Systems Thinking in 49 Communities Related to Healthy Eating, Active Living, and Childhood Obesity

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Background: Community partnerships to promote healthy eating and active living in order to prevent childhood obesity face a number of challenges. Systems science tools combined with group model–building techniques offer promising methods that use transdisciplinary team-based approaches to improve understanding of the complexity of the obesity epidemic. This article presents evaluation methods and findings from 49 Healthy Kids, Healthy Communities sites funded to implement policy, system, and environmental changes from 2008 to 2014. **Methods:** Through half-day group model–building sessions conducted as part of evaluation site visits to each community between 2010 and 2013, a total of 50 causal loop diagrams were produced for 49 communities (1 community had 2 causal loop diagrams representing different geographic regions). The analysis focused on the following evaluation questions: (1) What were the most prominent variables in the causal loop diagrams across communities? (2) What were the major feedback structures across communities? (3) What implications from the synthesized causal loop diagram can be translated to policy makers, practitioners, evaluators, funders, and other community representatives? **Results:** A total of 590 individuals participated with an average of 12 participants per session. Participants' causal loop diagrams included a total of 227 unique variables in the following major subsystems: healthy eating policies and environments, active living policies and environments, health and health behaviors, partnership and community capacity, and social determinants. In a synthesized causal loop diagram representing variables identified by at least 20% of the communities, many feedback structures emerged and several themes are highlighted with respect to implications for policy and practice as well as assessment and evaluation. **Conclusions:** The application of systems thinking tools combined with group model–building techniques creates opportunities to define and characterize complex systems in a manner that draws on the authentic voice of residents and community partners.

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Community partnerships (CPs) to promote healthy eating and active living in order to prevent childhood obesity face a number of challenges, including the politics associated with who is responsible for obesity (eg, individual vs society), disparities and stigma differentially impacting subpopulations, and competition for resources and influence. Systems science provides several tools and methods to address some of these challenges; for instance, behavior-over-time graphs enumerate context-specific variables and historic trends for these variables (see Hoehner et al,[1] in this supplement), causal maps specify the direction of influence in causal relationships and feedback loops among variables (elaborated in this article), and group model–building (GMB) techniques[2-6] engage constituents in systems design and development (included in both articles).

Public health investigators have used these types of tools and methods to link biological and population-level dynamics influencing obesity, examine causal interactions across multiple socioecological subsystems, observe subpopulation patterns to inform intervention design, and triangulate multiple data sources to understand complex social movements (eg, shifts in social norms and cultures).[7,8] Given the complexity of the obesity epidemic and the communities working to address the epidemic,[9,10] investigators designed and implemented systems science tools and methods as part of the evaluation of 49 Healthy Kids, Healthy Communities (HKHC) CPs. This article presents results from the GMB techniques used to develop and analyze causal maps for each of the 49 sites.

Background on HKHC

From 2008 to 2014, the HKHC national program of the Robert Wood Johnson Foundation (www.healthykidshealthycommunities.org) funded 49 CPs across the United States and Puerto Rico to implement healthy eating and active living policy, system, and environmental changes to support healthier communities for children and families, with special emphasis on reaching children at highest risk for obesity on the basis of race, ethnicity, income, or geographic location.[11]

Background on the HKHC Evaluation

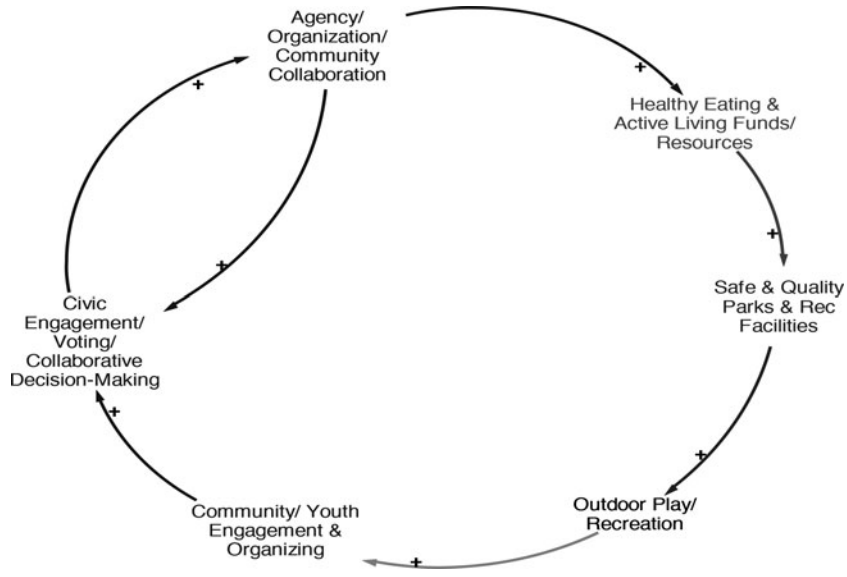
Evaluators designed a mixed-methods evaluation to assess successful plans, processes, and strategies for policy, system, and environmental changes to increase active living and healthy eating as well as to identify challenges encountered or failed approaches.[12,13] The evaluation was intended to build on community-based, participatory evaluation approaches in order to build capacity for conducting evaluation at the local level.[14] As part of the HKHC evaluation aim to conduct a qualitative cross-site process and impact evaluation among all 49 HKHC CPs, evaluators incorporated systems science methods, specifically GMB, to actively involve a wide range of community representatives (eg, residents, elected officials, government agencies, community-based organizations, businesses) in identifying trends and underlying feedback systems hypothesized by participants as driving local change in health behaviors and obesity. Implementation of these methods, described in detail in the following section, occurred from 2011 to 2013 and gave HKHC CPs an opportunity to discuss how their work affected or was affected by the community context.

