A Participatory Systems Approach for Visualizing and Testing Implementation Strategies and Mechanisms: Evidence Adoption in Community Coalitions

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Abstract

Background
The strengths of Implementation Science can be further enhanced by embracing methods that account for the complexity of real-world systems, complementing its existing focus on translating evidence into practice. Systems science offers an approach to understanding the interactions, feedback loops, and non-linear relationships that drive implementation processes. Despite its potential, practical examples of systems methods for designing and linking implementation strategies to mechanisms remain scarce. This case study demonstrates how systems methods can help operationalize implementation strategies and mechanisms within the context of a project called the Feasibility of Network Interventions for Coalition Adoption of Evidence-Informed Strategies initiative, which focuses on community coalitions advancing child health equity.

Methods
Using the Participatory Implementation Systems Mapping approach, the research team and a five-member Community Advisory Council engaged in a structured, four-stage process to identify system determinants, co-specify implementation strategies and mechanisms, and simulate dynamic behavior. Causal loop diagrams and stock-and-flow diagrams were developed to visualize relationships, inform strategy design, and test expected effects on knowledge, adoption, and coalition decision-making.

Results
The approach generated over 50 implementation determinants, organized into a coalition-focused conceptual systems framework (Stage 1); causal loop diagrams highlighting key feedback dynamics like knowledge diffusion and positive attitude toward evidence (Stage 2); and stock-and-flow diagrams translating five prioritized strategies into core system variables (Stage 3). Strategies, which included network weaving, informing local leaders, facilitating knowledge exchange, structured evidence review, and decision support tools, were operationalized with specific mechanisms (e.g., communication frequency, network density, perceived appropriateness). Simulations (Stage 4) showed that doubling review frequency increased knowledge by 17% but raised adoption by only 4% without complementary strategies. Adding decision support tools reduced time to reach adoption by 3 weeks, while introducing perceived relative advantage mid-simulation boosted adoption by 22%. Diffusion rates ranged from 0.02 to 0.08/week, moderated by social network quality.

Discussion
The study illustrates how systems science methods bridge qualitative insights with quantitative modeling to design and preliminarily test adaptive, contextually relevant implementation strategies. Visualizing feedback loops and representing relationships as stocks and flows provides a framework to assess how implementation strategies influence coalition processes and outcomes. The findings emphasize the importance of participatory processes to ensure strategies are practical and aligned with coalition priorities. Future work should focus on implementation, testing and scaling systems-based approaches to address implementation challenges.

Contributions to The Literature

- This paper introduces a practical, participatory approach for designing and refining implementation strategies and mechanisms using systems methods.
- It demonstrates how tools like causal loop diagrams and stock-and-flow diagrams can make complex implementation processes visible, testable, and adaptable.
- The study shows how engaging community partners in systems modeling helps tailor strategies to local dynamics, potentially supporting more equitable and context-sensitive implementation.
- It provides a step-by-step example of how to link strategies to mechanisms and outcomes within a real-world implementation system.
- This work responds to calls for applied systems methods in implementation science and advances a replicable method for embedding systems thinking into implementation planning.

A Participatory Systems Approach for Visualizing and Testing Implementation Strategies and Mechanisms: Evidence Adoption in Community Coalitions

Implementation science is increasingly incorporating systems science to address the complex challenges of translating evidence into practice (1–4). Traditional implementation approaches often treat implementation as a linear sequence of identifying barriers, applying discrete strategies and monitoring isolated outcomes. This simplification can limit their effectiveness in complex, real-world settings (5). Systems science complements these approaches by offering tools to examine feedback loops, nonlinear relationships, and evolving system behaviors that influence intervention adoption, scaling, and sustainability (1). It also highlights structural and environmental forces that shape implementation outcomes.

Participatory systems methods, particularly Community-Based System Dynamics and Group Model Building, have long offered structured, theory-informed approaches for engaging stakeholders in articulating mental models, surfacing feedback structures, and collaboratively refining system insights (6,7). These methods have been used across domains including health, education, and social policy, and are grounded in decades of conceptual and empirical development (8–11). Community-Based System Dynamics in particular provides a rigorous foundation for collaborative modeling that integrates community voice with systems thinking to support equity and local decision-making (6).

Recent scholarship has made important strides in integrating participatory systems methods into implementation science, though practical applications remain relatively rare. Whelan et al. (2023) found that few community-based interventions meaningfully combined systems approaches with implementation frameworks (2). Luke et al. (2024) propose a comprehensive framework for integrating systems thinking throughout the implementation process, highlighting bridging mechanisms that connect the two fields, such as feedback sensitivity (the ability of a system or intervention process to detect and respond to feedback signals, such as changes in stakeholder engagement or resource availability), system adaptivity (the capacity to modify implementation strategies in real time based on evolving conditions or outcomes), and boundary spanning (actively engaging individuals or organizations that operate across different sectors or system levels to facilitate coordination, knowledge exchange, and alignment of goals) (1). Braithwaite et al. (2018)

emphasized the need to move beyond linear logic models and embrace the complexity of adaptive health systems (3). Kim et al. (2023) offered generally applicable steps for applying systems methods to study mechanisms associated with predefined implementation strategies for an intervention with known implementation purposes and determinants (12). While these contributions advance the field, there remains a need for more detailed, practice-oriented examples that show *how to* engage stakeholders in surfacing implementation determinants and mechanisms, visualizing system behavior, and co-developing strategies that can be tested and adapted over time.

