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Bridges and Mechanisms: Integrating Systems Science Thinking into Implementation Research

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Keywords

complex systems, systems science, dissemination, implementation science, causal inference, mechanistic explanation

Abstract

We present a detailed argument for how to integrate, or bridge, systems science thinking and methods with implementation science. We start by showing how fundamental systems science principles of structure, dynamics, information, and utility are relevant for implementation science. Then we examine the need for implementation science to develop and apply richer theories of complex systems. This can be accomplished by emphasizing a causal mechanisms approach. Identifying causal mechanisms focuses on the "cogs and gears" of public health, clinical, and organizational interventions. A mechanisms approach focuses on how a specific strategy will produce the implementation outcome. We show how connecting systems science to implementation science opens new opportunities for examining and addressing social determinants of health and conducting equitable and ethical implementation research. Finally, we present case studies illustrating successful applications of systems science within implementation science in community health policy, tobacco control, health care access, and breast cancer screening.

INTRODUCTION

Complex systems: systems made up of heterogeneous elements that interact with one another, exhibit emergent behavior, persist over time, and adapt to changing circumstances

Context: the social environment or setting within which organizational or behavior change occurs

Systems science: interdisciplinary meta-science focused on complex natural and social systems

Emergent effects: observed properties or behaviors of a system that its parts do not have on their own

The most pressing public health and health care challenges of the twenty-first century (e.g., global pandemics, global warming, health and social inequities) are embedded within complex systems and thus resist easy study or solution. These wicked problems (79) require different conceptual approaches, alternative sources of data, and study designs that recognize the systemness of these problems (36).

Implementation science has a critical role in guiding research responses to these broad challenges. In particular, by speeding up the delivery of new scientific knowledge to public health and health care systems, identifying the best ways to implement and sustain evidence-based programs and policies, and conducting more equitable implementation research, society will be better able to meet and even solve some of these challenges (90, 103).

There have been a number of calls from implementation and social scientists over the past decade or so for integrating systems approaches into implementation science (e.g., 10, 11, 57, 71, 82). Despite these calls, applications of systems thinking and methodology remain rare, although some early examples are promising.

Perhaps the most compelling case for integrating systems thinking into implementation research comes from Hawe and colleagues (36). Although the authors frame their argument in terms of behavioral interventions, it applies equally well to implementation of new practices or policies. Rather than focusing primarily on the characteristics of the intervention itself, Hawe et al. (36) suggest that the proper focus is on the dynamic properties of the context into which the intervention is introduced. This approach implies that the organizational settings that are the target of implementation activities should be thought of as complex systems and that interventions will affect the "evolving networks of person-time-place interaction, changing relationships, displacing existing activities and redistributing and transforming resources" (p. 267). This viewpoint requires entirely different conceptions of implementation settings, processes, and outcomes. In fact, the authors' call serves as a critical inspiration for this review, in which we try to answer the question of what implementation science might look like if it deeply integrated systems science thinking into its own fabric.

OVERVIEW OF SYSTEMS SCIENCE

Systems science is an emerging interdisciplinary field focused on understanding complex systems wherever they occur, whether in nature, society, and technology or within science itself (13). In that sense, systems science is a meta-science because its focus is on all kinds of systems, not systems found within just one specific disciplinary boundary (65). Systems science looks at whole systems rather than focusing on the parts of those systems.

Complex systems have four defining characteristics: (*a*) They are made up of heterogeneous elements, (*b*) these elements interact with one another, (*c*) these elements produce emergent effects that are not explainable by reference to the individual elements of the system (i.e., "the whole is greater than the sum of its parts"), and (*d*) these effects are dynamic, i.e., they persist over time and can adapt to changing circumstances.

As a grounded example, consider **Figure 1**, which shows a causal map of the tobacco control system in the United States (68). This tobacco control system is made up of many heterogeneous elements (e.g., smokers, government agencies, researchers, tobacco companies, tobacco control policies, tobacco retailers, and the tobacco products themselves). These elements are spread across many sectors (e.g., industry, government, academia, economics). All these elements interact with one another, and the system behavior changes over time—for example, tobacco scientists develop new evidence supporting a policy for limiting sales of tobacco products near schools. This evidence

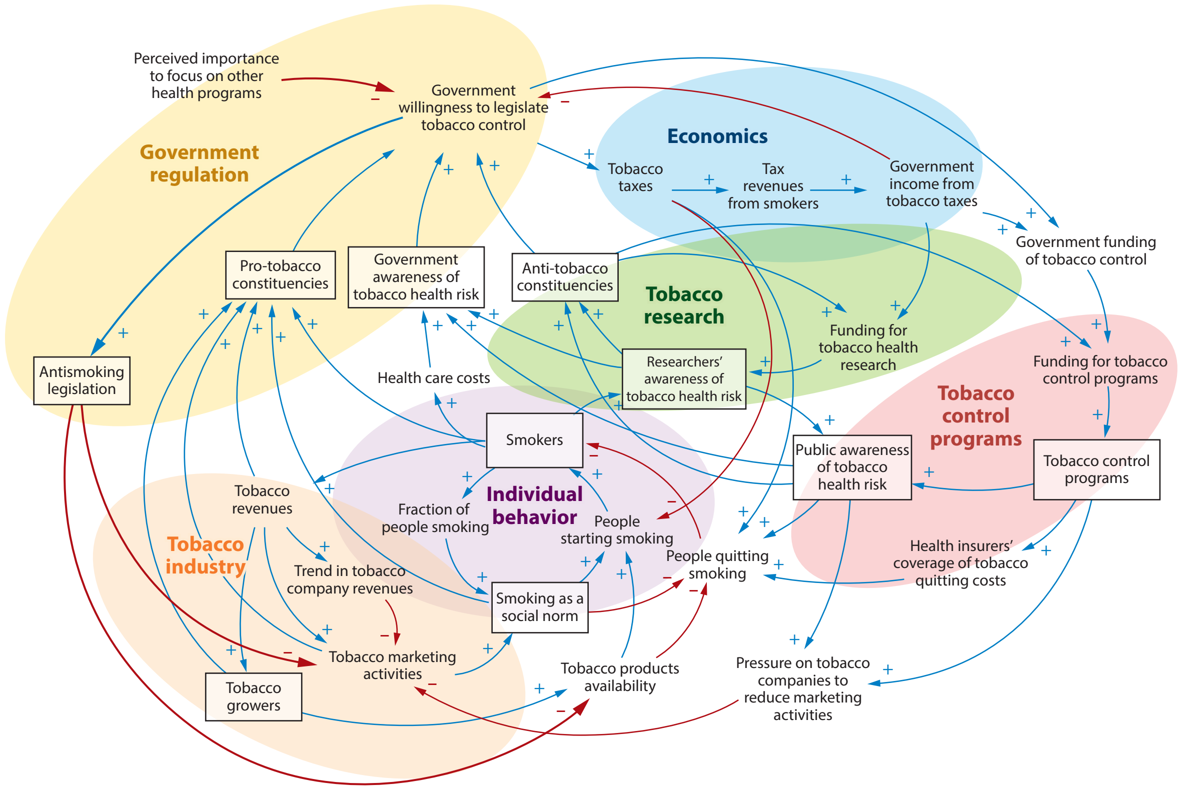

Figure 1

Complex system of tobacco control. This complex system is made up of heterogeneous elements (e.g., smokers, tobacco revenues, tobacco control programs) that interact with one another. Figure adapted with permission from Reference 68.

is used to implement new retailer policies, which in turn leads to changes in tobacco industry behavior (83).

