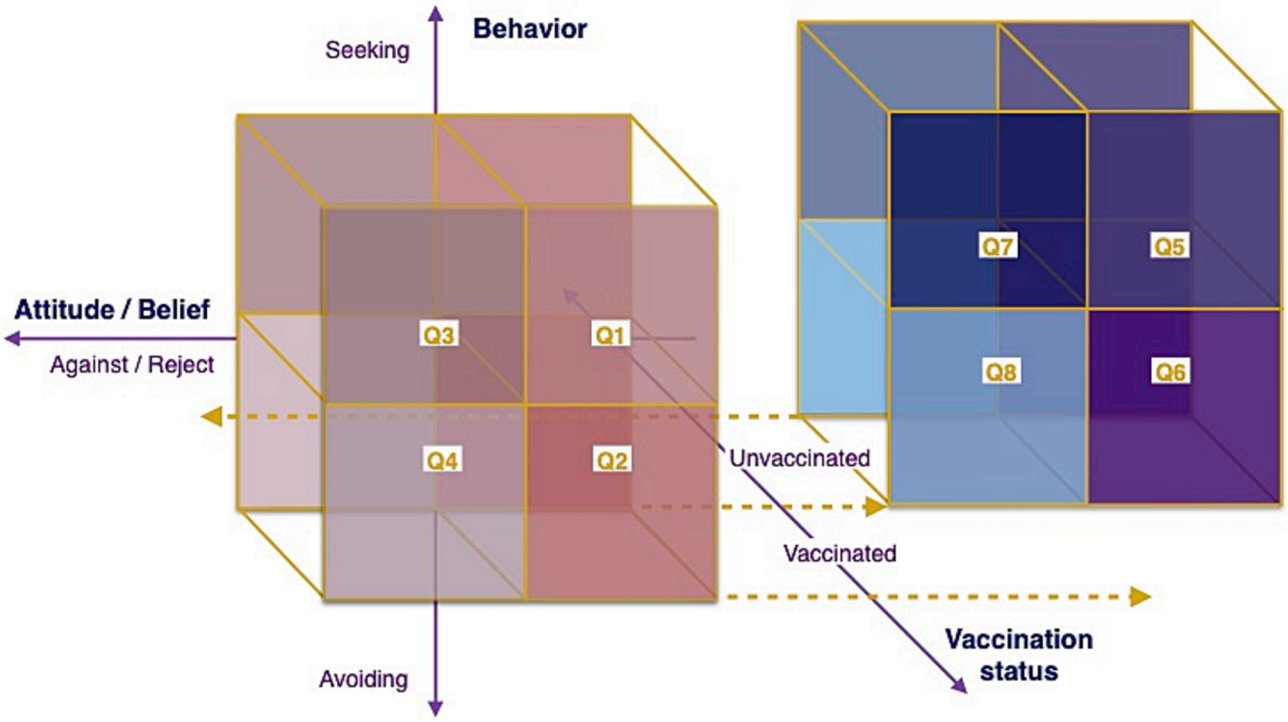

Fig. 2. Subdividing the Vaccine Demand Resilience (VDR) framework on attitudinal/belief and behavioral dynamics of vaccinated populations (left, in pink) and unvaccinated populations (right, in blue).