To help fill this gap, we present the Participatory Implementation Systems Mapping (PISM) approach, a structured application of Community-Based System Dynamics and Group Model Building that integrates causal loop and stock-and-flow modeling practices, particularly those developed through the Catalyzing Communities Initiative (13,14), with implementation science theories, models, and frameworks. Rather than treating implementation strategies as fixed or static, PISM engages partners in co-developing strategies by identifying system determinants, visualizing mechanisms of action, and simulating potential system behavior over time. It builds on and combines elements from seminal implementation mapping (15) and intervention mapping (16) literature, as described in Moore et al. (2025) (4). It also builds on foundational participatory modeling principles while explicitly linking these methods to implementation determinant frameworks (e.g., Consolidated Framework for Implementation Research, or CFIR (17)), implementation strategy taxonomies (e.g., Expert Recommendations for Implementing Change, or ERIC (18)), and strategy-mechanism specification guidance (19,20), with particular attention to modeling dynamic implementation pathways.

This paper presents a case application of PISM through the Feasibility of Network Interventions for Coalition Adoption of Evidence-Informed Strategies (FICAS) initiative, a new implementation intervention for the Stakeholder-Driven Community Diffusion intervention (4,14,21), supported by the Eunice Kennedy Shriver National Institute of Child Health and Human Development. FICAS aims to identify and test implementation strategies that promote the uptake of evidence-informed interventions (EIIs) within community coalitions advancing child health equity. Through eight structured meetings with a Community

Advisory Council (CAC), we used participatory modeling to identify determinants, define implementation strategies, map mechanisms, and simulate system behavior. The Methods section outlines our participatory approach; the Results describe the output of our approach; and the Discussion reflects on contributions, limitations, and future directions. This applied example contributes to a growing body of work at the intersection of systems science and implementation science, offering practical guidance for strategy design in complex, community-based settings.

The Components of Implementation Systems

Recent advances in implementation science focus on uncovering how and why strategies lead to desired outcomes by mapping implementation causal pathways: the dynamic processes connecting strategies, mechanisms, contextual factors, and outcomes (22). When combined with systems science, these pathways can be understood not as linear sequences but as part of a broader implementation system characterized by feedback, interdependence, and adaptation over time. Described below and summarized below in Table 1, each component of an implementation causal pathway corresponds to a system element, helping to explain the multilevel interacting processes that shape implementation success.

Table 1. Components of the implementation system viewed through a systems lens (adapted from (12) and (22))

From this perspective, implementation strategies can be viewed as leverage points within a system that can promote the adoption, integration, and sustainability of EIIs (20). Rather than discrete techniques applied to static barriers, strategies interact with stocks, flows, and feedback loops, shaping, and being shaped by, evolving system behavior. As cataloged in frameworks such as ERIC (18), these strategies often target structural or relational aspects of the system, such as leadership engagement or knowledge sharing, and can trigger reinforcing or balancing dynamics depending on context.

Implementation mechanisms, which explain how a strategy produces change, can be reinterpreted as causal chains or feedback structures that link strategic actions to system outcomes (20,22). For example, a strategy like network weaving may work through a reinforcing loop in which increased interaction quality accelerates knowledge diffusion and strengthens coalition cohesion. Within these mechanisms, mediators (e.g., readiness, trust) represent dynamic stocks or flows transmitting the effects of a strategy, while moderators (e.g., leadership turnover, resource constraints) can be understood as system conditions or parameters that alter those effects.

Proximal outcomes, such as increased knowledge or motivation, reflect near-term shifts in system behavior that may influence future dynamics. Over time, these changes can accumulate and reinforce new system patterns. Distal outcomes, such as sustained practice change or improved population health, emerge through longer-term interactions and may represent shifts in system equilibrium or tipping points.

Taken together, these components constitute an implementation system, a dynamic, multi-level network of actors, organizations, and contexts in which strategies, mechanisms, and outcomes evolve over time. Viewing implementation through a systems lens enables the identification of leverage points, anticipation of unintended consequences, and design of strategies that are adaptive, equity-oriented, and grounded in real-world complexity (1).

Methods

Study Design and Conceptual Foundations

We applied a formative implementation research design guided by the Standards for Reporting Implementation Studies (StaRI) statement (23). The goal was to specify and model implementation strategies and mechanisms in advance future delivery in a clinical trial. We used the PISM approach to support the co-design and iterative refinement of implementation strategies with community partners. This structured, participatory process involved qualitative and quantitative systems science methods to identify implementation determinants, visualize system dynamics, and model the potential pathways through which strategies influence adoption of EIIs.

Community Advisory Council Recruitment and Composition

A five-member Community Advisory Council (CAC) was recruited to guide the participatory modeling process. Members were intentionally selected to ensure diversity across racial, ethnic, and sectoral lines. The group included five women between the ages of 39 and 54: two identified as Black or African American, two as Latina, and one as White. They represented overlapping sectors such as early childhood care, hospitals, community-based organizations, and local government. While each brought distinct experiences and perspectives on promoting child health, they shared a commitment to advancing child health equity.

A group of this size was intentionally chosen to balance diversity, depth of engagement, and manageability. Groups of approximately five members can enable meaningful participation and dialogue while avoiding the logistical complexity and conversational limits of larger groups (24). This size allowed for equitable participation, relationship building, and in-depth reflection, which were essential for iterative systems modeling and trust-based collaboration (25).

Participatory Modeling Process Overview

The modeling process was carried out over eight semi-structured virtual meetings, each lasting 90 minutes (Table 2). These meetings followed a four-stage framework aligned with the PISM approach: (1) identifying and organizing implementation determinants, (2) mapping causal pathways and leverage points, (3) operationalizing strategies into dynamic models, and (4) refining and testing those strategies through simulation. Each meeting combined theoretical grounding, structured facilitation, and open discussion to integrate lived experience, research evidence, and implementation frameworks. Research team members introduced implementation theory, modeling techniques, and empirical literature to inform discussion. CAC members led the application of these ideas to practice, drawing on their personal and professional experiences to inform model development.