Focusing on systems as holistic entities requires different conceptual and methodological approaches compared with traditional health sciences research (59). Traditional assumptions such as linearity, homogeneity, replaceability (associated with randomization), and independence of observations are not tenable when studying heterogeneous, interconnected, and dynamic complex systems. Thus, systems science research in public health and related fields uses other kinds of tools, including system dynamics modeling, group model building, network analysis, agent-based modeling, microsimulations, systems mapping, etc. (56, 59, 97). These kinds of systems research methods have seen many recent public health applications, particularly in infectious diseases (HIV/AIDS, COVID-19), chronic diseases (obesity, tobacco control, mental health), health care systems (health care access), and health disparities (4, 21, 47, 54, 55, 66, 104).

System dynamics: computational modeling approach for understanding the nonlinear behavior of complex systems over time using stocks, flows, and feedback loops

Network analysis: analytic approach or paradigm focusing on relationships among social objects, such as people or organizations

BUILDING A CONCEPTUAL BRIDGE CONNECTING IMPLEMENTATION SCIENCE AND SYSTEMS SCIENCE

Building a bridge to connect systems science with implementation science is partly metaphorical but partly practical as well. Despite numerous earlier arguments for why it is important, how it should happen is still unclear. We start here by considering the integration from the two sides of the potential connecting bridge—first from systems science and then from implementation science.

Starting with Systems Science

Systems science has as its focus complex systems of all kinds. For implementation science, we thus start with the view that delivering scientific knowledge into the world happens within complex organizational, political, and historical social systems (8, 92). Moving beyond this starting axiom, we need to consider the fundamental properties or principles of these complex systems, which will guide us toward a new methodological tool kit for implementation science. **Table 1** presents a subset of important systems science principles (65), organized and chosen for their relevance to implementation science applications. These principles are put into four broad categories: systems structure, dynamics, information, and utility.

The two structural principles emphasize the makeup of complex systems. They are composed of different kinds of elements (i.e., not just people) and are structured hierarchically. The hierarchical nature of complex organizational systems is well understood within implementation science, for example how inner settings fit within outer settings (23). The dynamic properties of complex organizational systems, on the other hand, are less consistently examined in implementation research. Although experimental (e.g., prepost implementation intervention) studies are common,

Table 1 Selected principles of systems science most relevant for implementation science

Systems science principles	Relevance for implementation science
Structure	
Systems are holistic units made up of bounded networks of relations among heterogeneous parts	Systems themselves are an appropriate focus for study and intervention, suggesting that we can shift focus from properties of the implementation intervention to the heterogeneous nature of the organizational system itself.
Systems are processes organized in structural and functional hierarchies	Implementation interventions are embedded within hierarchical organizational structures; multilevel conceptions and methods should be the norm.
Dynamics	
Systems are dynamic on multiple time scales	Systems change over time as dissemination and implementation activities play out. Understand that stability (e.g., continued sustainment) is a result of dynamic processes.
Systems evolve and exhibit complexity	Properties of organizational systems cannot be fully explained through the perspective of the individual members of the system. Common implementation challenges (e.g., policy resistance) are not problems to be solved but properties of the system to be understood.
Information	
Systems encode knowledge, and receive and send information	Systems themselves contain information about themselves (e.g., organizational policies, administrative records, unwritten rules); this information leads to data collection methods that go beyond surveys of organizational members.
Utility for science and practice	
Systems can be understood and improved	Many tools are available to implementation scientists who want to measure and improve the systems within which implementation occurs. Systems improvement is well aligned with the goals of implementation science for delivering knowledge to improve health and quality of life.

Principles adapted from Mobus & Kalton (65).

these typically employ limited notions of how organizations and their evidence-based practices evolve over short and long periods of time (60). Also, implementation interventions can disrupt organizational systems in various ways that emerge over time and produce unexpected dynamics (36).

The information principle states that systems contain information about themselves. This principle is slightly more difficult to grasp, especially by social scientists who traditionally look to people as the primary or exclusive sources of data and knowledge. For implementation scientists, this principle (along with the previous structural principle emphasizing heterogeneous, interconnected elements) suggests that system information can also be obtained from nonhuman sources such as administrative records, organizational policies, electronic records, and even physical characteristics (e.g., hospital size, street traffic).

Finally, the utility principle is reassuring for implementation scientists; it reminds us that although these systems are complex, they can be understood and improved as long as we are willing to treat implementation-relevant organizational systems as coherent entities in their own right. That implies the need for different kinds of theories and conceptual frameworks, study designs, and analytic approaches.

Starting with Implementation Science

The fundamental conceptual metaphor that has driven implementation science from its beginning as a distinctive discipline is that of a pipeline (6). The pipeline model has been used to describe both the core orienting challenge (i.e., Why does it take so long to get so little scientific evidence into the hands of those who could use it?) as well as its overarching goal (i.e., How can we speed up delivery and extend the reach of scientific knowledge to communities and health care systems?) (35). In this model, scientific knowledge is first created and then passes sequentially through three main phases of dissemination, implementation, and sustainment (see the middle boxes in **Figure 2**, described in more detail below).

Implementation science has subsequently developed a plethora of conceptual frameworks that have been important for guiding empirical research (69, 96, 98), the most widely used of which include the Consolidated Framework for Implementation Research (CFIR) (23); RE-AIM (Reach, Effectiveness, Adoption, Implementation, and Maintenance), which has recently been incorporated into the Practical Robust Implementation and Sustainability Model (PRISM) (30); and the Implementation Outcomes Framework (74, 75). These popular frameworks have been most useful for laying out the landscapes of implementation research; by that we mean they are high-level frameworks that focus investigator attention on the most important constructs to measure related to implementation determinants, processes, and outcomes (61, 69).

McGinnis & Ostrom (61) point out that while frameworks provide basic conceptual vocabulary supporting descriptive inquiry, true theories move beyond frameworks by identifying specific causal relationships (which then allow testing of much richer and focused hypotheses). So, for example, while CFIR points to the importance of considering characteristics of both outer and inner settings, it is silent on how outer setting characteristics directly affect inner setting characteristics, let alone the likelihood of successful implementation. Notably, another framework that informs implementation determinants and processes—the Exploration, Preparation, Implementation, and Sustainment framework—has evolved to explicate various bridging factors that link the outer system with the inner organizational context (1, 51). But overall, implementation science lacks a wide number of field-guiding theories.

Another example of the need for richer theories comes from the important conceptual work of Proctor and colleagues (74), who identified implementation, service, and client outcomes. One