Group Model Building

Group model building is a participatory method for involving partners and community representatives in processes to better understand system behaviors.[3-5,15] It is based on foundations of system dynamics, or "the use of informal maps and formal models with computer simulation to uncover and understand endogenous sources of system behavior"[15(p211)]; endogenous sources are those that affect and are affected by other variables in the system. Although GMB was designed for formal system dynamics simulation models,[16,17] others have extended the approach to involve wider community participation through causal maps for purposes of problem structuring, system conceptualization, and capacity building.[3,4,18,19]

Causal maps, or causal loop diagrams, provide a broad view of the different components of a system, including major subsystems and how these are related through multiple feedback loops. In contrast to complex formal computer simulation models,[20] causal maps have the benefit of providing more transparent and recognizable benefits to lay audiences as tools for systems thinking. Causal maps also have fewer expertise, resource, and data requirements; therefore, these methods are more readily transferable to communities. Figures 1 and 2 present examples of causal loops, and Supplemental Digital Content Figure 1 (available

FIGURE 1 ● Active Living Policies and Environments Feedback Loop



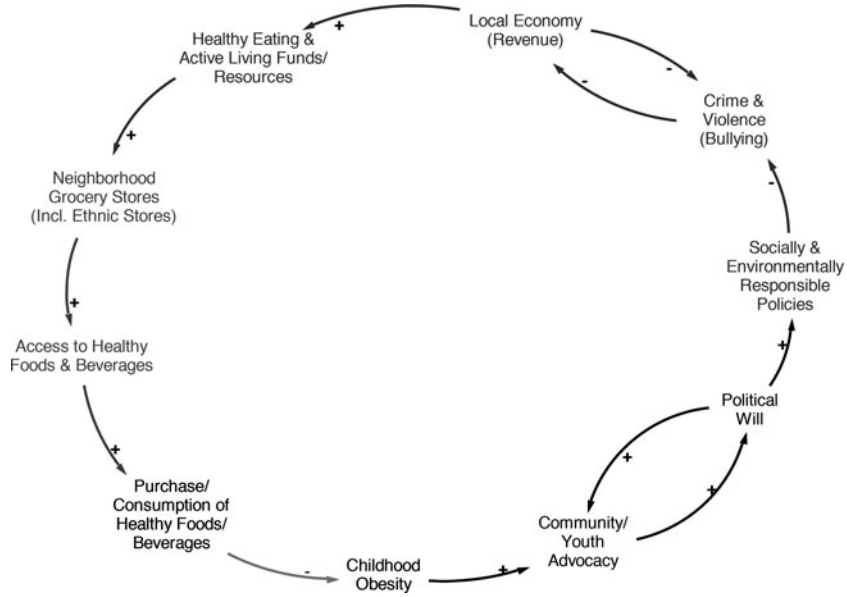
at: http://links.lww.com/JPHMP/A147) illustrates a causal map or causal loop diagram.

The GMB sessions for the HKHC evaluation were intended to introduce systems thinking at the community level by identifying the essential parts of the system and how the system influences policy and environmental changes to promote healthy eating and active living and to prevent childhood obesity through causal mapping of feedback loops for each of the 49 HKHC CPs. Using an inductive approach, GMB participants identified the essential parts of the system through variables produced during a behavior-over-time graph exercise (see companion article in this supplement[1]).

The purpose of this article is to describe the methods, results, and implications associated with a synthesis of the causal maps, or causal loop diagrams, for each of the 49 HKHC CPs. Specifically, this article addresses the following evaluation questions:

1. What were the most prominent variables in the causal loops diagrams across communities?

FIGURE 2 ● Healthy Eating Policies and Environments Feedback Loop



2. What were the major feedback structures across communities?
3. What implications from the synthesized HKHC causal loop diagram can be translated to policy makers, practitioners, evaluators, funders, and other community representatives?

Methods

From 2010 to 2014, the evaluation team worked collaboratively with HKHC CPs to design and implement 49 community-based, half-day GMB sessions as part of HKHC site visits as well as to develop customized community reports to support local dissemination efforts (see systems thinking in communities' storybooks, www.transtria.com/hkhc.php).

GMB session

Evaluators worked with HKHC project directors and project coordinators to host GMB sessions on these visits. The half-day sessions followed a structured protocol involving a sequence of GMB scripts[4,21,22] that are available in the *Healthy Kids, Healthy Communities Group Model Building Facilitation Handbook* (www.transtria.com/hkhc.php).

The GMB sessions had 2 main activities designed to gain insight into groups' common understanding of the policy, system, and environmental work going on in their community related to healthy eating, active living, and childhood obesity. The first activity was a 60-minute behavior-over-time graph exercise, in which participants individually created and shared graphs of things that affect or are affected by policy, system, and environmental changes in their community using a nominal group technique (ie, all participants described their top-ranked graph, followed by the second-ranked graph, and so on, until all graphs were shared or time ran out). The second activity was a causal loop diagram, or structural elicitation, 60-minute exercise, in which participants collectively shared their perceptions of causal relationships among variables generated from the first exercise to develop a causal loop diagram, or system map, illustrating the community's theory of change.

A wide range of community participants were recruited by HKHC project directors and project coordinators, including residents, elected officials, representatives from government agencies and community-based organizations, businesses, and university-based researchers. Most sessions were conducted in English, with exception of 4 sessions in communities using interpretation and translation services. All sessions were recorded and transcribed to add further context and clarification postsession to the interpretation and analysis of variables and causal relationships identified in the participants' stories.

Following the behavior-over-time graph exercise, facilitators selected approximately 9 to 12 variables to use as "seed" variables to start the causal loop diagraming exercise. Variables were primarily chosen to represent active living or healthy eating policy and environmental strategies for each HKHC CP; in addition, evaluators selected variables to reflect a range of health behaviors or outcomes, partnership or community capacity efforts, or social determinants of health, if these were identified. During training, the GMB modeler-facilitator received instructions on how to code the behavior-over-time graphs (see Hoehner et al[1] in this supplement) into the referenced categories and to incorporate the variables receiving the greatest amount of attention or discussion during the session into the causal loop diagram. The final set of variables selected by the modeler was approved by the facilitator and, subsequently, reviewed and approved by the session participants. See Table 1for examples of seed variables in each category.

The seed variables were written on white board paper posted to a wall prior to the sessions so that participants were able to make modifications to anything written on the paper during the sessions (eg, change to a variable name, addition of new variables). Participants were instructed to identify causal connections among the seed variables or to generate new variables to be added to the white board indicating causal relationships. As participants nominated links, facilitators drew the causal relationships using the conventions of system dynamics (see Table 2 and scripts from the handbook referenced previously) and highlighted simple balancing and reinforcing feedback loops as they emerged. The resulting causal loop diagrams were translated into Vensim software (www.vensim.com) as a product for further refinement and analysis.