Table 2. Meeting structure, activities, and iterative development of implementation strategies and mechanisms

Stage 1: Surfacing Determinants and Organizing System Relationships

In the first two meetings, participants collaboratively identified key determinants that influence the adoption of evidence-informed interventions. Using an online whiteboard (MURAL), the group brainstormed and prioritized determinants across CFIR domains, including individual-level factors such as self-efficacy and trust, coalition-level (inner setting) constructs like group knowledge and leadership, and contextual variables (outer setting) such as resource constraints and community strengths. Each determinant was evaluated based on its proximity to the adoption decision, its alignment with existing empirical literature or theory, and CAC feedback.

In the second meeting, the CAC organized the prioritized determinants into a conceptual systems framework structured around coalition formation, mobilization, and adoption. The research team introduced this three-stage structure at the start of the session, drawing from established theories including Community Coalition Action Theory (26), Theory of Planned Behavior (27), and Stakeholder-Driven Community Diffusion (21). Using MURAL, CAC members engaged in a collaborative drag-and-drop exercise to place determinants within the framework. They employed a color-coded voting and clustering system to group related variables and referenced CFIR constructs to guide placement. In making decisions, members reflected on when each determinant was most influential in the coalition's developmental process and what outcomes it shaped. While the relationships among determinants were discussed conceptually, specific feedback loops and interdependencies were explored in later stages. The meeting concluded with a visual map of the conceptual model that was iteratively refined over subsequent sessions.

Stage 2: Mapping Causal Pathways and Identifying Leverage Points

Meetings three and four focused on mapping the dynamic relationships among determinants using CLDs. In meeting three, the research team introduced examples of directed acyclic graphs and early pathway diagrams to prompt discussion, that were modeled after Lewis and colleagues' structured implementation mechanism diagrams (22). CAC members collaboratively defined relationships using a modified connection circle script (28) and identified potential feedback loops. After meeting three, the research team refined the CLDs for visual clarity. In preparation for meeting four, the research team identified and merged empirically tested network implementation strategies (29,30) with ERIC strategies to create a list of potential options.

In meeting four, a structured prioritization activity guided CAC members in selecting high-impact, contextually appropriate strategies. Iteratively referencing the CLDs, the CAC members independently rated each potential strategy on feasibility and expected impact. Ratings were discussed to identify areas of consensus and disagreement. The strategies that were rated as both feasible and impactful were then preliminary mapped onto the CLDs by reviewing which variables may be influenced directly, to visualize their theorized pathways to proximal and distal outcomes.

After meeting four, each selected strategy was reviewed for credibility based on prior evidence for its potential mechanism of action and its relative proximity to adoption behavior (e.g., network weaving was prioritized due to its documented role in enhancing knowledge diffusion and cross-sector collaboration (30,31)). To ensure feasibility and contextual fit, we also sought targeted expert input (e.g., social network scholars for network weaving) after the meeting.

Stage 3: Operationalizing Strategies Through Mechanistic System Modeling

The fifth and sixth meetings translated the CLDs into SFDs, supporting mechanistic modeling of the selected strategies. In the fifth meeting, the research team introduced SFD concepts, including stocks, flows, auxiliary variables, and time delays. The research team then worked with the CAC through a series of structured discussions to translate CLD variables into SFD variables, modifying as necessary to create coherent stock and flow narratives in context of existing CLD loops and hypothesized mechanism pathways. For example, the group knowledge of EII in the CLD was translated into a stock within the SFD to capture accumulations of group knowledge overtime. Conversely, the diffusion of adoption variable in the CLD was translated into a flow in the SFD to represent changing rates of adoption behavior that influences group knowledge of EIIs.

In the sixth meeting, the SFD was refined and each implementation strategy was broken down into smaller functional components using Proctor's strategy specification guidance (20). For example, the broad structured evidence review strategy was disaggregated into four parts: promoting network weaving, informing local leaders, facilitating knowledge exchange, and conducting review sessions. Each component was linked to relevant SFD variables and measurable implementation mechanisms, such as network density or interaction quality. Model refinement led to additional conversations where the CAC decided to rate and integrate an additional strategy into the model following the same process outlined in stage 2.

Stage 4: Refining, Quantifying, and Testing Strategy Pathways Through Simulation

The final two meetings focused on refining and simulating the stock and flow diagram. In meeting seven, the CAC and research team reviewed the six-stock model developed in Stage 3 and agreed to simplify it by removing coalition trust and coalition effectiveness as core stocks. Although these constructs were considered important, the group determined they were more appropriately represented as auxiliary variables that influence knowledge diffusion and adoption decision rates. This decision was informed by both CAC input and an assessment of whether the variables could be meaningfully parameterized using available data, literature, theory, or expert opinion.

To expand the representation of mechanisms, the team revisited each strategy pathway and evaluated candidate variables from the conceptual systems model and causal loop diagrams based on their relevance to core system flows and their potential for quantification. These variables were drawn from the conceptual systems model and CLDs and each one shaped critical flows in the system and helped clarify how strategies exert influence over time. Parameter values were derived through a combination of literature review, CAC input, expert opinion, and theoretical assumptions. For example, knowledge diffusion rates were estimated based on published studies (32,33) and triangulated with diffusion theory (34,35) and CAC insights. Where no direct estimates were available, parameters were left open for calibration in future implementation trials. Simulations were conducted both in advance of and during the final meetings to enable real-time discussion and interactive model exploration. During the meetings, the team ran behavior-over-time plots and summarized key metrics to help the CAC interpret system behavior. Together, the group assessed how changes in strategy intensity (e.g., doubling the frequency of structured evidence review sessions or increasing the number of leaders engaged) affected core system stocks. The team used this process to iteratively test and refine variable values, simulate different implementation scenarios, and assess model sensitivity. Parameter adjustments were made collaboratively during the sessions, with CAC members contributing their practical expertise to verify whether system behavior reflected plausible coalition dynamics.