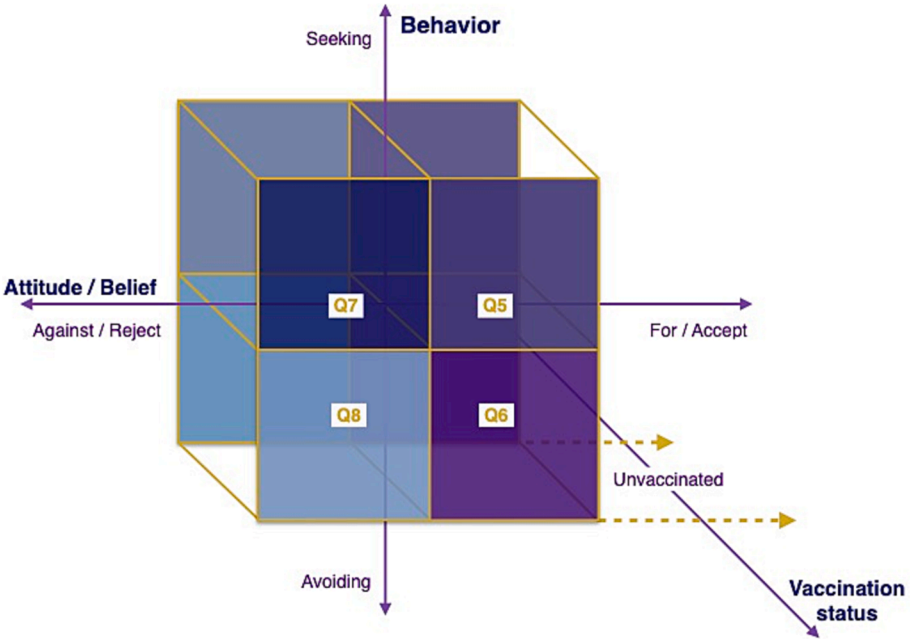

Fig. 3. Using the Vaccine Demand Resilience (VDR) framework to focus on attitudinal/belief and behavioral dynamics of unvaccinated populations.

particular vaccines. For example, in response to declining acceptance and vaccination rates of human papillomavirus (HPV) vaccine due to safety concerns, authorities in Denmark implemented a social media campaign to educate concerned parents about the safety and effectiveness of the vaccine [34,35]. The intervention included a Facebook page and a social media strategy to share a combination of factual information about HPV and cervical cancer to address knowledge gaps alongside personal narrative stories designed to improve negative attitudes. The intervention demonstrated user engagement and effectiveness of personal stories in creative positive dialogue through social media. As another example, an intervention in the United Kingdom sought to address a lack of acceptance of the measles, mumps, and rubella (MMR) vaccine by guided group discussions among parents about safety concerns and circulation of information pamphlets. This intervention helped to improve the quality of parents' decision-making process and resulted in higher vaccination uptake among those attending the parent meeting [36].

The impact of these interventions may depend on which quadrants of

the framework individuals are in initially related to vaccination seeking behavior and vaccination outcomes. For example, interventions targeting unvaccinated individuals in Q7 may gain confidence in vaccinations, moving to Q5 and then be vaccinated to reach Q1. Some individuals in Q8 may gain confidence in vaccines and move towards Q6, but a separate intervention may be needed to address the lack of vaccination seeking behavior. While individuals in both Q3 and Q4 are already vaccinated, they reveal a lack of resilience in vaccination demand through not believing in vaccinations and would still benefit from interventions targeting vaccination attitudes and beliefs. These interventions could support individuals in Q3 and Q4 to move towards Q1 and Q2, respectively, with stronger confidence in vaccines. This helps build resilience in demand even when requirements for vaccinations are relaxed or when access to vaccination services become less convenient.

It is important to note that halting these interventions to actively recommend vaccinations could move people in the opposite direction, resulting in negative attitudes and beliefs toward vaccination. For example, after the media reported unconfirmed reports of adverse effects after HPV vaccination in 2013, the Japanese Ministry of Health, Labor, and Welfare stopped proactively recommending the HPV vaccine [37]. This intervention from the Ministry, alongside a shift in newspaper contents focused on alleged victims and related lawsuits [38] sent a negative public health message about immunizations in Japan. Though the Ministry re-introduced the HPV vaccine as part of routine immunization in April 2022, HPV vaccination coverage plummeted to 1.87% as of 2021 [39].

3.2. Scenario 2. Interventions to change vaccination seeking behavior

The VDR framework can also be used to focus on populations not seeking vaccinations (Q2, Q4, Q6, and Q8) by designing interventions to increase vaccination seeking behavior. Incentive programs and reminder-recall interventions are examples of such interventions to facilitate or induce vaccination seeking by increasing convenience and affordability [40,41]. For example, a randomized control trial intervention in India illustrated the use of modest food incentives to change and sustain vaccine seeking behavior resulting in significantly more fully-vaccinated children [42]. Reminder-recall interventions can also be effective in preventing individuals from missing vaccination appointments or making them aware that they are due for vaccinations. For example, a study in Zimbabwe utilized mobile phone text message reminders for mothers whose children were due for vaccine doses, resulting in lower likelihood of delaying vaccinations and higher vaccination coverage [43].