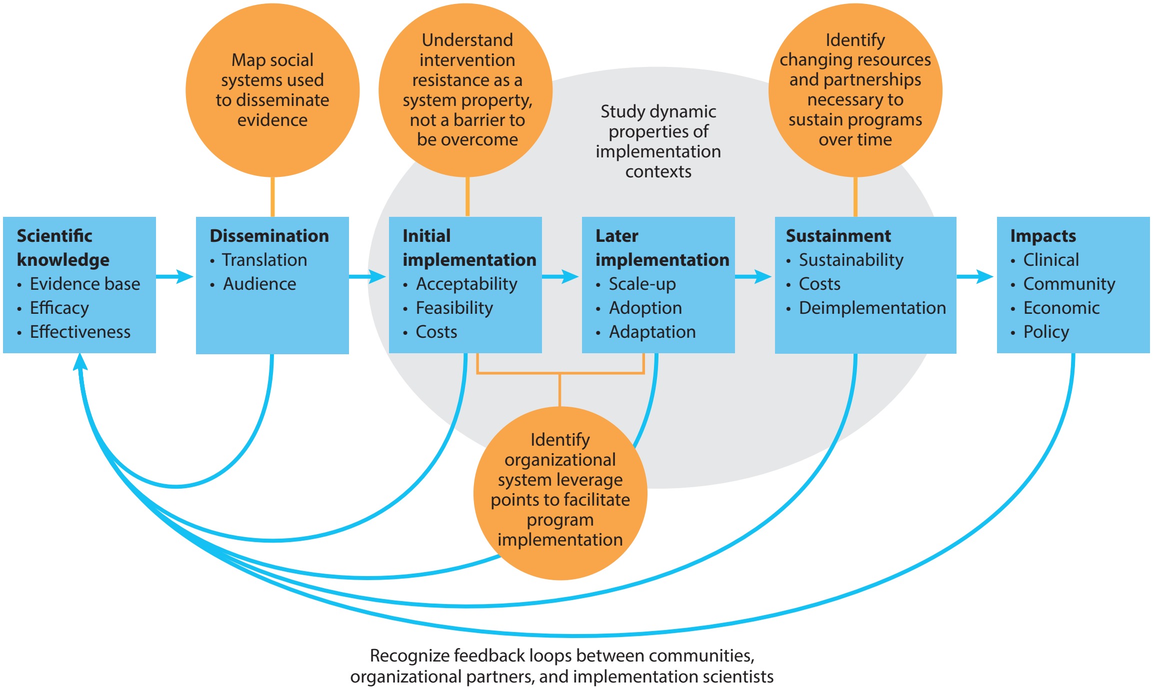

Figure 2

Unpacking the traditional pipeline model of implementation science with systems science concepts. The square boxes here represent the pipeline model of implementation science, where scientific innovations are translated into policy or practice applications; these are disseminated, implemented, and sustained in real-world settings. The circles and ovals depict examples of how the implementation process can be studied using a complex systems lens.

of the outcomes is penetration (also called reach). They defined penetration as the "integration of a practice within a service setting and its subsystems" (p. 70). This definition has important systems elements—integration is structural, and there is an explicit recognition of the hierarchical nature of organizational systems. Yet when reach is operationalized in implementation research, the metrics used are often simple counts or proportions (e.g., 26, see table 3). The integration of systems principles that describe organizational systems as being made up of heterogeneous elements that are interrelated and organized in structural and functional hierarchies could lead to more useful measurement approaches for reach that go beyond simple counts.

Implementation science has benefited from the application of true theories, although it is rare. The most important of these is Rogers' diffusion of innovations theory (80). This theory predates the emergence of implementation science but is one of the foundations for studying how scientific discoveries diffuse and can be disseminated across complex social and organizational systems. Diffusion of innovations theory provides more than just a conceptual vocabulary; rather, it makes specific statements and hypotheses about the kinds of people or organizations that are involved with diffusion (e.g., early adopters, opinion leaders), about how an idea or product spreads (from innovators to early adopters, and then on to the majority), about how the spread follows an S-shaped curve over time, and about how characteristics of the broader social system can impede or speed up diffusion (24). Diffusion of innovations theory is detailed enough that it describes how the dissemination of discoveries actually works, which leads to research that can advance causal thinking in ways that mere frameworks cannot.

MEETING IN THE MIDDLE: THE POTENTIAL OF A MECHANISMS FRAMEWORK FOR INTEGRATING SYSTEMS SCIENCE INTO IMPLEMENTATION RESEARCH

Unpacking the Pipeline Model

How should systems science be integrated with implementation science? One way to think about this concept is to unpack the traditional linear implementation science pipeline model; apply Hawe and colleagues' (36) suggestions about viewing interventions as disruptive events within dynamic evolving systems; view the result through the lens of systems science principles; and then determine what kinds of conceptions, study designs, and analytic approaches emerge.

Figure 2 presents an example of this type of thought experiment, where systems-oriented annotations have been added to the familiar implementation science pipeline model. The pipeline model posits that scientific knowledge proceeds linearly, through dissemination, implementation, and sustainment stages, to downstream health impacts. The annotations added around the pipeline illustrate how we might study dissemination, implementation, and sustainment processes using a systems lens. Systems principles of structure, dynamics, and information (**Table 1**) are featured in these annotations. For example, the structure principles suggest that mapping organizational social systems can be used to better understand dissemination processes and outcomes.

System dynamics is illustrated in multiple places. First, implementation and sustainment processes play out over time, and it is important to study these dynamics (e.g., 15). Second, although sustainment of a program may suggest system stability, stability is actually an outcome of an underlying dynamic system and should be studied as such (65). Similarly, the resistance we see when a new practice or policy is introduced is not an unintended consequence; policy resistance is an emergent property of a complex social system (95).

Finally, the information systems principles suggest that complex systems can be understood by examining how they encode and transmit knowledge. Knowledge transmission in systems is predicated on the presence of various types of feedback loops (78). For implementation science, the most important feedback loops show how various dissemination, implementation, and sustainability outcomes inform subsequent research and action (34).

The Potential of a Mechanisms Framework for Integrating Implementation Science and Systems Science

It is somewhat ironic that while implementation science has often been framed as a way to move beyond simplistic and artificial effectiveness studies, implementation research is still dominated by variations of randomized controlled trials (RCTs) (60, 84, 86). Limitations of RCTs are well known (9, 14, 100). RCTs are perceived as the gold standard study design for assessing the average effect of an intervention in a group of individuals. Randomization emphasizes internal validity at the expense of external validity. Implementation studies, on the other hand, are concerned with how interventions work (or do not work), under what conditions, and for whom in real-world settings (93). Therefore, they need to use methods that pay attention specifically to external validity.

More critically, although the main strength of RCTs is how they allow strong causal claims, this causal inference relies on a strict set of assumptions that are often violated in real-world settings. These assumptions also often require us to ignore contextual variability and social connections among study participants all in the name of replaceability and independence of observations (5, 49). A well-designed RCT allows us to estimate the effect of a treatment, intervention, or implementation strategy X on health outcome Y, but it is silent about how or why it worked. Given the complicated nature of most implementation strategies, we need to know not just whether the overall strategy worked, but what parts of the implementation package were most important, what parts were not necessary, how new policies shape physical and social environments, etc. (58).

Causal mechanism: the most immediate physical or social means by which something occurs or is accomplished

So, what are our alternatives? Over the past few decades, social scientists and philosophers of science have proposed a causal mechanisms framework that can help move beyond the limitations of experimental and associational study designs (37). Mechanisms have been increasingly prioritized in implementation science and at the intersection of health equity and implementation science (52, 89). Causal mechanisms are explanations "that identify the 'cogs and wheels' of the causal process through which the outcome to be explained was brought about" (37, p. 50). More simply, a causal mechanism is the most immediate physical or social means by which something occurs or is accomplished.

As a simple and practical example of causal mechanisms, consider again Roger's diffusion of innovations theory. Diffusion of innovations has had wide impact in part because it goes beyond simple associational assertions (e.g., that types of persons will be correlated with likelihood of innovation adoption) and provides a rich mechanistic explanation for innovation adoption. New knowledge (i.e., the innovation) spreads across a heterogeneous social system (e.g., opinion leaders versus early adopters), and the speed of the diffusion is based on various characteristics of the innovation as well as the social system actors and their communication relationships. This spread of information across a social system is the causal mechanism, and this spread of information is the appropriate target of study. The spread of information is also not something that can be easily captured by a variable-focused regression analysis. Instead, systems science tools such as network analysis would be much more revealing (99).

In implementation science, mechanisms are those processes or events that directly affect dissemination and implementation activities (e.g., diffusion, implementation strategies, adaptation, scale-up, and sustainability strategies) to effect desired implementation and health outcomes (48; 53, p. 3). With respect to the integration of systems science and implementation science, a mechanisms framework can help in at least four ways through (*a*) developing theory, (*b*) providing richer causal language, (*c*) identifying underlying mechanisms that drive higher-level associations, and (*d*) suggesting new study designs and analytic strategies.