Four scenarios were tested, both independently and in combination: (1) increasing review session frequency from once to twice per month, (2) introducing a new strategy to strengthen the adoption decision-making pathway, (3) combining high network density, strong interaction quality, and high perceived relative advantage, and (4) introducing high perceived relative advantage alone. These scenarios allowed the team to explore how layering strategies produced synergistic or diminishing effects.

Model outputs focused on the rate of knowledge accumulation, the growth of shared group knowledge, and the time required to reach a threshold for evidence adoption. Behavior-over-time plots visualized the progression of these stocks, while summary statistics captured system responses across scenarios. CAC members interpreted the outputs in real time, generated hypotheses about why certain strategies produced stronger effects, and identified potential opportunities for further intervention refinement. Notably, when simulations revealed only modest gains in adoption behavior despite improved knowledge accumulation, the team proposed an additional implementation strategy to address this gap. This strategy was discussed and validated with the CAC before being formally incorporated into the model.

Modeling Tools and Facilitation

The modeling process used MURAL for virtual, collaborative whiteboarding, and Vensim and Kumu for system mapping and simulation. While CAC members interacted directly with MURAL, the research team handled Vensim and Kumu modeling. The team provided orientation to MURAL in the first session and remained available throughout the process to support technical issues through email, phone, or video calls. Meetings were co-facilitated, with researchers guiding the structure, introducing concepts, and managing logistics, and CAC members leading practice-based applications and discussions. Pre-meeting materials were provided in multiple formats to accommodate different preferences and increase accessibility. CAC members could offer input in writing or asynchronously when needed. Facilitation emphasized flexibility, responsiveness, and the integration of diverse forms of knowledge throughout the modeling process.

Parameterization and Model Validation

Model parameterization drew from a combination of published literature, theoretical assumptions, expert input, and data generated through the participatory modeling process. Parameters were assigned values where empirical evidence or community insight allowed, while others were intentionally left free-floating for calibration in future implementation trials. For example, knowledge diffusion rate was influenced by variables such as network density, interaction quality, and closeness, with baseline, minimum, and maximum values informed by prior network intervention studies (33,36,37). Similarly, adoption decision-making rate was shaped by implementation acceptability, feasibility, and the strength of feedback effect, with directional assumptions guided by CFIR and CAC input.

Model validation was conducted using several standard approaches. First, face validity was established through member checking, as CAC members reviewed the stock-and-flow diagrams at multiple stages and confirmed that the models aligned with their real-world experience. Second, triangulation was applied by comparing qualitative data from CAC discussions, empirical literature, and theoretical constructs. Third, sensitivity analysis tested the model's robustness to variation in key parameters, such as changes in the frequency of structured evidence review sessions or the effectiveness of decision support tools.

Results

Stage 1: Surfacing Determinants and Organizing System Relationships

In the first stage, the CAC worked with the research team to construct a conceptual model of determinants and pathways influencing the adoption of EIIs. Across two meetings, members surfaced and refined over 50 potential determinants, which were organized using coalition and implementation theories. Prioritized determinants were systematically coded and compiled in Additional File 1. Participants categorized determinants into individual-, coalition-, and community-level influences, including self-efficacy, perceived benefits and barriers, knowledge, coalition leadership, trust, social capital, and structural conditions such as community discrimination or fragmented systems (38). Importantly, participants noted that static determinants alone could not capture the dynamic and relational nature of coalition functioning. In response, they introduced emergent properties such as collective efficacy, shared vision, and communication quality, variables that reflect how coalitions evolve over time and respond to internal dynamics.

The resulting conceptual model (Figure 1) is grounded in coalition theory and structured around three stages of coalition development: formation, mobilization, and adoption. In the formation stage, coalition demographics and social network structure shape group composition and early dynamics. During mobilization, coalition activities (e.g., meetings, communication, leadership development, and resource sharing) shape readiness for action, decision-making capacity, and collective influence. In the adoption stage, the coalition implements and diffuses EII-related behaviors, with the aim of changing local policies, systems, and environments to improve child health and community wellbeing.

All stages are shaped by broader contextual conditions, including socioeconomic inequality, community support for coalitions, and structural barriers. The model also incorporates key existing Stakeholder-Driven Community Diffusion intervention components (14,21), including coalition convening, stipends or seed funding, Group Model Building, and technical assistance, as inputs that support coalition development and capacity for EII adoption.

Figure 1. FICAS Conceptual Systems framework

Stage 2: Mapping Causal Pathways and Identifying Leverage Points

In stage 2, CAC members and researchers collaboratively constructed CLDs, with the help of directed acyclic graphs, to model dynamic relationships among key implementation determinants. Figure 2 illustrates the CLD selected for this study, with additional detail in Additional File 2 that describes the emergent functions of directed acyclic graphs and CLDs in PISM.

Figure 2. Causal Loop Diagram Integrating Implementation Strategies and Outcomes

Note. At this stage, it becomes apparent that the selected implementation strategy comprises multiple smaller strategies that must be unpacked and integrated into different components of the developing SFD. For now, it is sufficient to broadly understand how the overarching implementation strategy influences the implementation system as a whole.

Legend. Yellow variables = implementation outcomes; shades of green variables = proximal implementation strategy impact pathway

Two key loops emerged. The first loop, diffusion of knowledge, illustrates how reviewing evidence increases individual knowledge of EIIs, which in turn raises group-level knowledge. As group knowledge grows, the visibility and observability of the strategies improve, leading to greater knowledge diffusion through social networks and back into increased individual knowledge. This reinforcing structure highlights the importance of collective review and peer diffusion as mechanisms for implementation momentum. The second loop, reinforcing agency and positive attitude, begins with individual self-efficacy and perceived relative advantage of an EIIs. These feed into a stronger positive attitude toward evidence, which increases adoption likelihood. Adoption then reinforces perceived appropriateness and feasibility, further strengthening self-efficacy. This loop reflects how emotional and cognitive engagement drives adoption behavior, particularly when reinforced by early wins and peer modeling.