Evaluators then reviewed each causal loop diagram against the transcripts to ensure the range of variables and causal relationships generated through the behavior-over-time graph exercise and the causal loop diagram exercise were represented. Evaluators placed an emphasis on making sure the diagrams characterized the mental models as expressed during specific conversations as well as throughout the session. For example, the use of a term may shift during a conversation, with the group coming to an agreement by the end of the session. Therefore, the transcripts were used to identify and resolve any ambiguity. In some cases, participants also nominated links that did not appear in the diagram because the conversation was moving too quickly or there was too much crosstalk. Sometimes

TABLE 1 ● Causal Loop Diagram Variables (>20% of Community Partnerships)

	No. (%) of Community Partnerships		No. (%) of Community Partnerships
Active living policies and environments		Sense of community/cohesion/integration	22 (44.9)
Access to parks	41 (83.7)	Active living programs/promotions	22 (44.9)
Access to recreation facilities	40 (81.6)	Advocacy	21 (42.9)
Access to pedestrian/bike infrastructure	39 (79.6)	Civic engagement/voting/collaborative decision making	16 (32.7)
Schools/child care/afterschool programs' physical education, recess, and physical activity policies	36 (73.5)	Community empowerment/capacity/pride	14 (28.6)
Access to public transportation	27 (55.1)	Nutrition education	14 (28.6)
Active living policy adoption and enforcement	25 (51.0)	Youth engagement/champions	13 (26.5)
Urban sprawl	19 (38.8)	Healthy eating programs/promotions	13 (26.5)
Trails/greenways/gulches	18 (36.7)	Healthy eating and active living campaigns/media	13 (26.5)
Schools in neighborhoods	17 (34.7)	Affordability of recreation programs	13 (26.5)
Traffic safety/traffic calming/quality of streets	15 (30.6)	Community leadership/champions	12 (24.5)
Car ownership/dependence	13 (26.5)	Social determinants of health	
Healthy community design/land use/smart growth/new urbanism	12 (24.5)	Healthy eating and active living funding	45 (91.8)
Complete Streets	12 (24.5)	Safety/perceptions of safety	44 (89.8)
Maintenance of active living facilities	11 (22.4)	Employment/local businesses/livable wages	38 (77.6)
Healthy eating policies and environments		Crime and violence (bullying)	33 (67.3)
Access to healthy foods/beverages	44 (89.8)	Poverty/homeless	29 (59.2)
Fast food restaurants	36 (73.5)	Local economy/economic climate/city budget and revenue	27 (55.1)
Community gardens/small farms/CSA programs/cooperatives	35 (71.4)	Family time together/parents' time with children	24 (49.0)
Affordability of healthy foods/beverages	35 (71.4)	Academic curriculum/standardized testing	17 (34.7)
Healthy foods/beverages in schools (preparation of meals)	34 (69.4)	Educational attainment/academic performance	17 (34.7)
Farmers' markets/ mobile markets/produce stands	33 (67.3)	Education/vocational training	16 (32.7)
Government nutrition assistance (SNAP, WIC, CACFP)	27 (55.1)	Tax base (state or local)	15 (30.6)
Healthy eating policy adoption and enforcement	26 (53.1)	Price/cost of gas	14 (28.6)
Local food production (organic, sustainable farming)	26 (53.1)	Affordable, healthy housing/neighborhood environments	14 (28.6)
Corner/convenience stores	24 (49.0)	Economic development	12 (24.5)
Neighborhood grocery stores (including ethnic stores)	23 (46.9)	Racism/discrimination/segregation	11 (22.4)
Agribusiness/corporatization of farming	17 (34.7)	Air, water, and soil quality	11 (22.4)
Unhealthy food/beverage marketing/advertising	17 (34.7)	Access to health care (including dental)	11 (22.4)
Access to unhealthy foods/beverages	17 (34.7)	School/child care funding/ revenue	10 (20.4)
Government subsidized agriculture (commodities, pesticides, hormones)	16 (32.7)	Socially and environmentally responsible policies (recycling, health in all policies, equitable resource distribution)	10 (20.4)
School gardens	12 (24.5)	Health and health behaviors	
Zoning for urban agriculture/produce sales	12 (24.5)	Physical activity	47 (95.9)
Healthy food/beverage retail	10 (20.4)	Active transportation (walking/biking)	38 (77.6)
"Big box"/chain/ franchised stores	10 (20.4)	Sedentary/screen time/technology	34 (69.4)
Healthy foods/ beverages in child care	10 (20.4)	Outside play/use of recreation facilities	33 (67.3)
Partnership and community capacity		Overweight and obesity	28 (57.1)
Political will/public demand/priorities/ attitudes	35 (71.4)	Consumption of healthy foods/beverages	28 (57.1)
Community/parent/ employer/school engagement/organizing	34 (69.4)	Healthy food preparation/cooking at home	26 (53.1)
Health education/promotion/ knowledge/awareness	33 (67.3)	Consumption of unhealthy foods/beverages	25 (51.0)
Partnership and collaboration	31 (63.3)	Chronic diseases (and symptoms)	20 (40.8)
Support from policy makers and decision makers	28 (57.1)	Healthy eating	20 (40.8)
Organized sports and recreation programs	23 (46.9)	Childhood overweight and obesity	17 (34.7)
		Car use/driving	14 (28.6)
		Free, unstructured play/recreation	11 (22.4)
		Walk/bike to school	11 (22.4)
		Purchase of healthy foods/beverages	11 (22.4)

Abbreviations: CACFP, Child and Adult Care Food Program; CSA, community-supported agriculture; SNAP, Supplemental Nutrition Assistance Program; WIC, Special Supplemental Nutrition for Women, Infants, and Children.

TABLE 2 ● Systems Science Terminology and Symbols in Causal Loop Diagrams

Terms/Symbols	Meaning
Words	Variables of quantities that can increase and decrease
Arrow	Causal relationships of influence
Polarity (+)	Variables change in the same direction (both increase, both decrease)
Polarity (−)	Variables change in the opposite direction (one increases and the other decreases, or vice versa)
Feedback loop	2 or more variables in a causal sequence that "feeds back" to the original variable, completing a loop

the direction of the relationship between variables was mistakenly recorded on the diagram, or the nature of the relationship between variables was misrepresented. This happened when arrows were drawn in the wrong direction or the associated polarities, or positive and negative signs, did not reflect the quantitative relationship between variables. In causal loop diagrams, a plus sign ("+") from *x* to *y* means that as *x* increases, *y* increases, *and equivalently*, as *x* decreases so does *y.* Similarly, a minus sign ("−") from *x* to *y* means that as *x* increases, *y decreases*, and as *x* decreases, *y increases.* See Table 2 for basic terminology and symbols used in the causal loop diagrams. These situations called for modifications to the original causal loop diagram.

After reviewing and cleaning the causal loop diagrams in Vensim, the evaluators identified the feedback loops associated with each CP's primary strategies (ie, partnership and community capacity building as well as healthy eating and active living) and then created systems thinking storybooks for each CP. A total of 50 causal loop diagrams were produced for 49 communities (1 community had 2 causal loop diagrams representing different geographic regions).

To develop the synthesized causal loop diagram across communities, evaluators conducted a content analysis of the variables across all 50 causal loop diagrams. Variable names were independently coded into 5 major subsystems: healthy eating policies and environments, active living policies and environments, partnership and community capacity building, social determinants of health, and health and health behaviors. All variables from the causal loop diagrams were then entered into a database according to these 5 major subsystems in order to identify common variables across communities. While there were a number of variables that appeared in only 1 causal loop diagram, 80% of the variables across the 50 causal loop diagrams were accounted for by variables that appeared in 20% or more of the causal loop diagrams. Thus, evaluators chose to use 20% as the threshold for including a variable in the synthesized causal loop diagram. That is, if a variable appeared in 10 or more causal loop diagrams, it was included in the synthesized causal loop diagram.