Theory development. A mechanisms framework calls for the development and application of middle-range theories (63). Middle-range theories are not grand social theories that try to explain everything. Rather, they are smaller and more precise theories that identify a few factors that explain important but limited aspects of the outcomes (37). An important element of mechanistic middle-range theories is that they focus on how the interrelationships of social entities produce specific outcomes. Systems science perspectives are well-suited to inform middle-range theories of the problem (i.e., how determinants influence proximal and distal outcomes of interest) and of the solution (i.e., how implementation strategies can address determinants and improve outcomes of interest) (64). Greater use of middle-range theories can help implementation science by transforming general landscape frameworks, and these theories are well aligned with mechanism approaches that focus on causal pathways (46).

Causal language. Along with new theory development, the adoption of a causal mechanism approach can lead to richer causal language for implementation science (53). Implementation (and, presumably, dissemination and sustainability) strategies should be linked to mechanisms so that it is clear how and why a specific strategy will actually produce the intended implementation outcome(s). A mechanistic approach identifies not only how and why a given strategy works to address specific determinants (i.e., barriers and facilitators) but also contextual preconditions and moderators that influence whether or to what extent a mechanism will influence proximal and distal

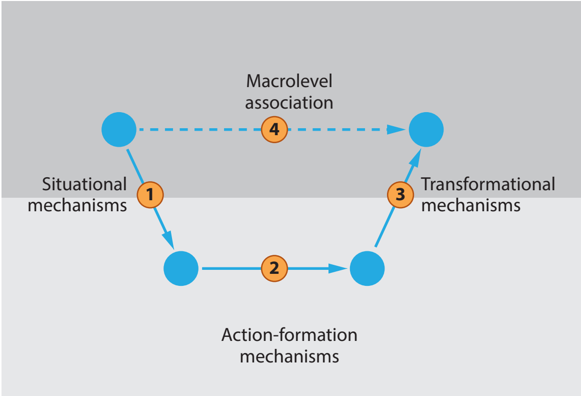

Figure 3

Coleman's boat, illustrating how high-level associations can be explained by lower-level social mechanisms. Figure reproduced with permission from Reference 37.

outcomes along the causal pathway (33, 53). These causal chains also shed light on the temporal ordering of mechanisms and outcomes, informing measurement and providing opportunities for interim checks on implementation progress. Embracing a causal framework forces implementers to specify how and why implementation efforts are likely to succeed (or fail), and systems science approaches enhance this framework by introducing dynamism and complexity into causal models that can be critiqued as being overly linear.

Identifying underlying mechanisms. The utility of a mechanism-based approach is illustrated in **Figure 3**, sometimes called Coleman's boat (18, 37). Most social science explanations are based on macrolevel associations, but these are inherently causally unsatisfying (hence the classic truism: "Correlation is not causation.") We can understand what drives the macro association only by identifying a series of underlying causal mechanisms.

For example, consider implementation studies of knowledge broker interventions. Introduction of knowledge brokers into health care and policy settings has increased evidence-informed decision-making (27, 81). The macrolevel association here could be the correlation between number of knowledge brokers in an organization and the strength or frequency of evidence-based decisions. However, knowledge brokers could produce changes in an organization's behavior in many ways. Using mechanism mapping, for example, Geng and colleagues (33) identified at least five different mechanisms, including relationship development, organizational capacity building, communication flow, staff skill development, and knowledge integration.

Using a similar mechanism approach for studying knowledge broker effects, we built an agent-based model of decision-making in state agencies (19). The agent-based model focused on policy opinion formation through interactions between members of organizational social networks. We found that knowledge brokers could speed up evidence-based decision-making, especially when organizational leadership was disconnected from other organizational staff. We can understand this result using Coleman's boat diagram (**Figure 3**). Staff members have more opportunities to learn about evidence-based policies when they work alongside knowledge brokers (situational mechanism). Individual staff form opinions about the policy that will lead them to support or not support policy adoption (action-formation mechanism). Finally, if organizational leadership (those who make the actual decision) are able to talk to enough staff, then they will be more likely to adopt the evidence-based policy (transformational mechanism). This path of mechanistic

Agent-based models: bottom-up modeling approach using computer simulations to observe actor behavior embedded within social and physical environments causes is specific and plausible. If replicated in real state agencies, then these results provide a more actionable road map than do high-level correlations.

Participatory modeling: any kind of systems or computational modeling that features community engagement, such as group model building

New study designs and analyses. A mechanisms framework calls for different types of study designs that can identify and examine the underlying mechanisms driving macrolevel associations. Systems science provides many such useful tools, including computational modeling (system dynamics, agent-based modeling), social network analysis, systems mapping, and participatory modeling (group model building) (40, 57, 67, 88). Other useful tools such as geographic information systems, organizational ethnography, mechanism mapping, intervention mapping, and a wide variety of other qualitative techniques can be used to provide important insights on how successful dissemination, implementation, and sustainability can be achieved (12, 33, 44, 45, 72).

Implications for Equity and Ethics in Implementation Science

An important implication of adopting a mechanisms framework is that it opens new opportunities for studying and addressing equity and ethics issues in implementation science. The social determinants of health (SDOH) movement has been critical for moving beyond a victim-blaming orientation in public health by pointing to social contexts as primary determinants of health inequities (70). However, SDOH approaches often lead to association studies that identify high-level correlations between contextual characteristics (e.g., healthy food access, safe neighborhoods) and downstream health outcomes. A determinants framework such as SDOH does not typically identify the underlying mechanisms by which inequities emerge within complex dynamic systems.

Population health can be viewed as an emergent property of complex social systems (42). In the same way, health inequities are emergent properties of these same systems. For example, determinants frameworks such as SDOH cannot explain how segregation in communities can arise even when all community members do not want to live in segregated neighborhoods. Schelling (85) and others have identified the kinds of social mechanisms that can drive these patterns of inequities that resist easy intervention (16). Computational modeling and other systems methods can be used by implementation scientists to incorporate the very organizational mechanisms that give rise to health disparities, and this mechanistic approach will also facilitate designing more effective antidisparity and antiracist interventions (2, 89).

Implementation science scholars recognize that dissemination and implementation themselves may run the risk of exacerbating existing, or even introducing new health inequities (7, 10). These are often framed as "unintended consequences" (e.g., 17, 22). This common phrase suggests that these consequences were unplanned and surprising and thus not susceptible to systematic study and action. However, as Sterman (95) points out, "[T]here are no side effects, just *effects*" (p. 505, emphasis in original). Implementations of new practices or policies are disruptive; there will be ripple effects across the system and over time (e.g., 77). As systems science–informed implementation researchers, we should always be aware of and plan for how the system responds to any new intervention. Participatory systems modeling approaches such as group model building (39) hold particular promise for helping to ensure equitable implementation research.

In addition to equity implications, a mechanisms framework also encourages more careful thinking about the ethical conduct of implementation research. Systems thinking and modeling require explicit recognition of fundamental questions of who matters, what matters, and what are the boundaries of the system? These are fundamentally ethical questions (76, 91). Building systems models for implementation research will require and facilitate clear explications of ethical stances, where we often do not move much beyond an inclusion (or the idea that more voices are better) approach for conducting implementation studies (94).

EXEMPLARS OF SYSTEMS-INFORMED IMPLEMENTATION SCIENCE PROJECTS

In this section, we present a set of short case studies that illustrate how systems science thinking and methods are being used in implementation research. They have been chosen not only to highlight good examples of systems and implementation science integration, but to suggest the diversity of systems science methods, implementation study designs, and health applications. These exemplars collectively demonstrate that although systems methods are somewhat rare in implementation science, they are being used to answer important research questions that are often not possible to address using more traditional study designs and analytic methods.

