

Influence of School Architecture and Design on Healthy Eating: A Review of the Evidence

We examined evidence regarding the influence of school physical environment on healthy-eating outcomes. We applied a systems perspective to examine multiple disciplines' theoretical frameworks and used a mixed-methods systematic narrative review method, considering both qualitative and quantitative sources (published through March 2014) for inclusion.

We developed a causal loop diagram from 102 sources identified. We found evidence of the influence of many aspects of a school's physical environment on healthy-eating outcomes. The causal loop diagram highlights multilevel and interrelated factors and elucidates the specific roles of design and architecture in encouraging healthy eating within schools.

Our review highlighted the gaps in current evidence and identified areas of research needed to refine and expand school architecture and design strategies for addressing healthy eating. (*Am J Public Health*. Published online ahead of print February 25, 2015; e1–e12. doi: 10.2105/AJPH.2014.302453)

Leah Frerichs, PhD, Jeri Brittin, MM, Dina Sorensen, MArch, Matthew J. Trowbridge, MD, MPH, Amy L. Yaroch, PhD, Mohammad Siahpush, PhD, Melissa Tibbits, PhD, and Terry T.-K. Huang, PhD, MPH, CPH

CHILDREN'S AND ADOLESCENTS'

diets have deteriorated in nutritional quality over the past 3 decades, contributing to increased rates of childhood obesity.^{1,2} The proportion of children's total energy intake from sugar-sweetened beverages has doubled, and their fruit and vegetable consumption has significantly decreased.^{3,4} Schools have substantial opportunities to address healthy eating because of their role in education and socialization and because they are a major source of food access, contributing up to 50% of many students' daily energy intake.⁵ However, in isolation, school-based nutrition education has not been proven to be consistently effective. This knowledge has driven interest and investment in development of new intervention strategies, including multifaceted approaches to creating school environments conducive to healthy eating.^{6,7}

An emerging area of investigation is the role of a school facility's physical design (e.g., siting, architecture, landscape features) as a mediator of healthy-eating behaviors and attitudes among children.⁷ Recently, interdisciplinary teams have begun to consider the potential of whole-building design to integrate multiple objectives throughout an entire built project to achieve optimum performance.⁸ In a similar fashion, Huang et al. used a systems-based approach and translated theory, research, and practice-based evidence into the Healthy Eating Design Guidelines (HEDGs) for School

Architecture. (A description of the collaborative process and items included in the initial version of the HEDGs was published previously.⁹) The HEDGs describe 10 spatial domains, each with a design-oriented objective and corresponding physical environment strategies (Table 1). These strategies incorporate a systems perspective, taking into account the interactions between spaces throughout the whole school building and its occupants as a system to facilitate and encourage healthy-eating practices and behaviors.

THEORETICAL FRAMEWORKS RELEVANT TO THE HEDGs

The HEDG systems-based approach requires understanding theories and frameworks from multiple disciplines and across individual, social, organizational, and community levels (Figure 1). The HEDG domains and strategies use these theories and frameworks to consider the transactions that occur between the environment and individual or group behavior across these levels. Thus, the physical environment can influence healthy eating through multiple pathways.

Behavioral economics and salutogenesis provide a basis to understand physical environment influences at the individual level. Many strategies from the HEDG domains (e.g., serving, educational signage and water access and vending machine) draw on

research in behavioral economics. This research has found that for most individuals, food consumption decisions are low in cognitive involvement and are shaped by environmental cues that range from the room, the furniture, and the container to the food itself.¹⁰ Visual cues (e.g., the way food is served, organized, and arranged) influence choices and consumption by shaping accessibility, reflecting social norms, and increasing salience of healthy-eating choices.^{10,11} The theory of salutogenesis guides many of the HEDG dining and aesthetics domain strategies. Salutogenesis asserts that an individual's motivation to engage in health-promoting (as opposed to risky) behaviors can be positively or negatively affected by internal and external stimuli; this perspective furthers understanding of physical environment influences on eating behavior.¹² Limited research has explored this theory in relation to children's dietary behaviors; however, commercial marketing practices that use aesthetics (e.g., color, sounds, spatial layout) to entice customers underscore its potential.¹³