Building on the CLDs, the group identified and prioritized four interrelated implementation strategies: (1) promoting network weaving, (2) facilitating knowledge exchange, (3) informing local leaders, (4) conducting structured evidence review sessions. Strategies were evaluated based on perceived feasibility and potential impact. For instance, the strategy promote network weaving was prioritized for its relative ease to integrate into existing coalition activities and its potential to accelerate the diffusion of knowledge loop. CAC members emphasized that fostering new cross-sector connections, especially between siloed or underrepresented groups, could increase opportunities for informal knowledge sharing and exposure to diverse perspectives. Network weaving was seen as a way to amplify knowledge diffusion beyond formal review sessions and embed learning in everyday interactions. The other implementation strategies were linked to specific loops in other CLDs.

Stage 3: Operationalizing Strategies Through Mechanistic System Modeling

The third stage focused on transforming the conceptual CLD loops from Stage 2 into a preliminary SFD (Figure 3), which provided a qualitative representation of how implementation strategies may causally influence the adoption of EIIs over time. The model included six core stocks (i.e., evidence review, knowledge of evidence, group knowledge of evidence, positive attitude toward evidence, coalition trust, and coalition effectiveness), each selected and refined through facilitated discussions with the CAC.

Figure 3. Stock-and-flow diagram of coalition adoption behavior and potential implementation strategies and mechanisms

The evidence review stock, modeled as an implementation strategy, captured the accumulation of structured sessions in which evidence was shared and discussed. One of its inflows, frequency of evidence review, represented how often such sessions occurred. The knowledge of evidence stock represented the accumulation of individual understanding, increased through a learning inflow informed by external information and expert contributions. This learning process was directly influenced by the inform local leaders strategy, which was modeled as an inflow into the knowledge of evidence stock, reflecting the introduction of relevant, often community-specific, evidence by respected leaders. The group knowledge of evidence stock reflected the coalition's shared understanding, which evolved through an inflow called speed of knowledge diffusion. This inflow was influenced by two auxiliary variables: the facilitate knowledge exchange strategy, which accelerated diffusion through improved communication and discussion quality, and the promote network weaving strategy, which expanded the reach of knowledge diffusion. This reach was modeled as a separate inflow variable that increased group knowledge by improving connections across sectors and member roles. The positive attitude toward evidence stock grew through an inflow called attitude improvement rate, influenced by exposure to relevant, understandable, and context-sensitive evidence during the review and deliberation process. Similarly, coalition trust and coalition effectiveness increased through the closeness of social connections, an inflow reflecting the depth of interpersonal relationships and collaboration quality across the group.

Additional File 3 further details the operationalization of the structured evidence review strategy. The umbrella strategy was disaggregated into four components: facilitate knowledge exchange, promoting network weaving, informing local leaders, and structured evidence review sessions. For each component, the CAC identified who within the coalition would be responsible for enactment, the level of the system targeted, the specific determinants addressed, and the intended implementation outcomes, such as enhanced group knowledge or improved coalition functioning. Each prioritized implementation strategy was embedded in the model to influence adoption behavior. Notably, the strategy use decision-support tools emerged as a final variable to add to the SFD, that would directly influence adoption decision-making.

The structured evidence review strategy was explicitly modeled as a stock that builds over time through consistent and inclusive sessions. Informing local leaders was incorporated as an inflow to individual knowledge, recognizing that leadership engagement shapes what information enters the system. Facilitating knowledge exchange was modeled as an auxiliary variable influencing the speed of knowledge diffusion across coalition members, while promoting network weaving expanded the reach of that diffusion by enhancing cross-sector and interpersonal connectivity. The use decision-support tools strategy was modeled as an auxiliary variable influencing the adoption decision-making rate. The resulting stock-and-flow diagram captured complex, nonlinear pathways of implementation, providing a foundation for simulation and hypothesis testing in Stage 4.

Stage 4: Refining, Quantifying, and Testing Strategy Pathways Through Simulation

In the final stage, the CAC and research team quantified the SFD and preliminarily simulated implementation strategy pathways. The simplified model emphasized four key stocks: knowledge of evidence, evidence review, group knowledge of evidence, and decision to adopt. During this stage, some CAC members expressed concern that simplifying the model risked obscuring important constructs such as trust or coalition leadership, which they felt were critical to their experience in coalitions. Others supported a more streamlined model to enhance clarity and simulation feasibility. These competing perspectives prompted a group discussion about balancing parsimony with representational fidelity, and the final model (Figure 4) reflects a negotiated compromise.

Figure 4. Final stock-and-flow diagram

Legend. Blue arrows = positive relationship, red arrows = negative relationship, blue variables = implementation strategies, orange variables = implementation outcomes, teal variables = implementation strategies.

Preliminary simulations revealed that increasing the frequency of evidence review sessions from once per month to twice per month accelerated the knowledge of evidence stock by approximately 17% over a 12-week period, particularly when the frequency of communication for the inform local leader success strategy exceeded once per week. However, this increase resulted in only a 4% improvement in the decision to adopt evidence stock, suggesting diminishing returns in the absence of complementary strategies such as decision support tools.