Project COMPACT

COMPACT (Childhood Obesity Modeling for Prevention and Community Transformation) was a groundbreaking international and multidisciplinary collaboration that applied principles of systems science and implementation science to community-based childhood obesity interventions. The overall goal of COMPACT was to identify what works, for whom, and under what circumstances, with a particular focus on sustainable implementation (29). The project team studied past successful community-based childhood health policy interventions, including Shape Up Somerville in the United States (31) and Romp & Chomp in Australia (25), to determine the underlying mechanisms of community policy implementation and subsequent behavior change. They then incorporated systems science concepts (e.g., dynamics over time, multiple levels of community systems) from disciplines such as engineering, management, evolutionary biology, and social science to develop a conceptual framework called stakeholder-driven community diffusion (3). This model was tested in Shape Up Under 5, a childhood obesity prevention intervention. Significant changes were seen in policies, systems, and environments that support childhood obesity prevention, and these were driven in part by observable changes in knowledge and engagement by community and coalition leaders (28).

Implementation science applications. A primary assumption of COMPACT was that successful community-level policy implementation can be understood by examining the underlying mechanisms (or engineering) for policy change. More specifically, upstream diffusion of community partner knowledge and engagement about childhood obesity prevention efforts through inter- and intra-organizational social networks leads to midstream health-promoting policy changes. This policy diffusion can then lead to downstream behavior change and positive health outcomes (3).

Systems science concepts and methods. COMPACT used a wide variety of systems science tools to develop and test their "whole-of-community" implementation approach (38, figure 2). Group model building and systems mapping were used to engage community partners and to develop the project's conceptual framework. Agent-based modeling and network analyses were used to identify the policy knowledge diffusion mechanisms, simulate policy diffusion processes, and reproduce real-world patterns of diffusion (43).

Health equity and community partnership elements. Although health disparities were not a primary focus of COMPACT, both researchers and community partners felt that participatory systems techniques such as group model building were critical for ensuring broad community engagement, promoting active group participation, and helping with "power leveling" (28).

Other resources. Christine Economos (co–principal investigator of Project COMPACT) presented an early vision for Shape Up Somerville, which can be viewed online (**https://nutrition.tufts.edu/video/movement-moments-christina-economos-tedxsomerville**).

Tobacco Town: Computational Modeling of Community-Based Tobacco Retail Policy Implementation

Tobacco Town is a series of projects that use computational modeling to study the potential effects of local-level tobacco policy implementation. Retail policies include interventions that restrict tobacco retailers around schools, that limit the proximity of tobacco retailers to one another, that restrict sales of tobacco products to certain kinds of retailer (e.g., adult-only tobacco shops), or that restrict sales of certain types of tobacco products (e.g., menthol cigarettes). The main finding of these studies is that there is no one-size-fits-all type of retail policy. Certain policies work better in some types of communities (e.g., urban communities with very high retailer densities) than others. This variability across communities and types of policies has important implications for future tobacco control policy development and implementation (55).

Implementation science applications. Tobacco Town is used to study potential policy implementation outcomes and mechanisms. In addition, results have been disseminated via community-facing dashboards (see below), fact sheets, policy briefs, and case studies (62).

Systems science concepts and methods. Agent-based modeling is used to create the virtual policy laboratory in Tobacco Town. Adult smoker agents (created using Census data and synthetic populations) (32) are placed in cities or towns that have accurate physical geography and tobacco retailer locations. These agents travel to and from work locations and make tobacco product purchasing decisions. Policy interventions are then added to the model, and the agent behaviors are observed to explore the potential effects of those policies. For example, when retailers are restricted from selling products near schools, then the agents tend to travel further and pay more money for cigarettes, ultimately lowering their purchasing and smoking rates. These models allow us to identify some of the underlying policy mechanisms that shape individual health behaviors in communities.

Health equity and community partnership elements. Tobacco Town was developed in close partnership with a national community advisory board made up of local tobacco control professionals from 30 large cities in the United States (62). In particular, their engagement led to the development of the Tobacco Swamps Dashboard, which allows local public health professionals and policy makers to explore potential retail policy effects for specific cities (20), with a particular emphasis on retailer disparities.

Other resources. The Tobacco Swamps Dashboard is available online (**https://aspirecenter.org/tobacco-swamps/**).

Modeling to Learn: VA Patient Health Care Access

Zimmerman and colleagues (104) used participatory system dynamics modeling within the context of one Department of Veterans Affairs (VA) outpatient mental health system to inform implementation planning for evidence-based psychotherapies. The limited reach of evidence-based psychotherapies within the VA led the researchers to examine system factors that influence local capacity for implementation, such as interdependent staffing, scheduling, and referral practices. Participatory system dynamics modeling was used both to model the problem (i.e., barriers to reach) and to evaluate two implementation plans to improve the reach of evidence-based practices, allowing the examination of trade-offs between the two approaches. The first strategy reduced intake appointments from 90 min to 60 min, while the second strategy streamlined specialty program referrals. Modeling with synthetic data ultimately indicated that both strategies would increase the reach of evidence-based practice appointments.

Implementation science applications. First, Modeling to Learn centered organizational and systems-level determinants and implementation strategies, which have been too often neglected in the field of implementation science (73, 101). Second, it focused on the planning phase of implementation and introduced a systematic, data-driven approach that involved key partners in the implementation effort, avoiding what the authors depicted as trial-and-error approaches to implementation planning. Third, it focused on the contextual fit between interventions and the settings in which they were implemented. Fourth, Zimmerman and colleagues' article underscored the importance of the implementation outcome of reach. Finally, the approach of "modeling to learn" is directly related to the notion of learning organizations (87).

Systems science concepts and methods. Participatory system dynamics modeling is an iterative process in which participants cocreate, test, and refine a model that represents a testable local theory of the system. Zimmerman and colleagues used administrative data and stakeholder estimates to create a stock and flow model of system structure and behavior, which reflected the rate, proportions, and accumulations of patient flows in the clinic over time (104, figure 2), and simulated the impact of two potential structural implementation strategies (i.e., changing intake appointment times and streamlining referral processes). A major product of Modeling to Learn was a client-facing model dashboard, where VA staff could interact with the VA system model and potential intervention outcomes in real time.

Health equity and community partnership elements. Participatory system dynamics is inherently partnered. The core modeling team included one champion from each service delivery team (managers, nurses, psychiatrists, social workers, and psychologists) who engaged in 14 h of modeling work, and the process also involved staff meetings with all staff and veterans with lived recovery experiences who have used mental health services within the system.

Other resources. Interested readers should see "The How and Why of Modeling to Learn: Participatory System Dynamics to Improve Evidence-Based Addiction and Mental Health Care" by Lindsey Zimmerman for more information (**https://cepim.northwestern.edu/calendar-events/2021-10-12-zimmerman**).

Mapping Social Determinants of Care-Seeking

Williams and colleagues (102) used participatory systems model building to identify the dynamic complexity underlying the widening cancer screening disparities between African American and white women, motivated by the fact that 50% of African American women diagnosed with breast cancer in North St. Louis never start treatment. Working with breast cancer patients, caregivers, family members, and health navigators, the team cocreated a causal map of determinants of treatment delays. The map included eight subsystems: mental health, access to health care, income, religion/spirituality, social support, knowledge on breast health, and personal mindset. The final model also shed light on leverage points in the system that could be used to promote early breast cancer treatment for African American women. At the end of the study, participants developed a set of recommendations: (*a*) form a community-based action group on women's health, (*b*) design and implement patient navigation strategies, (*c*) educate women's partners about breast cancer, and (*d*) develop mental health interventions to enhance women's self-esteem.

Implementation science applications. This study provided an example of how to understand the underlying mechanisms leading to a gap between evidence and practice (breast cancer treatment initiation), a central topic in implementation science. The structures and patterns in the treatment determinants model can be used to plan more effective evidence-based practice implementations.

Systems science concepts and methods. Group model building was the primary systems tool used to produce a shared mental map of breast cancer treatment delays in African American communities (39). The workshop series consisted of three two-hour sessions with community members (sessions 1 and 3) and community support groups (sessions 2 and 3). In sessions 1 and 2, participants identified and discussed variables contributing to the lack of breast cancer treatment initiation and codeveloped causal maps describing the dynamic nature of disparities. In session 3, they developed a consolidated map that reflected participants' stories and nominated places in the system that they thought should be changed through feasible interventions.