HEDG strategies also use social cognitive theory and proxemics to understand physical environment influences at the interpersonal level. Interventions that rely on social cognitive theory use techniques, such as observational and experiential learning, that involve social interaction with and within physical spaces featured in several HEDG domains (e.g., teaching kitchen, on-site food

TABLE 1—Healthy Eating Design Guideline Domains, Objectives, and Design Strategies

Domain	Objective	Sample Strategies
Commercial kitchen	Design an open commercial kitchen to facilitate the procurement, preparation, and storage of fresh, organic, whole foods that are prepared in a manner to preserve nutritional value.	Provide kitchen equipment such as ovens, tilt skillets, and steamers that allow for a variety of cooking methods for fresh foods.
Teaching kitchen	Design complementary hands-on teaching kitchen areas for students and extracurricular organization use.	Provide sufficient counter or work space for processing of fresh foods. Provide areas conducive to teaching, presentation, and demonstration cooking. Create teaching kitchen as a hands-on learning environment with equipment that is safe and accessible to children.
Serving	Design cafeteria to function efficiently to maximize dining time for students, while effectively encouraging the selection and enjoyment of healthy foods and beverages.	Provide space for healthy grab-and-go meal options in the snack or express line. Provide space for multiple healthy choices in each food category (celery and carrots). Position salad bars away from walls for 360° circulation.
Dining	Reconceive dining areas as places of enjoyment and relaxation, configured to fully support healthy food initiatives.	Design dining areas to recognized national standard for seating capacity, to avoid overcrowding. Create a variety of seating options and social arrangements, recognizing that not all students will be comfortable in a given configuration.
Aesthetics of healthy food environments	Design spaces to provide a relaxing atmosphere conducive to the enjoyment of food and social interaction.	Incorporate appealing colors and lighting. Feature fresh, preserved, or prepared food in public spaces.
Educational signage, wayfinding, and marketing	Deploy graphic design and signage elements throughout the school environment to reinforce the healthy-eating message.	Provide educational (nutritional) information on food choices. Highlight information on seasonal fresh foods incorporated into the school food program. Locate educational signage so that it is visible from the “point of choice” in the server zone.
Water access and vending machines	Support healthy eating through design and policy strategies focused on the school physical environment that facilitate access to drinking water and discourage unhealthy food and drink choices from vending machines.	Provide ready access to potable water and cups in dining areas. Replace vending machine content with healthy food and beverage options.
On-site food production	Provide spaces for on-site food cultivation and production, coordinated with curricular and extracurricular activities.	Create a school garden. Include on-site food production resources (e.g., garden, greenhouse) in construction documents for building facility, where possible.
Integrated healthy food education facilities	Identify and provide programming opportunities to extend healthy food messaging throughout the school.	Provide a school wellness center readily accessible to all students, designed to support nutritional counseling and integrated with related school functions such as the health educator or school nurse. Design food spaces to support curricular and extracurricular activities and community education.
Integrated healthy food community	Support healthy eating and local food production in the community.	Design food spaces for flexibility and multiple uses by the school, school affiliates, and community groups. Provide community garden space for local use.

Source. Adapted from Huang et al.⁹

production).¹⁴ These strategies seek to affect dietary behavior by improving constructs such as healthy-eating social norms and self-efficacy. Like social cognitive theory, theories of proxemics and environmental psychology draw on interrelationships between social behavior and space and consider how individuals actively

perceive, construct meanings, and use space through social interactions.^{7,15,16} These theories have not been applied to healthy-eating interventions, but they have been used in the physical design of school buildings. The transactional nature between physical and social environments became clear during the 1970s when

new school designs featured open-space planning that necessitated divergence from traditional teaching styles.^{17–19} Changes to classroom features have been shown to alter both teaching methods and student learning behaviors; for example, reading nooks affect children’s reading behaviors.²⁰