The synthesized causal loop diagram was developed by taking the aggregation or union of the links between these variables across the 50 causal loop diagrams. This was initially done in an incremental fashion by adding links from one causal loop diagram to another to yield the union of 2 diagrams and then adding a third causal loop diagram to that for the next iteration until the final diagram represented all the links between the identified variables. This diagram was simplified by focusing on the feedback relationships and then compared against community diagrams to ensure that the synthesized diagram had the capacity to retell the stories from each community.

● Results

A total of 590 individuals participated across 49 communities, with an average of 12 participants per session. Table 3 provides session characteristics and selected HKHC CP characteristics by HKHC CP.

A synthesis of all 50 casual loop diagrams is presented in Supplemental Digital Content Figure 1 (available at: http://links.lww.com/JPHMP/A147), reflecting subsystems, feedback structures, and structural elements corresponding to policies, environments, local collaborations, and social determinants that influence healthy eating, active living, and, ultimately, childhood obesity. As illustrated in this figure, the causal loop diagram provides a way to visualize all the elements of the system and their interactions, with a focus on causal relationships as opposed to associations. The causal loop diagram represents a holistic perspective of the system and several subsystems. To digest the depth and complexity of the diagram, it is helpful to examine it in terms of the subsystems of influence, including healthy eating policies and environments (red), active living policies and environments (blue), health and health behaviors (orange), partnership and community capacity (purple), and social determinants (green).

What were the most prominent variables in the causal loop diagrams across communities?

Participants' causal loop diagrams included a total of 2399 variables extracted from the transcripts for the behavior-over-time-graph and causal loop diagram exercises; this represented a total of 227 unique variables across all CPs. Common variables for each major subsystem are identified in this section; other less common

TABLE 3 ● Group Model Building Session Characteristics and Selected Community Partnership Characteristics

	Session Characteristics		Community Partnership Characteristics		
Community Partnership	No. of Participants	Spanish Translation?	No. of Partners	Population Size	% Below Poverty
Baldwin Park, California	14	Yes	15	75 390	16.0
Benton County, Oregon	14		29	85 579	21.0
Boone/Newton Counties, Arkansas	10		13	45 233	16.9
Buffalo, New York	11		15	261 310	29.9
Caguas, Puerto Rico	15	Yes	34	142 893	37.1
Central Valley, California	20 (2 sessions)	Yes (1 session)	37	3 971 659	20.8
Charleston, West Virginia	15		52	51 400	16.4
Chattanooga, Tennessee	10		35	167 674	22.9
Chicago, Illinois	11		38	2 695 598	21.4
Columbia, Missouri	21		46	108 500	22.9
Cook County, Georgia	12		27	17 212	23.0
Cuba, New Mexico	11		22	731	28.7
Denver, Colorado	10		50	600 158	18.8
Desoto/Marshall/Tate, Mississippi	9		36	227 282	13.0
El Paso, Texas	11		22	649 121	23.3
Fitchburg, Massachusetts	14		24	40 318	19.0
Flint, Michigan	8		26	102 434	38.2
Grant County, New Mexico	14		29	29 514	16.6
Greenville, South Carolina	9		37	58,409	18.6
Hamilton County, Ohio	8		15	802 374	15.9
Houghton County, Michigan	9		18	36 628	22.8
Houston, Texas	10		29	2 099 451	21.5
Jackson, Mississippi	5		15	173 514	0.1
Jacksonville, Florida	12		25	821 784	15.2
Jefferson County, Alabama	14		29	658 466	16.2
Kane County, Illinois	16		27	515 269	10.1
Kansas City, Missouri	12		36	605 573	19.4
Kingston, New York	14		43	23 893	16.5
Knox County, Tennessee	13		23	432 226	13.7
Louisville, Kentucky	16		38	91 411	21.9
Milledgeville, Georgia	13		34	597 337	17.5
Milwaukee, Wisconsin	19		22	17 715	43.3
Moore/ Montgomery, North Carolina	6		34	594 833	27.0
Nash/Edgecombe, North Carolina	13		26	116 045	16.1
New Orleans, Louisiana	7		35	152 392	18.4
Oakland, California	12		28	343 829	25.7
Omaha, Nebraska	14		13	390 724	19.6
Palm Springs/Lake Worth/Greenacres, Florida	9		26	408 958	15.5
Philadelphia, Pennsylvania	10		14	1 526 006	25.6
Phoenix, Arizona	10	Yes	27	1 445 632	20.3
Portland, Oregon	11		30	735 334	16.5
Rancho Cucamonga, California	11		26	165 269	5.5
Rochester, New York	17		40	210 565	31.1
San Antonio, Texas	13		33	1 327 407	19.2
Seattle, Washington	8		37	1 931 249	10.5
Somerville, Massachusetts	9		46	75 754	14.9
Spartanburg, South Carolina	10		17	284 307	16.2
Washington, District of Columbia	9		13	601 723	18.9
Watsonville/Parajo Valley, California	21		29	152 152	14.8
Total	590	4			

variables are included in Supplemental Digital Content Table 1 (available at: http://links.lww.com/JPHMP/A148).

Active living policies and environments

For the active living policies and environments subsystem, a total of 30 different variables were generated, with 14 represented in at least 20% of the CPs' causal loop diagrams (see Table 1). Of the 14 variables, several supported active transportation (eg, access to public transportation, Complete Streets) or recreation (eg, access to parks, access to trails). Some referenced community design and land use (eg, urban sprawl, school siting) or motorized transportation (eg, traffic safety, car dependence). Two broadly referred to policy adoption and enforcement or maintenance of environments, and 1 was specific to school and child care policies and environments for active living.

Healthy eating policies and environments

In the healthy eating policies and environments subsystem, participants identified a total of 48 different variables, with 20 represented in at least 20% of the CPs' causal loop diagrams (see Table 1). Of the 20 variables, some referenced access to healthy or unhealthy foods and beverages generally and then many of the others depicted settings for purchase or consumption of foods and beverages (eg, fast food restaurants, farmers' markets, child care). Several focused on food production settings, such as gardens and farms, yet distinguished the setting (school vs community), scale (small farms vs agribusiness), or approach (organic vs sustainable). A couple referred to the affordability of foods and beverages as well as nutrition assistance. Similar to active living, policy adoption and enforcement and land use (eg, zoning for urban agriculture/produce sales) were identified. And, finally, unhealthy food and beverage marketing and advertising were included.