Health equity and community partnership elements. The participatory systems modeling approach used here not only engaged diverse participants, but also helped balance power differentials between researchers and community members and provided community members with tools and knowledge to understand how to intervene within their own treatment systems. Some women became navigators for others as a result, highlighting how group model building sessions may facilitate active engagement of community members.

CONCLUSION

This review is a response to the numerous calls over the years for linking systems science thinking and methods to implementation science (11, 57, 71). Hawe and colleagues (36) reframed the discussion by suggesting that we view implementation interventions as disruptive events in complex organizational and community systems. Despite these calls, there is little detailed guidance on how integrating systems science with implementation science could or should work.

Bridging systems and implementation science can proceed from either direction. Complex systems principles of structure, dynamics, information, and utility can be easily applied to implementation science goals and challenges. Conversely, the core implementation science pipeline of knowledge generation, moving through dissemination, implementation, and sustainment can be unpacked to reveal many opportunities to apply complex systems thinking to study design, measurement, and analysis. Most critically, a greater use of mechanistic explanations will help the field by focusing empirical research on the underlying structures and processes that actually produce beneficial implementation and health outcomes.

This vision of a systems-imbued implementation science has a number of important benefits, including

- Greater use of research methods that are better aligned with the characteristics of the problems being studied;
- The potential for richer theory development by adopting methods that support mechanism identification and enhance causal thinking;
- Systems approaches support health equity both by recognizing the systemic structures and processes that lead to health disparities and by including research methods (e.g., group model building) that encourage diverse participation; and
- Systems methods produce knowledge, tools, and resources that help engage community stakeholders, encourage planning and action, and increase impact (50).

Causal mechanisms are the bridge that connects systems science with implementation science. Mechanistic explanations have a long history. For example, Leonardo da Vinci used mechanistic explanations to understand the world around him, and he believed that the entire world and all its objects were machines. "As Leonardo and others led Europe into a new scientific age, he ridiculed astrologers, alchemists, and others who believed in nonmechanistic explanations of cause and effect" (41, chapter 12).

Many have noted the challenging nature of implementation science. It deals with complicated, multidimensional interventions and implementation strategies that are situated within complicated and dynamic organizational settings, are carried out over long time periods, and are often focused on multiple types of individual and organizational level outcomes (1, 104). That is, implementation science is challenging because it deals with complex systems. However, as we have seen, complex systems can be studied, understood, and improved. So, the solution to this complexity conundrum is to embrace it by bringing systems thinking and methods more fully into implementation research.

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LITERATURE CITED

1. Aarons GA, Hurlburt M, Horwitz SM. 2011. Advancing a conceptual model of evidence-based practice implementation in public service sectors. *Adm. Policy Ment. Health* 38(1):4–23
2. Alegría M, O'Malley IS. 2022. *Opening the black box: overcoming obstacles to studying causal mechanisms in research on reducing inequality*. Rep., William T. Grant Found., New York. **https://wtgrantfoundation.org/wp-content/uploads/2022/03/Alegria-Omalley_WTG-Digest-7.pdf**
3. Appel JM, Fullerton K, Hennessy E, Korn AR, Tovar A, et al. 2019. Design and methods of Shape Up Under 5: Integration of systems science and community-engaged research to prevent early childhood obesity. *PLOS ONE* 14(8):e0220169
4. Auchincloss AH, Riolo RL, Brown DG, Cook J, Diez Roux AV. 2011. An agent-based model of income inequalities in diet in the context of residential segregation. *Am. J. Prev. Med.* 40(3):303–11
5. Barton AH. 1968. Bringing society back in: survey research and macro-methodology: *Am. Behav. Sci.* 12(2):1–9
6. Bauer MS, Kirchner J. 2020. Implementation science: What is it and why should I care? *Psychiatry Res.* 283:112376
7. Baumann AA, Cabassa LJ. 2020. Reframing implementation science to address inequities in healthcare delivery. *BMC Health Serv. Res.* 20(1):190
8. Begun JW, Zimmerman B, Dooley K. 2003. Health care organizations as complex adaptive systems. In *Advances in Health Care Organization Theory*, ed. SM Mick, ME Wyttenbach, pp. 253–88. San Francisco: Jossey-Bass
9. Berwick DM. 2008. The science of improvement. *JAMA* 299(10):1182–84
10. Braithwaite J, Churruca K, Long JC, Ellis LA, Herkes J. 2018. When complexity science meets implementation science: a theoretical and empirical analysis of systems change. *BMC Med.* 16(1):63
11. Burke JG, Lich KH, Neal JW, Meissner HI, Yonas M, Mabry PL. 2015. Enhancing dissemination and implementation research using systems science methods. *Int. J. Behav. Med.* 22(3):283–91
12. Calancie L, Anderson S, Branscomb J, Apostolico AA, Lich KH. 2018. Using behavior over time graphs to spur systems thinking among public health practitioners. *Prev. Chronic Dis.* 15:170254

13. Capra F, Luisi PL. 2014. *The Systems View of Life: A Unifying Vision*. Cambridge, UK: Cambridge Univ. Press
14. Cartwright N. 2009. What is this thing called "efficacy"? In *Philosophy of the Social Sciences: Philosophical Theory and Scientific Practice*, ed. C Mantzavinos, pp. 185–206. Cambridge, UK: Cambridge Univ. Press
15. Chambers DA, Glasgow RE, Stange KC. 2013. The dynamic sustainability framework: addressing the paradox of sustainment amid ongoing change. *Implement. Sci.* 8(1):117
16. Clark WAV. 1991. Residential preferences and neighborhood racial segregation: a test of the Schelling segregation model. *Demography* 28(1):1–19
17. Coiera E, Ash J, Berg M. 2016. The unintended consequences of health information technology revisited. *Yearb. Med. Inform.* 25(1):163–69
18. Coleman JS. 1990. *Foundations of Social Theory*. Boston: Harvard Univ. Press
19. Combs T, Nelson KL, Luke D, McGuire FH, Cruden G, et al. 2022. Simulating the role of knowledge brokers in policy making in state agencies: an agent-based model. *Health Serv. Res.* 57(S1):122–36
20. Combs TB, Ornstein JT, Chaitan VL, Golden SD, Henriksen L, Luke DA. 2022. Draining the tobacco swamps: shaping the built environment to reduce tobacco retailer proximity to residents in 30 big US cities. *Health Place* 75:102815
21. Currie CSM, Fowler JW, Kotiadis K, Monks T, Onggo BS, et al. 2020. How simulation modelling can help reduce the impact of COVID-19. *J. Simul.* 14(2):83–97
22. Dadich A, Vaughan P, Boydell K. 2023. The unintended negative consequences of knowledge translation in healthcare: a systematic scoping review. *Health Sociol. Rev.* 32(1):75–93
23. Damschroder LJ, Aron DC, Keith RE, Kirsh SR, Alexander JA, Lowery JC. 2009. Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. *Implement. Sci.* 4(1):50
24. Dearing JW, Cox JG. 2018. Diffusion of innovations theory, principles, and practice. *Health Aff.* 37(2):183–90
25. De Silva-Sanigorski AM, Bell AC, Kremer P, Park J, Demajo L, et al. 2012. Process and impact evaluation of the *Romp & Chomp* obesity prevention intervention in early childhood settings: lessons learned from implementation in preschools and long day care settings. *Child. Obes.* 8(3):205–15
26. D'Lima D, Soukup T, Hull L. 2022. Evaluating the application of the RE-AIM planning and evaluation framework: an updated systematic review and exploration of pragmatic application. *Front. Public Health* 9:755738
27. Dobbins M, Robeson P, Ciliska D, Hanna S, Cameron R, et al. 2009. A description of a knowledge broker role implemented as part of a randomized controlled trial evaluating three knowledge translation strategies. *Implement. Sci.* 4(1):23
28. Economos CD, Calancie L, Korn AR, Allender S, Appel JM, et al. 2023. Community coalition efforts to prevent childhood obesity: Two-year results of the Shape Up Under 5 study. *BMC Public Health* 23(1):529
29. Economos CD, Hammond RA. 2017. Designing effective and sustainable multifaceted interventions for obesity prevention and healthy communities. *Obesity* 25(7):1155–56
30. Feldstein AC, Glasgow RE. 2008. A Practical, Robust Implementation and Sustainability Model (PRISM) for integrating research findings into practice. *Jt. Comm. J. Qual. Patient Saf.* 34(4):228–43
31. Folta SC, Kuder JF, Goldberg JP, Hyatt RR, Must A, et al. 2013. Changes in diet and physical activity resulting from the Shape Up Somerville community intervention. *BMC Pediatr*. 13(1):157
32. Gallagher S, Richardson LF, Ventura SL, Eddy WF. 2018. SPEW: Synthetic Populations and Ecosystems of the World. *J. Comput. Graph. Stat.* 27(4):773–84
33. Geng EH, Baumann AA, Powell BJ. 2022. Mechanism mapping to advance research on implementation strategies. *PLOS Med*. 19(2):e1003918
34. Geng EH, Mody A, Powell BJ. 2023. On-the-go adaptation of implementation approaches and strategies in health: emerging perspectives and research opportunities. *Annu. Rev. Public Health* 44:21–36
35. Green LW, Ottoson JM, García C, Hiatt RA. 2009. Diffusion theory and knowledge dissemination, utilization, and integration in public health. *Annu. Rev. Public Health* 30:151–74
36. Hawe P, Shiell A, Riley T. 2009. Theorising interventions as events in systems. *Am. J. Community Psychol.* 43(3–4):267–76