HEDG strategies also draw on frameworks that recognize the transactions between the physical environment and organizational-level constructs such as social structures, hierarchies, and behavioral patterns.^{21–25} Architecture has been shown to stabilize and give durability to these constructs by creating visual cues

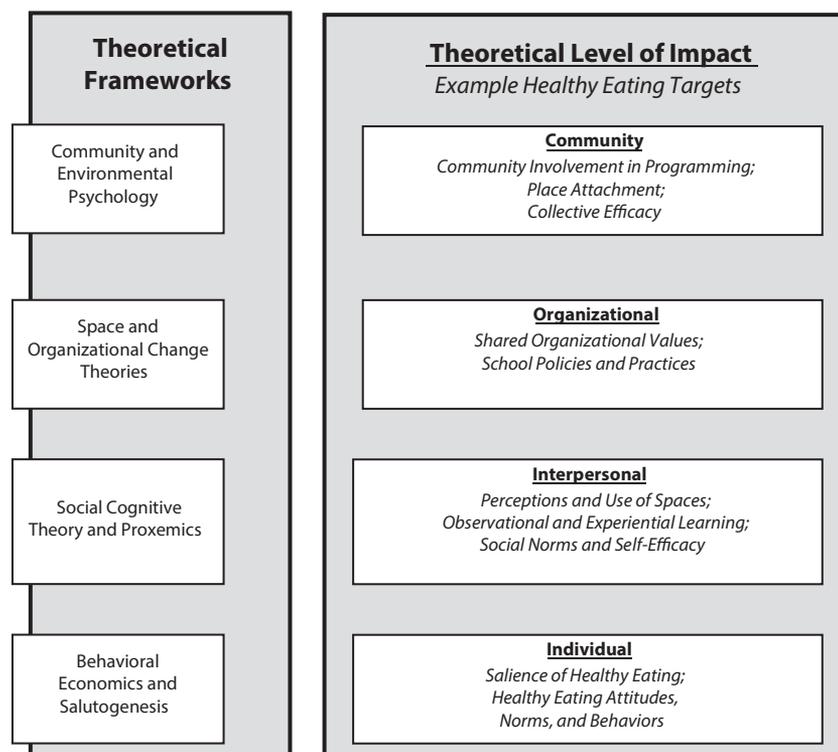


FIGURE 1—Major theoretical frameworks for school physical environment influences on healthy eating, their respective levels of impact (building from individual- to community-level impacts from bottom to top), and corresponding examples of healthy eating targets.

that symbolize shared values.²³ Some school-based healthy-eating interventions have focused on changing policy and social structures,^{26–28} but few have considered the physical environment’s influence on organizational-level outcomes.

Diffusion of innovations provides a useful framework to clarify the potential mechanisms and pathways of physical environment influence at the organizational level.²⁹ This theory has been applied in school settings to understand how characteristics of interventions (e.g., relative advantage, compatibility, complexity, amenability to testing, and observability) influence adoption and implementation of health promotion

interventions.^{30,31} The physical design of school spaces can influence characteristics of healthy-eating programming and practices. For example, in the commercial kitchen domain, the HEDGs provide strategies for the school’s food production facilities that can reduce the complexity of preparing meals that include fresh fruits and vegetables. In addition, strategies pertaining to several HEDG domains (e.g., integrated healthy food education, teaching kitchen) prompt inclusion of distinct spaces to address healthy-eating education and recommend colocation to create visibility and connection to social interaction spaces (e.g., cafeteria). These spaces and their colocation increase observability

of healthy eating, thereby strengthening visual cues of healthy eating as a shared organizational value.