The knowledge diffusion rate, influenced by strategies like network weaving and quality facilitation, ranged between 0.02 and 0.08 per week. These rates were more sensitive to underlying network density, interaction quality, and the frequency of structured knowledge exchange. Introducing decision support tools within simulations reduced the average time to reach the adoption threshold (≥0.5 likelihood) from 28 to 25 weeks, particularly when perceived evidence appropriateness exceeded 0.7 on a 0–1 scale. Further, perceived relative advantage, which incorporates dimensions of complexity and adaptability, had a strong influence on coalition readiness. When introduced at week 36, it accelerated the decision to adopt evidence stock by 22% over the subsequent 15-week period. These dynamics are visualized in the behavior-over-time plots (Additional File 4). Together, these simulations suggest that while increasing review frequency builds knowledge, strategic layering, particularly decision support and attention to evidence characteristics, may have potential to translate knowledge gains into adoption.

Discussion

This paper addresses a gap in implementation science by demonstrating how systems science methods can be used to design and specify strategies and mechanisms in ways that make them more explicit, actionable, and trackable within complex implementation systems. It builds on theoretical insights of frameworks like CFIR by offering a concrete, systems-based approach that integrates qualitative insights with quantitative modeling found in approaches like PISM (4,39,40). It responds to calls for practical applications of systems science in implementation research and contrasts with existing approaches, such as Kim et al.'s (12) iterative method, which offer general guidance but do not prescribe specific sequences or combinations of systems methods in absence of known determinants and strategies. In contrast, this study employs a bottom-up, stakeholder-driven process using a defined set of systems tools that make strategy design and evaluation both practical and replicable.

This work makes several notable contributions to implementation science, both through methodological innovations in the application of systems methods and through findings generated from applying those methods in the FICAS Initiative. First, it introduces an innovative integration of participatory modeling with deliberate matching of strategies and mechanisms to implementation determinants to help make sure implementation strategies are both contextually grounded and driven by community partner input. Second, it advances a dual-method modeling approach by combining CLDs for mental and narrative system mapping with SFDs for simulation and testing. Third, the application of these methods led to a detailed operationalization of implementation mechanisms, revealing how strategies such as network weaving could accelerate knowledge diffusion and how engaging local leaders could support evidence-informed decision-making. Finally, by framing strategies like network weaving and leader engagement as network interventions, this work highlights how leveraging social structures can play a pivotal role in accelerating the adoption of EIIS, a key hypothesis of the FICAS initiative.

Advancing the Understanding of Implementation Strategies and Mechanisms

In implementation science, strategies and mechanisms have traditionally been conceptualized as discrete and often linear pathways, emphasizing direct causal relationships between actions and outcomes. Enola Proctor's and Byron J. Powell's foundational work on strategies and mechanisms highlights their critical role in explaining how and why implementation strategies achieve their intended effects, yet the operationalization of these concepts has often been limited to isolated domains or processes (18,20). A systems-oriented perspective reframes strategies and mechanisms as dynamic, interdependent processes embedded within complex systems (2). This approach shifts the focus from addressing singular barriers or applying static strategies to understanding how multiple factors interact across levels (i.e., individual, interpersonal, and community) and how these interactions evolve over time (1).

This reframing provides one response to calls in the literature for more nuanced approaches to implementation research that account for the multifaceted and interconnected nature of real-world contexts (1–3). For example, frameworks like CFIR and have advanced multi-level considerations, but integrating a systems perspective deepens this understanding by explicitly modeling feedback loops, emergent behaviors, and the ripple effects of strategies across actors and settings. This perspective underscores the importance of tailoring strategies to target leverage points within a system, aligning actions with the unique dynamics of each implementation context. A community-based systems approach not only enhances theoretical understanding but also provides practical tools for designing adaptive and scalable interventions by considering the interplay between implementation strategies, mechanisms, and outcomes.

The structured evidence review implementation strategy in our study serves as an illustrative example of how systems science can be used in conjunction with implementation guidelines to disaggregate a proposed implementation strategy into smaller, actionable, quantifiable components. At its core, the strategy aims to enhance coalition members' understanding and application of EIIs. However, rather than treating it as a monolithic strategy, the approach detailed in this paper disaggregates the strategy into elemental components to facilitate the identification of mechanism pathways. Each core strategy is then operationalized into measurable parts; for example, informing local leaders is quantified by variables such as the number of leaders engaged, the type and relevance of evidence shared, modes and frequency of communication, and the level of leader participation in evidence dissemination activities. This granular approach builds on prior work emphasizing strategy customization, as seen in the ERIC framework (18), which highlights the importance of tailoring strategies to fit the specific needs and dynamics of a given implementation system.

Challenges and Future Directions

The PISM approach proposed and applied in FICAS demonstrates the potential of integrating systems science methods into implementation strategy design. However, several limitations must be acknowledged. One key limitation lies in the trade-off between model complexity and usability. While SFDs can represent the dynamic nature of implementation processes, models that are too complex risk losing clarity and accessibility, particularly for community and clinical partners. This tension is well-documented in the systems modeling literature (41), which emphasizes the need for models that are as simple as possible while still capturing essential system behaviors.

In FICAS, efforts to maintain parsimony (e.g., streamlining the number of stocks and flows) were necessary to support stakeholder engagement but may have excluded some relevant system dynamics. Even with these simplifications, the cognitive burden of interpreting CLDs and SFDs can pose challenges, particularly for researchers and community partners unfamiliar with systems modeling (42). To mitigate this, we implemented several practical strategies to improve accessibility. First, models were built and discussed iteratively in smaller segments, allowing time for clarification and feedback. Second, we used plain-language definitions for all variables and added visual cues such as color-coding, legends, and consistent labeling across diagrams. Third, sessions were co-facilitated by a researcher and a community liaison to foster dialogue, ensure conceptual clarity, and invite real-time interpretation from partners. These steps helped increase understanding and usability, though we recognize that further tool development and training will be necessary for broader application of participatory systems methods.