Differences in COVID-19 vaccine acceptance across ethnic groups in the United Kingdom well illustrates the complexity of intervening [44]. Specific reasons for not seeking vaccinations and the quadrants individuals are in can impact the effectiveness of interventions to alter vaccination seeking behavior. If vaccination avoiding behavior is due to attitudes and beliefs about vaccinations as well as their behaviors, as with individuals in Q4 and Q8, interventions only improving vaccination seeking behavior may not be sufficient in inducing vaccination resilience without also incorporating vaccine acceptance interventions. In contrast, individuals in Q6 already accept the benefits of vaccination and hence, addressing the reasons for not seeking vaccination along with adequate supply and ease of access could get individuals toward Q5 and subsequently Q1, building resilient vaccination demand. While individuals in Q2 are vaccinated and accept the benefits of vaccination, they may be at risk of partial or incomplete vaccinations unless reasons for not seeking vaccinations are addressed.

During the COVID-19 pandemic, a number of strategies have been used in the United States of America (US) to encourage individuals to receive COVID-19 vaccines including making the vaccine free at the point of care, making vaccinations available through a wide variety of outlets, having pharmacists vaccinate in the community, and getting public endorsements from trusted leaders [45]. Efforts were also made to encourage people to continue to seek routine immunizations by having infection prevention policies for immunizers and recipients in order to reduce people's fear of acquiring COVID-19 at health facilities [46]. There were also frequent public health messages to encourage seasonal influenza vaccination during the COVID-19 pandemic to decrease the potential for additive burden on healthcare systems [47,48].

3.3. Scenario 3. Interventions to change vaccination status

Policy makers can utilize vaccination mandates or school vaccination requirements to influence vaccination status without necessarily changing the attitudes and beliefs of individuals who may otherwise be unvaccinated in the absence of these policies [49,50]. Individuals in Q3 and Q4 of the framework represent individuals who are vaccinated despite rejecting the benefits of vaccination and may only be vaccinated because of such policies. For example, in the US, all states have legislation requiring enrolled students to receive specified vaccines, where exemptions vary from state to state. As of August 2023, five states (California, Connecticut, Maine, New York, and West Virginia) do not allow non-medical exemptions to school immunization requirements [51,52]. Australia, Germany, Italy, and Slovenia have also introduced vaccination mandates, with consequences for non-compliance including exclusion from schools or financial penalties [49,51]. Among the 28 Global NITAG (National Immunization Technical Advisory Group) Network countries, 14 reported mandatory elements in their national immunization programs (Albania, Argentina, Belgium, Canada, Chile, Cote D'Ivoire, Indonesia, Jordan, Kazakhstan, Latvia, Maldives, Uganda, US, Uruguay) [53]. Wide variations were observed with respect to the immunizations required, population groups affected, grounds for exemptions, and penalties for non-compliance, illustrating the complexity of mandates [53].

The extent to which governments and/or employers adopt COVID-19 vaccine mandates has become a point of discussion as it affects attitudes towards and uptake of vaccinations. In the US, some employers and universities have made COVID-19 vaccination a condition for work and/or student enrollment, subject to exemptions based on disability or religious objections [54]. Some private employers require influenza vaccines for employees in healthcare settings and are considering extending this to COVID-19 vaccines.

The effectiveness of mandates especially among those rejecting the benefits of vaccination (Q3 and Q4) depends largely on the availability of exemptions and ease of enforcement of mandate penalties. For instance, individuals could pay the non-compliance fines and remain unvaccinated or claim exemptions where allowed and thus remain unvaccinated (Q7 and Q8). While some mandates include provision for mandatory counselling by health officials whereby individuals claiming exemptions have to receive educational information about vaccines, they have not yet been shown to change attitudes and beliefs (Scenario 1) [51,55]. Moreover, it is important to understand the ways in which mandates may impact subpopulations differently. In Australia, individuals of low socio-economic status may have been most impacted negatively by immunization requirements for eligibility of families to receive family assistance payments, yet they are also the group most likely to face higher vaccine access barriers [56].

3.4. Scenario 4. Interventions to strengthen patient-provider communication

Vaccination beneficiary-focused interventions to change attitudes and beliefs, improve vaccine seeking behavior, or policies to require vaccination are particularly effective in improving vaccination coverage when complimented by health provider-oriented interventions to reduce missed opportunities for vaccination [57,58]. As illustrated by Q5 in the framework, individuals could accept the benefits of vaccination and seek vaccination but remain unvaccinated due to vaccination system factors.