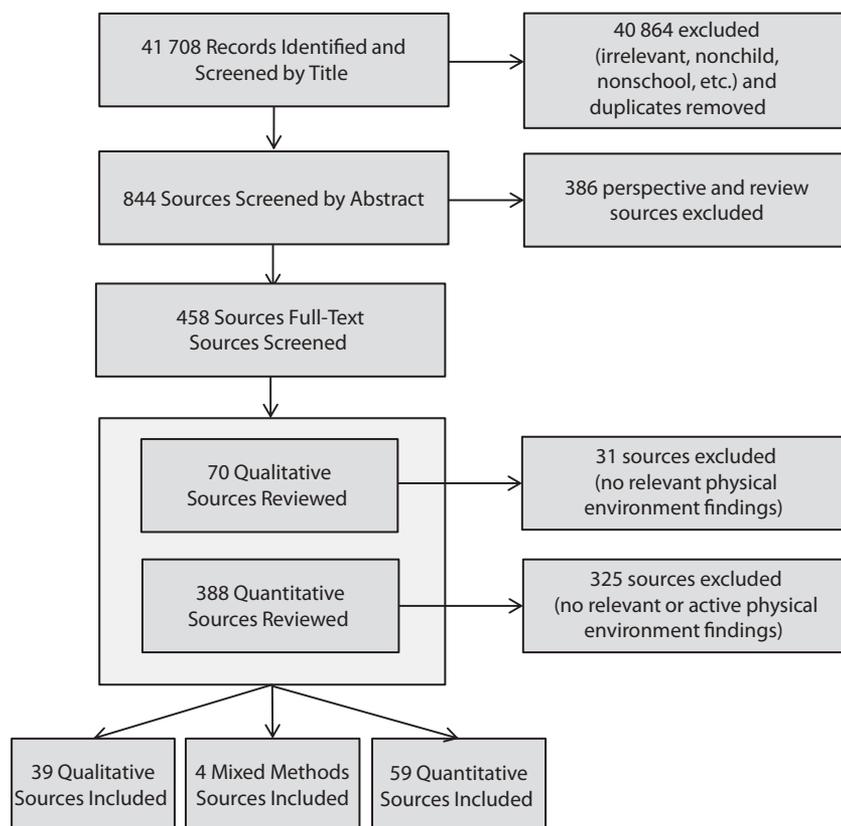
Finally, HEDG strategies related to the integrated healthy food community and other domains are also guided by environmental and community psychology research. This field assesses how the physical environment contributes to community-level outcomes, exploring relationships with individual and social behaviors, attitudes, and perceptions of place.^{32–34} Research has found associations between individual social and emotional attachment to physical neighborhoods, subjective and objective neighborhood physical

conditions, and health.^{35–39} Furthermore, place-based initiatives that foster social interaction, such as community gardens, have been found to increase the meaning of and attachment to such spaces, shape social norms, and increase collective efficacy.^{39,40} The importance of community outreach and engagement in school-based interventions that address healthy eating is well recognized,⁴¹ but school-based research has not considered the influence of school design and space on these outcomes.

Evidence relevant to the HEDGs and ongoing efforts to accelerate translation of evidence from environmental design and childhood obesity prevention research into real-world use have not been comprehensively consolidated. We aimed to synthesize literature regarding architecture in school settings through a systems lens to frame research findings in a school’s socioenvironmental context. We reviewed scientific literature to describe the extent of formative and outcomes evidence relevant to understanding the HEDG strategies’ potential to influence healthy eating. We also created a causal loop diagram, guided by the literature, to visualize interrelationships among constructs from the theoretical frameworks.

METHODS

We conducted a comprehensive literature search (through March 2014) in the following databases: PubMed/Medline, CINAHL, Avery Index to Architectural Periodicals, psychINFO, and Educational Administration Abstracts. We used Medical Subject Headings (MeSH) search codes where possible, with the following terms: (Schools[mesh] OR school*) AND



Note. Top left box indicates the total number of records found, which were reduced through a series of exclusion processes to the 102 final sources reviewed.

FIGURE 2—Source inclusion process for literature review of influence of school physical environment on healthy eating.

(“facility design and construction” [mesh] OR “environment design” [mesh] OR “city planning” [mesh] OR architecture OR environment OR “school design” OR “building design” OR “built environment” OR “cafeteria design” OR “canteen design”) AND (diet [mesh] OR obesity/prevention and control [mesh] OR “health promotion” [mesh] OR “Child Nutrition Sciences” [mesh] OR “Nutrition Policy” [mesh] OR “healthy eating”). For databases that did not use MeSH, we used a similar key word structure.