37. Hedström P, Ylikoski P. 2010. Causal mechanisms in the social sciences. *Annu. Rev. Sociol.* 36:49–67
38. Hennessy E, Economos CD, Hammond RA, Sweeney LB, Brukilacchio L, et al. 2020. Integrating complex systems methods to advance obesity prevention intervention research. *Health Educ. Behav.* 47(2):213–23
39. Hovmand P. 2013. *Community Based System Dynamics*. New York: Springer
40. Huang W, Chang C-H, Stuart EA, Daumit GL, Wang N-Y, et al. 2021. Agent-based modeling for implementation research: an application to tobacco smoking cessation for persons with serious mental illness. *Implement. Res. Pract.* 2:26334895211010664
41. Isaacson W. 2017. *Leonardo da Vinci*. New York: Simon & Schuster
42. Jayasinghe S. 2015. Social determinants of health inequalities: towards a theoretical perspective using systems science. *Int. J. Equity Health* 14(1):71
43. Kasman M, Hammond RA, Mack-Crane A, Purcell R, Korn AR, et al. 2023. Using agent-based modeling to extrapolate community-wide impact from a stakeholder-driven childhood obesity prevention intervention: Shape Up Under 5. *Child. Obes.* 19(2):130–38
44. Kiekens A, Dierckx De Casterlé B, Vandamme A-M. 2022. Qualitative systems mapping for complex public health problems: a practical guide. *PLOS ONE* 17(2):e0264463
45. Kilbourne AM, Geng E, Eshun-Wilson I, Sweeney S, Shelley D, et al. 2023. How does facilitation in healthcare work? Using mechanism mapping to illuminate the black box of a meta-implementation strategy. *Implement. Sci. Commun.* 4(1):53
46. Kislov R, Pope C, Martin GP, Wilson PM. 2019. Harnessing the power of theorising in implementation science. *Implement. Sci.* 14(1):103
47. Klovdahl AS. 1985. Social networks and the spread of infectious diseases: the AIDS example. *Soc. Sci. Med.* 21(11):1203–16
48. Koorts H, Cassar S, Salmon J, Lawrence M, Salmon P, Dorling H. 2021. Mechanisms of scaling up: combining a realist perspective and systems analysis to understand successfully scaled interventions. *Int. J. Behav. Nutr. Phys. Act.* 18(1):42
49. Kruskal W. 1988. Miracles and statistics: the casual assumption of independence. *J. Am. Stat. Assoc.* 83(404):929–40
50. Kwan BM, Brownson RC, Glasgow RE, Morrato EH, Luke DA. 2022. Designing for dissemination and sustainability to promote equitable impacts on health. *Annu. Rev. Public Health* 43:331–53
51. Lengnick-Hall R, Stadnick NA, Dickson KS, Moullin JC, Aarons GA. 2021. Forms and functions of bridging factors: specifying the dynamic links between outer and inner contexts during implementation and sustainment. *Implement. Sci.* 16:34
52. Lewis CC, Boyd MR, Walsh-Bailey C, Lyon AR, Beidas R, et al. 2020. A systematic review of empirical studies examining mechanisms of implementation in health. *Implement. Sci.* 15(1):21
53. Lewis CC, Klasnja P, Powell BJ, Lyon AR, Tuzzio L, et al. 2018. From classification to causality: advancing understanding of mechanisms of change in implementation science. *Front. Public Health* 6:136
54. Long E, Gardani M, McCann M, Sweeting H, Tranmer M, Moore L. 2020. Mental health disorders and adolescent peer relationships. *Soc. Sci. Med.* 253:112973
55. Luke DA, Hammond RA, Combs T, Sorg A, Kasman M, et al. 2017. Tobacco Town: computational modeling of policy options to reduce tobacco retailer density. *Am. J. Public Health* 107(5):740–46
56. Luke DA, Harris JK. 2007. Network analysis in public health: history, methods, and applications. *Annu. Rev. Public Health* 28:69–93
57. Luke DA, Morshed AB, McKay VR, Combs TB. 2023. Systems science methods in dissemination and implementation research. In *Dissemination and Implementation Research in Health*, ed. RC Brownson, GA Colditz, EK Proctor, pp. 269–90. Oxford, UK: Oxford Univ. Press. 3rd ed.
58. Luke DA, Ornstein JT, Combs TB, Henriksen L, Mahoney M. 2020. Moving from metrics to mechanisms to evaluate tobacco retailer policies: importance of retail policy in tobacco control. *Am. J. Public Health* 110(4):431–33
59. Luke DA, Stamatakis KA. 2012. Systems science methods in public health: dynamics, networks, and agents. *Annu. Rev. Public Health* 33:357–76