These include supply-side factors, such as the lack of vaccine supply, lack of healthcare provider to provide the immunization, lack of health care provider recommendations for vaccination, or healthcare provider discrimination, which could all impede access to vaccinations. Since healthcare provider recommendations are one of the strongest predictors of vaccinations [59], providers and clinical staff – individuals in the clinical setting who may be involved in prescribing, administering, or recommending a vaccine [60]– could encourage unvaccinated individuals in Q6 and Q8 to seek vaccinations and individuals in Q2 and Q4 to continue to get vaccinations. Such health care provider recommendations must be respectful of potential recipients' lived experiences, be culturally informed and sensitive to previous health system rebuffs. Healthcare provider discrimination could be harmful, where providers dismissing families refusing vaccines can have legal, ethical, and negative population health and trust implications [61].

Interventions to strengthen immunization supply chains, to minimize mismatch between vaccine supply and vaccinator at a vaccination site, to improve patient-provider communication [62], and reduce missed opportunities for vaccination can ensure that individuals in Q5 and Q7 who seek vaccinations are vaccinated. For example, a multicomponent intervention in the US utilized provider reminders, education, and performance reports to improve vaccination rates by reducing missed opportunities for vaccination among a network of primary care providers [63]. A presumptive announcement approach has been found to project more confidence about vaccinations and increase the odds of parents accepting vaccines [64,65]. Another intervention includes built-in reminders linked to electronic health records to reduce missed opportunities for vaccination, thus leading to increased vaccination coverage in the US [66].

4. Discussion

Fostering vaccination resilience requires understanding the dynamics of vaccination demand and implementing appropriate interventions to increase and maintain vaccination demand. The second strategic objective of the Global Vaccine Action Plan highlights the importance of individuals and communities in immunization systems, specifically highlighting demand-side factors and actions of individuals playing a role in shaping key immunization program outcomes [30]. The Immunization Agenda 2030, passed by the World Health Assembly in August 2020, similarly emphasizes four core principles – people focused, country owned, partnership based, and evidence guided initiatives [67]. Commitment and demand for vaccinations is one of the strategic principles of the global Immunization Agenda 2030 strategy [67]. Developing a resilient immunization system further contributes to countries working to achieve universal health coverage, pandemic preparedness, and the United Nations' Sustainable Development Goals [68–70].

Our VDR framework presents a mechanism to understand how different individuals within a community may make decisions about vaccination. The intersections among three dimensions of the framework – attitude/beliefs, behavior, and outcomes – are essential to appreciate the large population heterogeneity and numerous barriers to vaccination. It emphasizes the need for further data to translate global guidance to country-specific or community-specific situations to improve vaccination demand. Our framework aids immunization program managers, communication officers and health-related organizations designing programs to improve immunization coverage by recognizing the potential levers available to influence vaccination demand. By highlighting the population's views on vaccines in a systematic way, the VDR framework can provide a differentiated lens for program managers and policy makers to more thoughtfully consider interventions and policies to improve vaccination resilience.

There were three key lessons in the development of the VDR framework. First, a framework that aids in describing the population dynamics of those individual-level decisions further supports our understanding that vaccination decision-making is complex and dynamic, a well-documented and accepted fact. Existing methods to understand vaccine acceptance and uptake such as the 3Cs (complacence, confidence, convenience), 5 Cs (confidence, complacency, constraints, collective response and calculation), 7 Cs (confidence, complacency, constraints, collective response, calculation, compliance and conspiracy) and 5As (access, affordability, awareness, activation, acceptance) and the Behavioural and Social Drivers models are limited for exploring the complexity of this decision-making process [20,23,71–73]. Our framework not only identifies the degree to which individuals may be hesitant or opposed to vaccination, but also the resilience of vaccination decisions among people who are vaccinated to maintain immunization coverage. As illustrated by individuals in Q2, Q3, and Q4 quadrants of the matrix, individuals can be vaccinated without necessarily accepting the benefits of vaccination or seeking vaccination. In contrast, individuals in Q1 are also vaccinated *and* have resilient vaccination demand, as they accept vaccine benefits and seek vaccination.