Inclusion Criteria

We used a mixed-methods systematic narrative review

method and considered both qualitative and quantitative sources for inclusion.⁴² We defined qualitative studies as research contributing to process or formative knowledge through methods such as focus groups and interviews.⁴³ We defined quantitative studies as research contributing to knowledge regarding associations and impact that used cross-sectional, longitudinal, quasi-experimental, or experimental study designs.⁴³ We included studies of children in kindergarten through 12th grade. We excluded studies outside the school setting, as well as those in preschool and university settings.

We reviewed multicomponent school-based interventions but included them in our findings only if process or outcome evidence revealed that a physical environment component specifically contributed to intervention impact. We identified 102 sources for inclusion in our review (Figure 2).

We reviewed each source to identify the type of study, setting, population, frameworks or theories applied, and key findings. We used an iterative and translational process to operationalize and map the research studies to HEDG spatial domains (Table 1). This process required reconceptualizing

a study’s theoretical frameworks and findings to determine their applicability to designing a school at a practical level (i.e., the HEDG spatial domains).⁹ Thus, studies did not always explicitly indicate a spatial element but might implicitly provide evidence of design strategies (e.g., studies related to dietary associations with accessibility of a la carte food items indicated the relevance of designing food service spaces to optimize healthy food selection). One author (L. F.) reviewed qualitative sources and identified findings relevant to physical environment influences. We identified themes among relevant findings across multiple qualitative sources and notable findings from single sources, which we conceptually mapped to the HEDG domains.

Causal Loop Diagramming

Environmental approaches generally conceptualize subdomains of influence: physical, policy, social, and cultural. These domains, however, are not mutually exclusive. Successful translation of available evidence into practice (e.g., the design of a new or renovated school to help support healthy eating) must consider these factors holistically. Strategies that target 1 dimension must consider the potential influence for addressing healthy eating in the context of the larger school system. For example, the US Department of Agriculture had to scale back school nutrition policy changes introduced in 2012 after schools reported challenges to implementing them, such as increased food waste and outdated kitchen facilities.⁴⁴

Interrelationships among environments, behavior, and health outcomes are recognized across multiple theories. For example,

social cognitive theory's concept of reciprocal determinism suggests that mutual influence exists between behavior, personal factors, and environment,¹⁴ and research from the field of proxemics has supported the notion that social behaviors are influenced by perceptions and use of the physical environment.¹⁵ Although these theories indicate that relationships exist, none provide the tools needed to describe entire systems. A systems approach is needed to understand the complex interactions among individual factors, behavior, and socioenvironmental influences.⁴⁵ Systems-thinking tools and techniques can help bridge multiple theories and improve understanding of interconnections and feedback loops among factors across levels of influence, including social, physical, and organizational context.^{46,47}

Therefore, we determined constructs from identified theories, frameworks, and HEDG domains and the connections among them. We used this information to create a causal loop diagram—a graphical and visual notation for representing system structures that are difficult to describe with linear methods, cause-and-effect chains, and textual descriptions.⁴⁸ Causal loop diagrams illustrate elements within a system and use arrows to establish causal links between them. The direction of the links is identified with positive and negative signs according to the respective relationships, and closed sequences of causes and effects among elements are identified as balancing or reinforcing feedback loops.

RESULTS

We located 39 sources that contributed to the qualitative findings,^{49–87} 59 that contributed to quantitative findings,^{88–146} and

4 that used mixed methods and contributed to both.^{147–150} We identified 19 themes or notable findings from qualitative sources across all domains (Table A, available as a supplement to the online version of this article at <http://www.ajph.org>). Quantitative studies and their key findings are summarized by domain in Table B (available as a supplement to the online version of this article at <http://www.ajph.org>). The majority of studies were from the United States (n = 71) and Europe (n = 17). Australia (n = 7), Canada (n = 6), Taiwan (n = 1), Costa Rica (n = 1), and South Africa (n = 1) were also represented. One study included 18 middle-income countries (e.g., Brazil, China, Mexico). Quantitative studies were conducted with elementary students (n = 25), middle school students (n = 13), high school students (n = 4), or a combination of students across grades (n = 20). School staff participated in 25 qualitative studies, parents in 8, and children in 15.