Partnership and community capacity

With respect to the partnership and community capacity subsystem, participants produced a total of 27 different variables, with 17 represented in at least 20% of the CPs' causal loop diagrams. Of the 17 variables, many corresponded to community organizing and advocacy, including political will, youth or civic engagement, partnership and collaboration, advocacy, and youth or community leadership. One also highlighted support from policy makers and decision makers. A couple referred more generally to sense of community and community empowerment. Some described programs and promotions, such as health education or sports and recreation. And, one specifically identified the affordability of recreation programs.

Social determinants of health

For the social determinants of health subsystem, participants discussed a total of 82 different variables, with 19 represented in at least 20% of the CPs' casual loop diagrams. Of these 19 variables, several referred to harmful social conditions, beliefs, or practices, such as crime, poverty, and segregation. In addition to poverty, a handful of others also focused on financial or economic-related circumstances, including employment, affordable housing, economic development, and funding for healthy eating and active living. A handful of other variables also referenced schools or education related to curricula and standardized testing, educational attainment, and vocational training. Others identified access to health care, families spending time together, and socially and environmentally responsible policies.

Health and health behaviors

Finally, in the health and health behaviors subsystem, participants identified a total of 40 different variables, with 15 represented in at least 20% of the CPs' causal loop diagrams. Of these 15 variables, many referenced physical activity, or complementary sedentary behaviors, including active transportation, screen time, outdoor recreation, and driving. Several focused on healthy eating and consumption of unhealthy foods and beverages as well as food preparation and purchasing healthy foods and beverages. The remaining referred to overweight and obesity or chronic diseases.

What were the major feedback structures across communities?

Through the model, specific types of causal relationships, or feedback loops, underlying the behavior of the dynamic system, can be identified to provide insights into what is working or not working to support the intended outcomes (in this case, increases in healthy eating and active living and decreases in childhood overweight and obesity).

Active living policies and environments

An example feedback loop representing active living policy and environmental variables in the synthesized causal loop diagram is shown in Figure 1. This illustration is a reinforcing loop and may be interpreted as follows:

> With more safe, quality parks and recreation facilities, more children are outside playing. In turn, this can stimulate greater youth civic engagement and collaboration across youth and other community organizations. With collaboration, more funds and resources can be generated to support healthy eating

and active living. Some of these funds can be used to increase the safety or quality of parks and recreation facilities.

In a reinforcing loop, the effect of an increase or decrease in a variable continues through the casual pathway and reinforces the increase or decrease in the initial variable. In isolation, this reinforcing loop can be a "virtuous cycle" when all of these assets positively support one another, but *the same feedback loop* can also be a "vicious cycle" when a decrease in one variable is perpetuated around the loop into a downward spiral. This reinforcing loop is only one part of the larger causal loop diagram (see Supplemental Digital Content Figure 1, available at: http://links.lww.com/JPHMP/A147), with a total of 1555 feedback loops that incorporate safe and quality parks and recreation facilities and "compete" for influence over the variables in the loop. Some of these influences further reinforce the direction of change, whereas others balance or counteract the direction of change. At some point, these reinforcing influences (good or bad) level off as balancing feedback loops ultimately limit the upward or downward trends. For example, communities may become saturated with safe and quality parks and recreation facilities, reducing the added value of new safe and quality parks and recreation facilities. Similarly, there may be so many unsafe, poor quality parks and recreation facilities that kids are unable to play outside.

Healthy eating policies and environments

Another example feedback loop representing healthy eating policy and environmental variables in the synthesized causal loop diagram is shown in Figure 2. This illustration is a balancing loop and may be interpreted as follows:

> Increased access to healthy foods and beverages provides more opportunities to purchase and consume these products. Healthier eating behaviors can help reduce rates of childhood obesity. Yet, with declines in rates of childhood obesity, this may also reduce the perceived need for childhood obesity advocacy initiatives. Thus, there is likely to be a subsequent decrease in political will to address this issue, resulting in fewer new or modified policies along these lines. As attention to childhood obesity may have stimulated policy discussions in related topics, such as reduced crime and violence to increase safe trips to local food vendors, these declines in political will may be met with increases in crime and violence. With more crime and violence, there is a corresponding decline in the local economy and funds that are designated to healthy eating and active living initiatives. With a declining economy and reductions in funding, neighborhood food stores may also have to shut down, as small businesses have a difficult time thriving in this climate. Therefore, this sequence may lead to a reduction in access to healthy foods and beverages.

In a balancing loop, the effect of changes in variables within the loop is to counteract or balance the direction of change. Rather than accelerating the direction of change (reinforcing loops), balancing loops tend to slow down the rate of change so that, in addition to counteracting the initial change, they also tend to push a system toward some stable goal. In Supplemental Digital Content Figure 1 (available at: http://links.lww.com/JPHMP/A147), this loop is disconnected visually (eg, the connection from childhood obesity to community and youth advocacy is not a direct connection). To improve the readability of the diagram and minimize the links from crossing over other links, these figures use "shadow" variables indicated by an open and closed bracket (eg, "<childhood obesity>").

What implications can be translated to various audiences?

In addition to the examples provided in Figures 1 and 2, many other feedback structures emerged from the HKHC communities' causal loop diagrams and several exemplary themes are presented in Table 4. Looking at the synthesized causal loop diagram (see Supplemental Digital Content Figure 1, available at: http://links.lww.com/JPHMP/A147), partnership and community capacity structural elements landed in a central position in the synthesized causal loop diagram, suggesting the critical role of these elements in fueling the change process in communities. Likewise, social determinants appear to have a cascading influence on all of the other subsystems and feedback structures in the diagram. The diagram also highlights several places where active living and healthy eating subsystems intersect (eg, automobile use with air, water, and soil quality with potable water; public transportation with access to healthy foods).