Second, we learned that the dimensions of the VDR framework are implacably intertwined and that examining one single factor at a time is insufficient to understand the whole. As the components are interrelated and decision-making is dynamic, looking at them solo can obscure one's understanding of why individuals may or may not vaccinate. In our matrix, we map three dimensions to demonstrate that there can be incongruence among attitudes/beliefs, behaviors, and vaccination outcomes. For vaccination demand to be resilient, there needs to be "perfect" positive congruity of attitudes/beliefs, behaviors, and vaccination outcomes (Q1). Incongruence exists across the three axes in 6 of the 8 quadrants. Symbolically, the three axes may shift to form unequally-sized quadrants, depending on the population and context. For example, fear of acquiring COVID-19 when people visit health facilities to get routine immunizations have reduced care seeking and increased unvaccinated populations. While the COVID-19 vaccines raised people's appreciation for vaccines initially, misinformation and disinformation about COVID-19 vaccines also affected people's attitudes and beliefs about vaccinations [19,74,75]. Further, attitudes and behaviors that exhibit as hesitancy, passivity, and complacency toward vaccination likely exist along a spectrum, and individuals and populations can occupy different spaces within quadrants and along the axes. Thus, successful interventions that affect vaccination demand cannot be unidimensional or static and must be contextual. A combination of interventions, such as those outlined in our scenario examples, will be necessary to target the multiple dimensions of vaccination demand.

Finally, the incongruencies found in our matrix reinforced for us the importance of listening to the target audience. Simply understanding one dimension – individuals' attitudes/beliefs, behaviors, or vaccination status may not be good predictors of future vaccination outcomes. For instance, individuals in Q5 can remain unvaccinated despite accepting and seeking vaccination perhaps due to missed opportunities for vaccination and lack of healthcare provider recommendations [58,76] among other context-specific factors. Conversely, only examining vaccination status is insufficient as some vaccinated individuals may need additional reassurance to continue to demand vaccinations in the future. It is essential to listen to individuals and communities to understand the contextual factors and drivers of their vaccination demand. Vaccination demand is also fluid, where demand may be different from vaccine to vaccine and could change over time, requiring flexible and context-specific interventions.

We note some limitations to our study. First, while our VDR framework is grounded in evidence from published literature and builds upon prior frameworks of vaccination demand, it is possible that we may have omitted other important factors as we could not include them all. We focused on the key factors and dimensions captured in our matrix. Second, while we solicited expert feedback in the development of the framework, our matrix has not yet been validated widely or tested as a tool for decision-making. Within a community, the number of individuals in each quadrant would depend on the circumstances and not all quadrants may have equal weight. Third, our analysis is focused on

demand-side factors and assumes an existing vaccination system and adequate vaccine supply as well as health care providers to administer the vaccines. However, vaccine supply-side factors are also critical to increasing and maintaining immunization coverage [77–79], and the success of the interventions outlined in our scenario examples depends on availability and access to vaccinations. In some situations, the scarcity of a vaccine may stimulate demand [80]. While in others repeated efforts to obtain a vaccine only to be met by stockouts and/or no health care provider to give the vaccine may undermine trust in the system and drive down demand. Despite these limitations, our analysis and our VDR framework provide a new conceptual tool for immunization stakeholders, partners, and policymakers to probe the complex dimensions of vaccination demand and craft interventions to promote vaccination resilience. The VDR framework can be adapted to explore context-specific dynamics of vaccination demand including specific vaccines or populations, as well as during disease outbreaks and pandemics. Further work is needed to better understand and adapt the framework in different contexts including in low- and middle-income country (LMIC) settings.

5. Conclusion

As we look to the Immunization Agenda 2030, which is focused on leaving no one behind, there is a need to pay greater attention to building resilience in vaccination demand globally. As vaccines successfully reduce vaccine-preventable diseases making it harder to observe their value, it becomes even more important to demonstrate the need for, and benefits of vaccinations, particularly routine immunizations across the life course. While vaccines cannot be given without adequate supply, challenges are growing on the demand-side to ensure that individuals accept, seek, and become vaccinated. We developed the VDR framework to unravel some of the complexities of vaccination demand, where individuals could encounter incongruence among their attitudes/beliefs, behaviors, and vaccination outcomes. Building resilience in vaccination demand requires these incongruences to be addressed and ameliorated, so that more individuals could trust, pursue, and receive vaccinations. In the event that vaccines are not available, resilience in vaccination demand ensures that individuals would request and advocate for vaccinations. Examining the resilience of vaccination demand is critical, not only to increase vaccination coverage and leave no one behind, but also to make routine immunizations sustainable worldwide.

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Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ms. Nakamura previously worked for the World Health Organization. Dr. Schuh previously consulted with the World Health Organization. Other authors declare no relevant conflicts of interest or financial relationships.

Data availability

No data was used for the research described in the article.

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