The iterative, participatory process used in FICAS required substantial investments of time, facilitation, and technical modeling expertise. Each session required between 10 and 25 hours of preparatory work and up to two hours of facilitation. This may limit feasibility in settings with fewer resources, limited systems science capacity, or low stakeholder availability. Effective use of PISM requires not only conceptual knowledge of implementation science but also practical skills in systems modeling, collaborative facilitation, and the use of tools like CLDs and SFDs. Additionally, the approach assumes a level of stakeholder engagement and readiness that may not exist in all contexts. Generalizing or scaling this method will likely require capacity-building efforts, simplified modeling tools, and institutional support to sustain engagement over time.

While FICAS focused on developing and refining strategies in collaboration with community partners, the approach has not yet been tested across a broad range of implementation contexts. Its generalizability and adaptability to different intervention settings, sectors, or populations remain to be determined. Future work should focus on expanding the application of PISM to other implementation challenges, such as designing strategies in clinical care, education, or policy reform. Testing the approach across diverse contexts will help assess its transferability and refine methods for adapting model structures and participatory processes.

Incorporating additional system elements (e.g., policy environments, funding systems, and socio-political contexts) could enhance the model's ability to reflect structural determinants of implementation success. Future iterations of this approach should also explore the integration of emerging frameworks from implementation science, including equity-focused and behavior change models, to increase relevance and reach. Moreover, since many of the strategies developed in FICAS qualify as network interventions (29,30), future research should investigate how intentionally designed network strategies function as drivers of implementation. Despite growing interest in using networks to accelerate evidence diffusion, there is limited empirical evidence on how such strategies operate within dynamic, real-world systems to improve adoption of EIIS.

There is a pressing need to evaluate the scalability and impact of systems-based approaches in implementation science more broadly. This includes testing their utility in supporting large-scale change efforts, developing structured guidance for training and capacity-building, and identifying policy levers that can support adoption of systems-informed methods. Routine embedding of systems thinking into research and practice will require institutional buy-in, workforce development through targeted training programs, sustained funding mechanisms, and accessible modeling tools that enable local adaptation and use. Routine use of systems modelling for implementation requires building cross-disciplinary teams that include systems scientists, investing in training for practitioners to interpret models, and securing institutional support for iterative, participatory processes. Funding mechanisms should recognize the time and expertise required for model development and ongoing facilitation.

In addition to participatory and conceptual challenges, the study also faced technical modeling considerations. While formal model calibration was limited, parameter values were informed by longitudinal data from the Catalyzing Communities Initiative (e.g., knowledge of evidence, participation in coalition activities, and social network data including trust, closeness, and frequency of contact) (13,33), theoretical assumptions from scholarly literature, and CAC input. A planned trial will provide additional data to strengthen future calibration and validation efforts. Preliminary sensitivity analyses were conducted on key stocks to assess model behavior under varying assumptions, though further systematic sensitivity testing will be important as the model evolves. These technical steps are essential for enhancing the model's precision and utility for implementation planning.

Conclusions

This manuscript demonstrates the application of PISM as a structured, community-engaged approach to strategy design in implementation science. Through a formative case study, we show how participatory systems methods, including causal loop diagrams and stock-and-flow diagrams, can be used to surface implementation determinants, link strategies to mechanisms, and simulate potential outcomes within a complex system. The key contribution of connecting systems science with implementation science lies in making mechanisms visible, testable, and adaptable over time. This integration supports the co-development of strategies that are not only evidence-informed but also context-responsive and equity-oriented. While this work is grounded in a single case, it provides a replicable model for how implementation research can benefit from systems-based thinking and methods, helping the field shift from linear planning toward more adaptive, mechanism-driven, and stakeholder-aligned approaches.

List of Abbreviations

PISM = Participatory Implementation Systems Mapping

SDCD = Stakeholder-driven Community Diffusion

CFIR = Consolidated Framework for Implementation Research

CLD = Causal Loop Diagram

EIIs = Evidence-Informed Intervention

ERIC = Expert Recommendations for Implementing Change

FICAS = Feasibility of Network Interventions for Coalition Adoption of Evidence-Informed Strategies

SFD = Stock-and-flow Diagrams

CAC = Community Advisory Council

Declarations

Ethics approval and consent to participate

The activities described in this manuscript were reviewed and determined not to constitute human subjects research by the Institutional Review Board (IRB).

Consent for publication

Not applicable.

Availability of data and materials

All data generated or analyzed during this study are included in this published article [and its supplementary information files].

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

TM conceived of the study, led the participatory modeling process, analyzed data, and wrote the manuscript. YC co-led the participatory modeling process, supported model development, contributed to data interpretation, and assisted in writing and revising the manuscript. MP and BK provided critical feedback during manuscript revisions. All authors read and approved of the final manuscript.

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Table 1. Components of the implementation system viewed through a systems lens (adapted from (12) and (22))

Term	Typical Definition	Systems Science Lens	Examples From Current Study
Strategy	A specific method or technique used to enhance the adoption,	A leverage point within a system that can influence feedback loops and shift system behavior over time. Strategies are	Promote network weaving*, facilitate knowledge exchange, inform local leaders, provide

	implementation, and sustainability of an intervention.	seen as interventions targeting specific nodes or relationships within a system.	structured evidence review sessions, use decision support tools
Mechanism	The pathway through which a strategy produces its effects, including mediators and moderators. Mechanisms explain how or why a strategy leads to outcomes.	A causal pathway or feedback loop within a system that connects strategies to outcomes. Mechanisms often involve reinforcing or balancing loops that drive system behavior.	Network density, interaction quality (including close and trusting relationships), sector heterogeneity, key connections
Mediator	A variable that explains the relationship between a strategy and an outcome. Mediators describe how or why a strategy works.	A stock, flow, or node within the system that transmits the effect of a strategy to an outcome. Mediators are often part of causal chains or feedback loops.	Interaction quality**, network density, key connections
Moderator	A factor that affects the strength or direction of the relationship between a strategy and an outcome. Moderators explain when or for whom a strategy works.	A system parameter, condition, or external factor that alters the behavior of feedback loops or the impact of interventions within the system.	Sector heterogeneity, key connections, interaction quality
Proximal outcome	An immediate or short-term result of a strategy, often closer to the implementation process.	A near-term shift in system behavior, stocks, or flows that reflects early changes in the system's dynamics. Proximal outcomes may influence downstream feedback loops.	Intervention adoptability, feasibility, and other implementation outcomes
Distal outcome	A longer-term or ultimate result of a strategy, often related to broader population-level impacts.	A system-level change emerging from cumulative feedback loops and interactions over time. Distal outcomes often represent changes in system equilibrium or population health trends.	Broad diffusion of evidence and coalition adoption of an evidence-informed intervention