Along with the practical implications presented in Table 4, the HKHC communities' causal loop diagrams also suggested many questions for assessment and evaluation of this work (Table 5). In some communities, the GMB sessions helped build participants' skills and knowledge related to the various subsystems and their interactions and these may be transferred to other health topics or community conversations. Several community examples are included in this supplement.[23-26]

Discussion

The causal loop diagram ties together the behavior-over-time graphs, the participants' stories and dialogue, and feedback loops to understand the common

TABLE 4 ● System Insights Derived From Feedback Structures in HKHC Communities' Causal Loop Diagrams

Active living policies and environments

- Communities capitalize on local parks, trails, and recreation facilities as places to convene neighbors and community representatives to advocate for changes to support access to healthy eating and active living resources and services in the community; these are also good places to increase voter registration (eg, booths in the park or along the trail).
- Public recreation facilities increase the health of community members and beautify their neighborhoods.
- Integrating park design strategies and extracurricular programs reduces youth time in gangs or violent behaviors and increases outdoor activity and community safety.
- Improvements to parks, trails, and recreational facilities increases residents' perceptions of safety in the community, and these perceptions strongly influence parents' decisions to allow their kids to use the facilities for walking and bicycling.
- The identification of trails, gulches, and greenways as pathways supporting safe walking and bicycling commutes reduces residents' driving trips and the amount of time kids spend sedentary in vehicles.
- Parks and play spaces that facilitate both opportunities for physical activity and resident interaction and engagement support sustainability of the quality of these spaces by increasing collaboration of local partners that can generate resources to invest in these spaces.
- Over time, the loss of hours of physical activity per day has not yet reversed in response to efforts to add a few parks and trails to the area, so these efforts require greater focus and intensity to increase park and trail use.
- Increasing perceptions of urban safety plays a major role in maintaining urban density and increasing active transportation.
- Infrastructure for pedestrians and bicyclists increases the number of families being active together; sidewalks and bike lanes—along with traffic calming and other safety measures—create opportunities for families to choose active rather than sedentary transportation modes.
- Improvements to, and expansion of, public transit and bike infrastructure has a good return on investment by stimulating economic development and private investment in the local community.
- Designing a public transit system with more, shorter routes is desired, yet the shorter-term costs (eg, more buses) need to be considered alongside the longer-term costs and savings (eg, vehicle maintenance, increased ridership, gas prices).

Healthy eating policies and environments

- A strategic focus of the food policy council on increasing the number of and/or participation in community and school gardens or small farms has the added benefit of rallying community support for the council.
- Urban gardens and farms increase neighborhood revitalization and limit or reverse suburban sprawl, as residents feel less vulnerable to crime or violence in urban areas; by drawing residents back into more dense, urban neighborhoods, the gardens and farms minimize geographic isolation in suburban dwellings.
- Community gardens and urban agriculture designed to enhance youth and community engagement can focus on learning about native fruit and vegetables as well as agricultural practices of ancestors; this engagement also connects youth and community residents to other programs and services available in the community.
- Because increasing access to nonprocessed foods requires greater food preparation, partners must also build residents' skills and confidence in preparing healthy meals.
- Demand for increased food security and the availability of vacant lots for urban agriculture create the "perfect storm" for a local food production, distribution, and sales system to serve the local population.
- The dramatic decline in healthy food retailers alongside the dramatic increase in unhealthy food retailers may be, in part, attributable to discriminatory practices associated with increasing rates of obesity; efforts to eliminate these discriminatory practices may help increase access to fresh, healthy foods in marginalized communities.
- Lower-income areas continue to face a lack of access to healthy foods and beverages, and the entire community appears to have higher costs for healthy foods and beverages.
- With the percentage of calories from processed foods steadily increasing over time, farmers' markets provide opportunities to reduce residents' consumption of unhealthy foods and replace these calories with those from healthier foods; this, in turn, supports and potentially increases the vendors at the market.
- Farmers' markets have the benefit of increasing a sense of community.
- The slight increase in healthy corner stores may be bolstered by advocacy efforts to increase demand for healthy foods and beverages among residents.
- Greater numbers of healthy corner stores—as well as other healthy food vendors—can lead to a more competitive local market for healthy foods and beverages that may help drive down costs and increase access.
- Corner stores—similar to fast food restaurants—are perceived to increase access to unhealthy foods and beverages by people in the community; this presents an opportunity to increase the number of healthy corner stores to change residents' perceptions of these food vendors as providers of healthy food and beverage alternatives.

(*continues*)

TABLE 4 ● System Insights Derived From Feedback Structures in HKHC Communities' Causal Loop Diagrams (*Continued*)

- Unhealthy corner stores contribute to less community safety and to greater consumption of unhealthy foods and beverages; because these safety issues harm the financial stability of the community leading to fewer resources to support access to healthy foods, public safety officials may be good partners to create safer, healthier communities.
- With the low numbers of food vendors accepting SNAP benefits, strategies to engage residents in advocacy initiatives to demonstrate demand for these services in the community may push this agenda forward; at the same time, residents need to be made aware of the food vendors accepting WIC or SNAP benefits so that vendors view these services as a good investment of their time and effort.

Partnership and community capacity

- Higher rates of childhood obesity increase resident engagement and attention to this issue; as rates of obesity decline, it may be difficult to maintain these advocacy efforts in order to sustain improvements that have been made.
- Strategic partnerships to engage residents in advocacy initiatives stimulate support and funding from city government agencies.
- Parent knowledge and awareness is key to their engagement in efforts to increase healthy eating and active living and reduce childhood obesity; this knowledge and awareness increases their skills to interact with their children through cooking meals at home or engaging in physical activity.
- Incorporation of efforts to increase community knowledge and empowerment generates more community engagement to bolster advocacy efforts (eg, programmatic and promotional efforts to complement policy, system, and environmental changes can enhance overall advocacy).
- Nontraditional partners with expertise in community engagement and organizing enhance more traditional advocacy approaches targeting policy makers and decision makers.
- Financial resources for healthy eating and active living activities and organizations may disincentivize collaboration unless the funds are specifically designed to support partnerships.
- New collaborations forged with city agency representatives or community organization leaders generate more political will in various sectors of the community for those whose voices are not well represented.
- Creating opportunities to increase the cultural competency of agency and organizational staff (eg, training and technical assistance) and resources to support language justice (eg, translation and interpretation services) increases engagement of nontraditional partners, including those who do not speak English.
- Collecting, analyzing, and applying data to understand differences in subpopulations help communities to recognize and address community concerns, such as access to resources and fears of civic engagement.
- Strong social ties—in the family and in the community—developed in association with access to healthy foods and beverages instill trust and increase engagement in ways that promote greater advocacy to support healthy eating initiatives; maintenance of these connections between food and social relationships increases sustainability of healthy eating initiatives.
- Building civic networks among current transit users, pedestrians, and bicyclists to organize community and city council support through neighborhood associations improves policies for active transportation.
- By focusing on gardens and small farms, communities stimulate civic engagement and community organizing through neighborhood associations to increase support from the city council.
- The overall decline in knowledge of healthy foods suggests the timeliness of increasing personnel prepared to educate and increase awareness of the benefits of healthy eating and active living in the community.
- Building partnerships and relationships with developers who prioritize equity, sustainability, and practicality (eg, mixed-income housing, greater population density, mixed commercial and residential land uses) improves residents' stability, both geographically and economically.
- The inclusion of partners with funds or other in-kind resources (eg, volunteers, space, equipment) and a focus on funding sources that may be sustainable over time (eg, annual city budget allocation) improves the longevity of these initiatives over time.
- "Upstream" efforts to increase community and social engagement in order to draw the attention of policy—and decision makers to the importance of health-centered community design leads to increases in access to safe parks, trails, and outdoor facilities.
- Efforts to build political will—particularly support from policy makers—for improvements to transit and bike infrastructure benefit from economic data forecasting how short-term expenditures have substantive long-term financial gains for the city government and the community as a whole.
- Working with employers to engage employees stimulates community engagement, particularly for those who have little time outside of work to invest in these healthy eating and active living initiatives.
- With deeper roots in the community (eg, longevity, relationships), residents have more time and feel more confident voicing their concerns and opinions to civic leaders in order to improve or maintain healthy eating and active living assets in the community.