60. Mazzucca S, Tabak RG, Pilar M, Ramsey AT, Baumann AA, et al. 2018. Variation in research designs used to test the effectiveness of dissemination and implementation strategies: a review. *Front. Public Health* 6:32
61. McGinnis MD, Ostrom E. 2014. Social-ecological system framework: initial changes and continuing challenges. *Ecol. Soc.* 19(2):30
62. McKay V, Vogel M, Combs T, Brossart L, Endrizal A, et al. 2022. Tailoring dissemination of evidence to preferences of tobacco control partners: results from an academic-community partnership. *Subst. Abuse Treat. Prev. Policy* 17(1):29
63. Merton RK. 1968. *Social Theory and Social Structure*. New York: Simon and Schuster
64. Meza RD, Moreland JC, Pullmann MD, Klasnja P, Lewis CC, Weiner BJ. 2023. Theorizing is for everybody: advancing the process of theorizing in implementation science. *Front. Health Serv.* 3:1134931
65. Mobus GE, Kalton MC. 2014. *Principles of Systems Science*. New York: Springer
66. Morshed AB, Kasman M, Heuberger B, Hammond RA, Hovmand PS. 2019. A systematic review of system dynamics and agent-based obesity models: evaluating obesity as part of the global syndemic. *Obes. Rev.* 20(S2):161–78
67. Muttalib F, Ballard E, Langton J, Malone S, Fonseca Y, et al. 2021. Application of systems dynamics and group model building to identify barriers and facilitators to acute care delivery in a resource limited setting. *BMC Health Serv. Res.* 21(1):26
68. NCI (Natl. Cancer Inst.). 2007. *Greater Than the Sum: Systems Thinking in Tobacco Control*. Washington, DC: NCI, US Dep. Health Hum. Serv., Public Health Serv., Natl. Inst. Health
69. Nilsen P. 2015. Making sense of implementation theories, models and frameworks. *Implement. Sci.* 10(1):53
70. Nilsen P, Bernhardsson S. 2019. Context matters in implementation science: a scoping review of determinant frameworks that describe contextual determinants for implementation outcomes. *BMC Health Serv. Res.* 19(1):189
71. Northridge ME, Metcalf SS. 2016. Enhancing implementation science by applying best principles of systems science. *Health Res. Policy Syst.* 14(1):74
72. Palinkas LA, Zatzick D. 2019. Rapid Assessment Procedure Informed Clinical Ethnography (RAPICE) in pragmatic clinical trials of mental health services implementation: Methods and applied case study. *Adm. Policy Ment. Health* 46(2):255–70
73. Powell BJ, Beidas RS. 2016. Advancing implementation research and practice in behavioral health systems. *Adm. Policy Ment. Health* 43(6):825–33
74. Proctor E, Silmere H, Raghavan R, Hovmand P, Aarons G, et al. 2011. Outcomes for implementation research: conceptual distinctions, measurement challenges, and research agenda. *Adm. Policy Ment. Health* 38(2):65–76
75. Proctor EK, Bunger AC, Lengnick-Hall R, Gerke DR, Martin JK, et al. 2023. Ten years of implementation outcomes research: a scoping review. *Implement. Sci.* 18(1):31
76. Pruyt E, Kwakkel J. 2007. *Combining system dynamics and ethics: towards more science?* Paper presented at the 2007 International Conference of the System Dynamics Society and 50th Anniversary Celebration, Cambridge, MA, July 29–Aug. 2
77. Pullmann MD, Dorsey S, Duong MT, Lyon AR, Muse I, et al. 2022. Expect the unexpected: a qualitative study of the ripple effects of children's mental health services implementation efforts. *Implement. Res. Pract.* 3:26334895221120797
78. Richardson GP. 2012. System dynamics: simulation for policy analysis from a feedback perspective. In *Qualitative Simulation Modeling and Analysis*, ed. PA Fishwick, PA Luker, pp. 144–69. New York: Springer
79. Rittel HWJ, Webber MM. 1973. Dilemmas in a general theory of planning. *Policy Sci*. 4(2):155–69
80. Rogers EM. 2003. *Diffusion of Innovations*. New York: Free Press/Simon and Schuster. 5th ed.
81. Romney W, Salbach N, Parrott JS, Deutsch JE. 2020. A knowledge translation intervention designed and implemented by a knowledge broker improved documented use of gait speed: a mixed-methods study. *J. Geriatr. Phys. Ther.* 43(3):E1–10
82. Rosenthal J, Arku RE, Baumgartner J, Brown J, Clasen T, et al. 2020. Systems science approaches for global environmental health research: enhancing intervention design and implementation for

household air pollution (HAP) and water, sanitation, and hygiene (WASH) programs. *Environ. Health Perspect.* 128(10):105001
83. Ross H, Tesche J, Vellios N. 2017. Undermining government tax policies: common legal strategies employed by the tobacco industry in response to tobacco tax increases. *Prev. Med.* 105:S19–22
84. Salanitro AH, Estrada CA, Allison JJ. 2008. Implementation research: beyond the traditional randomized controlled trial. In *Essentials of Clinical Research*, ed. SP Glasser, pp. 217–44. New York: Springer
85. Schelling TC. 1971. Dynamic models of segregation. *J. Math. Sociol.* 1:143–86
86. Schliep ME, Alonzo CN, Morris MA. 2017. Beyond RCTs: innovations in research design and methods to advance implementation science. *Evid.-Based Commun. Assess. Interv.* 11(3–4):82–98
87. Senge PM. 2006. *The Fifth Discipline: The Art & Practice of the Learning Organization*. New York: Doubleday. Revis. ed.
88. Sheldrick RC, Cruden G, Schaefer AJ, Mackie TI. 2021. Rapid-cycle systems modeling to support evidence-informed decision-making during system-wide implementation. *Implement. Sci. Commun.* 2(1):116
89. Shelton RC, Adsul P, Oh A, Moise N, Griffith DM. 2021. Application of an antiracism lens in the field of implementation science (IS): recommendations for reframing implementation research with a focus on justice and racial equity. *Implement. Res. Pract.* 2:26334895211049482
90. Shelton RC, Chambers DA, Glasgow RE. 2020. An extension of RE-AIM to enhance sustainability: addressing dynamic context and promoting health equity over time. *Front. Public Health* 8:134
91. Silva DS, Smith MJ, Norman CD. 2018. Systems thinking and ethics in public health: a necessary and mutually beneficial partnership. *Monash Bioeth. Rev.* 36(1–4):54–67
92. Simon HA. 2001. Complex systems: the interplay of organizations and markets in contemporary society. *Comput. Math. Organ. Theory* 7:79–85
93. Singh NS, Kovacs RJ, Cassidy R, Kristensen SR, Borghi J, Brown GW. 2021. A realist review to assess for whom, under what conditions and how pay for performance programmes work in low- and middle-income countries. *Soc. Sci. Med.* 270:113624
94. Sisk BA, Mozersky J, Antes AL, DuBois JM. 2020. The "ought-is" problem: an implementation science framework for translating ethical norms into practice. *Am. J. Bioeth.* 20(4):62–70
95. Sterman JD. 2006. Learning from evidence in a complex world. *Am. J. Public Health* 96(3):505–14
96. Tabak RG, Khoong EC, Chambers DA, Brownson RC. 2012. Bridging research and practice: models for dissemination and implementation research. *Am. J. Prev. Med.* 43(3):337–50
97. Tracy M, Cerdá M, Keyes KM. 2018. Agent-based modeling in public health: current applications and future directions. *Annu. Rev. Public Health* 39:77–94
98. Univ. Colo. Denver. 2023. Helping navigate dissemination and implementation models. *Dissemination & Implementation Models in Health*. **https://dissemination-implementation.org**
99. Valente TW. 2005. Network models and methods for studying the diffusion of innovations. In *Models and Methods in Social Network Analysis*, ed. PJ Carrington, J Scott, S Wasserman, pp. 98–116. Cambridge Univ. Press
100. Victora CG, Habicht J-P, Bryce J. 2004. Evidence-based public health: moving beyond randomized trials. *Am. J. Public Health* 94(3):400–405
101. Wensing M, Grol R. 2019. Knowledge translation in health: how implementation science could contribute more. *BMC Med.* 17(1):88
102. Williams F, Colditz GA, Hovmand P, Gehlert S. 2018. Combining community-engaged research with group model building to address racial disparities in breast cancer mortality and treatment. *J. Health Disparities Res. Pract.* 11(1):160–78
103. Woodward EN, Matthieu MM, Uchendu US, Rogal S, Kirchner JE. 2019. The health equity implementation framework: proposal and preliminary study of hepatitis C virus treatment. *Implement. Sci.* 14(1):26
104. Zimmerman L, Lounsbury DW, Rosen CS, Kimerling R, Trafton JA, Lindley SE. 2016. Participatory system dynamics modeling: increasing stakeholder engagement and precision to improve implementation planning in systems. *Adm. Policy Ment. Health* 43(6):834–49