*Selected implementation strategy for the table and current study.
**Mechanisms can sometimes be mediators and moderators. For example, interaction quality (closeness and trust), which facilitates knowledge exchange and collaboration, explains how network weaving leads to evidence adoption (mediator), and enhances or limits the effectiveness of weaving depending on closeness and trust levels (moderator).

Table 2. Meeting structure, activities, and iterative development of implementation strategies and mechanisms

Stage	Meeting Number	Function of Meeting	Meeting Activities	Status of Implementation Strategies and Mechanisms
PISM Phase 1 Stage 1: Surfacing Determinants and Organizing System Relationships	Meeting 1	Exploring and Prioritizing Key Intervention Determinants	Identified key determinants across CFIR levels (e.g., trust, self-efficacy, social support), brainstormed additional determinants, and prioritized them based on proximity to evidence adoption.	Identified intervention determinants act as precursors to identifying potential implementation strategies.
	Meeting 2	Organizing Determinants into a Conceptual Systems Framework	Organized determinants into a systems conceptual framework grounded in both theory and practice, and structured around coalition formation, mobilization, and adoption.	Preliminary systems conceptual framework begins to help identify areas and/or relationships within the intervention to be influenced by implementation strategies.
PISM Phase 1 Stage 2: Mapping Causal Pathways and Identifying Leverage Points	Meeting 3	Creating Causal-Loop Diagrams to Understand Determinant Relationships	Identified feedback loops and causal relationships among determinants and visualized these relationships using CLDs to identify leverage points and mechanisms.	Relationships and feedback loops within the CLD help identify specific implementation strategies that will best influence implementation outcomes; implementation mechanisms emerge from aligning implementation strategies in the CLD.

	Meeting 4	Refining CLDs to Identify and Integrate Implementation Strategies and Outcomes	Refined CLDs to incorporate implementation strategies and desired implementation outcomes in context of the implementation system.	Refined CLD is used to conceptually integrate and iteratively modify implementation strategies and mechanisms for optimal implementation and intervention outcomes.
PISM Phase 2 Stage 3: Operationalizing Strategies Through Mechanistic System Modeling	Meeting 5	Designing SFDs to Mechanize Determinant Relationships	Transitioned CLDs into mechanized SFDs by defining stocks, flows, and auxiliary variables (e.g., knowledge of evidence, coalition trust).	CLD translation to SFD is used to mechanize implementation strategies and mechanisms and plan for quantifying their relationship with the implementation system.
	Meeting 6	Using Stock-and-flow Diagrams to Formalize Implementation Strategies and Mechanisms	Specified implementation strategies (e.g., structured evidence review) by unpacking them into actionable components such as knowledge exchange and network weaving.	Implementation strategies are refined by ensuring they are the smallest core function of an activity; defined using Proctor's framework (20); and re-substantiated with associated mechanisms using theory, partner feedback, and empirical literature.
PISM Phase 2: Stage 4: Refining, Quantifying, and Testing Strategy Pathways Through Simulation	Meeting 7	Refining Stock-and-flow Diagrams to Prepare for Quantification	Streamlined core stocks and flows for clarity and quantification, simplifying strategies for focused simulation and practical utility.	Further refined SFD is used to ensure inclusion of implementation strategies into mechanisms that make sense in context of achieving model parsimony, available data, and balancing partner priorities with project goals.
	Meeting 8+*	Stock-and-flow Diagram Quantification & Scenario Testing	Quantified and tested SFD components for simulation modeling to evaluate strategies and mechanisms.	Implementation strategies and mechanisms are quantified; system behavior is modeled and tested

CFIR = Consolidated Framework for Implementation Research; CLD = Causal Loop Diagram; SFD = Stock-and-flow Diagram. *Additional meetings can be held to collaboratively test new or adapt existing strategies.

Table 3. Operationalizing Implementation Mechanisms

Implementation strategy umbrella	Implementation strategy component	Quantifiable measures of associated implementation mechanisms
Structured Evidence Review	Informing Local Leaders	Number of local leaders engaged, type and relevance of evidence shared, modes of communication, frequency of communication, level of participation by leaders in evidence dissemination activities
	Facilitating Knowledge Exchange	Number and frequency of knowledge-sharing forums, proportion of coalition members participating in these opportunities, extent of bidirectional communication, perceived openness and inclusivity in discussions, number of tools used to facilitate exchange, frequency of interactions where knowledge exchange occurs
	Promoting Network Weaving	Density of relationships within the coalition, proportion of coalition members with connections to key knowledge holders, representation of different sectors, proportion of underrepresented groups included in weaving efforts, number of new relationships or partnerships fostered, number of activities aimed at creating new connections, quality of interactions between connected individuals, perceived trust and collaboration within the network, sectoral reach of shared knowledge, instances of cross-sector collaboration
	Structured Evidence Review Sessions	The number of structured evidence review sessions, the frequency of structured evidence review sessions, the number of participants in evidence review sessions