Social determinants of health

- Identifying community environments requiring immediate improvements to increase access to opportunities for physical activity and healthy eating is critical to support healthy behaviors for youth outside of school and afterschool programs.
- When equitable, sustainable developments demonstrate success in model communities, they can be translated into new or improved developments throughout the region.
- Neighborhood associations are difficult to organize in lower-income urban neighborhoods as well as sprawling suburban communities.

(*continues*)

TABLE 4 System Insights Derived From Feedback Structures in HKHC Communities' Causal Loop Diagrams (*Continued*)

Addressing community safety is a necessary step to support use of outdoor recreation facilities.
Strategies to increase resident civic engagement, particularly among new immigrants or other marginalized populations, is relatively unrepresented in the public sector in communities.
Communities can expand the reach of outdoor extracurricular activities to youth from poorer families to help break the cycle of poverty.
With moderate- to higher-income disparities in communities, public transportation is a fundamental service to increase access to jobs, particularly for those who may not be able to afford a car or gas prices.
Jobs are an essential ingredient to creating equity (reducing disparities and discrimination), safety, and a stable economy.
A stronger economy provides the resources necessary to create an efficient public transportation network that gets more people in the community walking and biking to and from public transit stops to their residential or other destinations.
Healthy eating and active living behaviors have influence on residents' economic viability, which, in turn, influences the overall economy of the community.
Health and health behaviors
With the increase in access to many different forms of technology, such as TVs, computers, video games, and interactive phones, it is necessary for parents to serve as role models, teaching their kids healthy and active behaviors rather than enabling sedentary behaviors.
Families spending more time together in physically active pursuits encourage more active lifestyles for children.
Students gain social benefits from interacting with other students, parents, school staff, or neighbors while walking and biking to school.
Teaching youth to prepare meals and snacks with fresh fruit and vegetables gives them opportunities to inform and educate their families and friends about the benefits of healthy eating in order to generate greater collaboration and support in the community.
Increasing rates of overweight, obesity, and diabetes reduces health and quality of life, including the ability to work and maintain a steady income; thus, addressing these health problems minimizes unemployment, poverty, and reliance on government assistance.

Abbreviations: HKHC, Healthy Kids, Healthy Communities; SNAP, Supplemental Nutrition Assistance Program; WIC, Special Supplemental Nutrition for Women, Infants, and Children.

behaviors of systems affecting health across communities and to stimulate greater conversation related to an HKHC theory of change, including places to intervene in the system and opportunities to reinforce what is working. This article only begins to uncover the many subsystems, feedback structures, and system insights from the HKHC GMB sessions.

Through causal loop diagrams, people can share mental models and enrich them. Causal maps assist in improving the process of thinking about the structure of a problem by having community members describe the feedback loops and associated effects as well as recognize more immediate versus delayed responses, self-reinforcing side effects, and possible sources of policy resistance, which are often ignored when they are not mapped in a causal diagram.

In comparing computer simulation versus causal mapping, Homer and Oliva[20] describe that the latter is useful for describing the possible causes and solutions for a problem situation. Causal loop diagrams are used not just to create simulation and quantified models but also to provide detailed system description and stand-alone policy analysis.[20] Coyle[27] reviews several examples of qualitative models and defines the role of such models in finding policy insights. For example, causal loop diagrams describe the complex problem in a limited space in contrast to narratives that take larger space.[27] Also, causal loop diagrams are helpful reminders to distinguish causal from associational relationships during discussions so that these conversations lead to the identification of feedback loops to explain behavior or insights.

Group model building is a powerful method because it actively involves a wide range of participants in modeling a complex system. Decision makers, community partners, and trained modelers each take part in causal loop diagram development. This process leads to deeper and shared insights among participants while they create the causal loop diagrams that are grounded in community experience. Because of the broad involvement in creating the causal loop diagrams, this process promotes "buy-in" to high-leverage prevention policy recommendations.

The causal loop diagrams complement each CP's work plan by mapping how the partnership's goals influence what is happening in the community and how the resources interact within the system. These diagrams can provide insight into the ways that changes in various strategies, policies, and activities are related and may synergistically impact the community. Furthermore, these diagrams represent data about the feedback structures within a community from the perspective of partners living and engaged in the community. Resulting diagrams can be used by community partners in several ways; for example, communicating prevention strategies and programs; revising or designing policy, system, and environmental strategies; and designing evaluation efforts.

TABLE 5 ● Assessment and Evaluation Questions Derived From Feedback Structures in HKHC Communities' Causal Loop Diagrams

Active living policies and environments
What factors can increase employers' and policy makers' attention to safe parks, trails, and outdoor facilities?
What are the optimal numbers and types of public recreation facilities for a neighborhood or urban area?
Who lives within a 1- or 2-mile radius of safe, quality parks and recreation facilities? Who does not?
How does community safety influence the use of public recreation facilities? What types of renovation or maintenance strategies help increase residents' perceptions of safety?
What characteristics of parks and play spaces promote unstructured, free play among youth and families?
What funds have collaborators successfully secured for parks and play spaces? How can these resources be sustained into the future?
What is the rate of sprawl in communities (ie, how many residents are moving from urban neighborhoods to suburban neighborhoods)?
How do residents' perceptions of safety influence their use of motorized vehicle for transportation?
What streets have accommodations for pedestrians, bicyclists, and drivers? Are they safe for all users? What is still needed (eg, traffic calming measures, more sidewalks and bike lanes)?
What is a "safe street" for kids? What policies, facilities, and amenities need to be in place for kids to walk or bike safely (eg, speed limits, bike lanes, street lighting, crosswalk treatments)?
What types of public transit and bike infrastructure are best suited to stimulating economic development and attracting private investment?
What are the public transportation access points, hours of service, reliability of service, route length and duration, etc? What is the cost of using public transportation?
What is the quantity and quality of public recreation facilities within a 1-mile radius of child care center and after-school programs?
Healthy eating policies and environments
What is the quantity and quality of food vendors within a 1-mile radius of child care center and after-school programs (eg, access to fruit and vegetables, access to junk foods)?
What is the optimal number of school or community gardens or farms for a neighborhood or urban area?
What is the potential for local food production, given the vacant urban lots available for agriculture? What development patterns will sustain the ability to meet these food production requirements into the future?
What are the factors that led to the substantial decrease in healthy food retailers and the complementary increase in unhealthy food retailers over the last 60-70 y? Does this vary by different subpopulations? Do any of these factors relate to discriminatory practices based on overweight and obesity?
What are the characteristics of a "healthy corner store" (eg, access to produce, limited access to unhealthy foods and beverages)?
Does an increase in the number of healthy food vendors increase competition in the local market that drives down the cost of healthy foods and beverages? If so, how?
What is the proportion of unhealthy food and beverage products to healthy food and beverage products sold by local food vendors (eg, farmers' markets, corner stores, grocery stores)? How do these products differ by cost, product placement within the stores, and marketing or signage in and around the stores?
Do sales of healthy foods and beverages increase with greater access to these products in the stores? Can the store owners profit from the sale of fresh fruit and vegetables and other healthy foods and beverages?
What factors lead to an increase in demand for healthy foods and beverages in communities?
What are the attributes of unhealthy corner stores that contribute to less community safety?
How many food vendors (eg, grocery stores, farmers' markets, corner stores) have EBT machines and accept SNAP benefits? Accept WIC vouchers? What is the average distance residents have to travel in order to purchase foods and beverages using SNAP benefits or WIC vouchers?
Partnership and community capacity
What types of partnerships increase resident engagement and participation in advocacy?
How does social engagement increase sense of community and, in turn, sense of identify? What are the key ingredients to a successful approach?
What drives community collaboration when funding support is not available?
What are successful funding structures to incentivize partnership and collaboration?
What are the ways that residents can interact with civic leaders to influence policy and environmental changes?
What are some ways to assess empowerment in the community generally and specifically with respect to policy and environmental changes to support healthy eating and active living?
What is the influence of an increasing number of advocacy initiatives in the community on community knowledge and empowerment?
How does awareness and civic engagement related to healthy eating, active living, and childhood obesity differ according to various subpopulations in communities?
What indicators of political will have led to successes in drawing local media attention to healthy eating, active living, and childhood obesity in communities?
Social determinants of health
Does poverty and reliance on governmental assistance limit social engagement among residents in communities? If so, how?

(*continues*)

TABLE 5 ● Assessment and Evaluation Questions Derived From Feedback Structures in HKHC Communities' Causal Loop Diagrams (*Continued*)

What are the primary drivers of the relatively high-income disparities in the community? What subpopulations tend to have lower incomes and what subpopulations tend to have higher incomes? What jobs, if any, are accessible to these different populations?
What factors influence neighborhood safety (eg, rates of crime, violent actions)? Are these the same factors that influence perceptions of neighborhood safety? What are the actual rates of crime and violence as compared with perceptions?
What strategies have been effective in engaging parents to spend more time with their children? How much of this time is physically active vs sedentary?
How do schools and child care agencies make decisions about curricula dedicated to academics as compared with physical education, active recess, or other nonacademic pursuits?
What is the proportion of the population that is food insecure? How many residents are WIC or SNAP recipients? How much produce is required to meet the demands of this population?
Health and health behaviors
What are unintended benefits of families being active together (eg, improvements in family dynamics and relationships, children learning to better navigate their environments)?
What public recreation facilities are used by what groups in the community (eg, children, adolescents, people in poverty)? Are surrounding residents more or less active?
What are the appropriate types and numbers of extracurricular programs to support increased outdoor activity among children and adolescents?
Are residents who use parks and recreation facilities more likely to be civically engaged in the community? If so, how does this work? What are the facilitators and barriers?
What types of trips are made by car, bike, and foot in communities? Who is using the current active transportation infrastructure and who is not (eg, adults, children)?
What are the reasons residents do or do not use public transportation in the community?
What healthy foods and beverages are most likely to purchased and consumed in communities? Does this vary by subpopulation?
What are the connections between food and social relationships (eg, eating meals together)? What facilitates these connections? What gets in the way of these connections?
Does participation in gardens or farms predict social outcomes (eg, perceptions of neighborhood safety, civic engagement)?
What is the impact of greater consumption of unhealthy, processed foods on students' academic and testing performance?
How does poorer health status affect poverty and reliance on government assistance?

Abbreviations: EBT, electronic benefits transfer; HKHC, Healthy Kids, Healthy Communities; SNAP, Supplemental Nutrition Assistance Program; WIC, Special Supplemental Nutrition for Women, Infants, and Children.

Limitations

An example of the limitations of qualitative models and their use in finding policy insights is the obesity system map published by the Foresight Program of the UK Government Office for Science.[28] This model was developed through engagement of various stakeholders, including scientists, private sector parties, and government departments. The qualitative model has 108 variables and more than 300 causal links. Finegood et al[28] described this map as a useful tool to convey the complexity of the obesity challenge to the field; yet, the complexity of the map may lead to perceptions that it is not feasible to tackle this problem. Causal maps often display dense information that makes it difficult to comprehend the details. In essence, these models may be useful for describing the complexity as opposed to discovering further system insights. This was a major challenge to synthesizing all 50 HKHC causal loop diagrams.

In addition, GMB draws on knowledge and skills from system dynamics and systems thinking. This requires some introductory training in systems thinking or system dynamics that includes the use of behavior-over-time graphs and causal loop diagrams, identifying feedback loops, and distinguishing reinforcing and balancing feedback loops. In system dynamics, the goal is to identify and understand the system feedback loops, or the cause-effect relationships that form a circuit where the effects "feed back" to influence the causes. There are many different feedback loops interacting simultaneously to influence or to be influenced by each of the variables. Some variables may strengthen or increase values for variables they influence, whereas other variables may limit or decrease these variables. However, causal loop diagrams cannot be used for dynamic behavior inference but only for describing structure.[29] Determining the feedback loop or loops that dominate the system's behavior at any given time and validating the dynamic hypothesis are more challenging problems and, ultimately, require the use of computer simulations.

The application of systems thinking tools combined with GMB techniques creates opportunities to define

and characterize complex systems, with multiple interfacing subsystems (eg, healthy eating, active living, social determinants), in a manner that draws on the authentic voice of residents and community partners. Benefits at the community level include the development of a shared language and a common understanding of the system across various disciplines and sectors as well as the identification key leverage points in the system for intervention. For the field, insights derived from a synthesis of findings across communities may highlight community assets and resources that yield the greatest return on investment as well as root causes of poor health outcomes, disparities, and inequities perpetuating resistance to interventions. While these conversations and methods are highly complex, they are also necessary to move toward positive systems change.

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