Findings by Domain

Serving and water access and vending machine domains. These domains had the largest bodies of evidence (31 pertained to serving and 23 to water access and vending machines). Relevant to the serving domain, qualitative studies found that youths and school staff reported short school meal times and long cafeteria service lines (n = 5)^{49,68–71} and easy access and appeal of unhealthy snacks and competitive foods (n = 7) as negatively affecting food choices.^{49,57,69,70,72–74} Two studies from Europe found that youths and teachers perceived that both limited access to and poor quality of water in the school reduced intake.^{80,148} In qualitative studies, school staff, parents,

and youths reported that the presence of less healthful food and drinks in vending machines influenced their choices (n = 3),^{49,57,70} or they suggested removing vending machines or offering more healthful items to improve healthy-eating choices (n = 4).^{64,73,76,78}

Findings were mixed among cross-sectional studies (n = 7) that assessed associations between dietary behaviors or patterns (e.g., sugar-sweetened beverage consumption, fruit and vegetable intake) and food availability via the cafeteria a la carte line (serving domain), vending machines (water access and vending machine domain), or both. With regard to food availability in vending machines, 3 of 7 studies observed associations between increased access to less healthful items and poorer dietary behaviors.^{97,120,128} However, 1 study found that elementary students in schools with vending machines that offered more healthful items had significantly higher intake of nutrient-poor foods.⁹⁹

With regard to a la carte food availability, findings of 2 of 4 studies supported associations between food access and behaviors, both among middle school students. One study found that increased access to more healthful a la carte line items was associated with decreased consumption of sugar-sweetened beverages.⁹⁹ The other study found that increased availability of less healthful items was associated with decreased intake of fruit.⁹⁷

We found evidence regarding the water access and vending machines domain in 9 longitudinal, quasi-experimental, or experimental studies. Four of these studies assessed interventions that increased availability of healthful items and reduced availability of

less healthful items in vending machines. One found significant improvements in uptake of targeted items, measured by sales¹³²; in another, participants self-reported significant improvements.¹³¹ The other 5 studies implemented strategies to improve accessibility of water; 4 found significant improvements in water consumption measured either via self-report (n = 2)^{124,126} or observations of volume used or served (n = 2).^{127,148} Sugar-sweetened beverage consumption did not significantly decrease among the 3 studies that measured and reported this outcome, however.^{124,125,148}

We found 16 studies that addressed the serving domain with a longitudinal, quasi-experimental, or experimental design that evaluated the influence of altering the accessibility of both healthful and less healthful items (e.g., adding a salad bar, introducing a healthy convenience line) on student dietary behaviors. Of these studies, 7 of 8 that used plate waste analysis,^{104,106,107,109,110,115,118} 3 of 5 that used sales data,^{112,116,117} and 1 of 2 that used self-reported measures^{101,114} found that increased accessibility of healthful items or decreased accessibility of less healthful items improved dietary behaviors. One study collected both sales and self-reported data and found significant improvements in sales of healthier items, but no significant improvements in self-reported consumption.¹¹⁷

On-site food production domain. A total of 21 studies (6 qualitative, 14 quantitative, and 1 mixed methods) were relevant to this domain; all assessed school garden programs in the United States, Australia, or the United Kingdom. Of these studies, 6 of 11 that reported dietary behavior

outcomes^{133,137–139,141,145} and 9 of 10 that reported dietary-related psychosocial outcomes (e.g., willingness to try or preferences for vegetables)^{135–138,140,142,143,145,149} found significant improvements.

Qualitative studies found that school staff and youths believed that the benefits of garden programs extended beyond healthy-eating outcomes (e.g., improving social skills; $n = 4$)^{81–83,149} and that integration with other academic subjects was feasible ($n = 4$).^{83–86} On the other hand, 4 studies also discovered significant barriers to school gardening programs in the intensive time and resource requirements for ongoing maintenance.^{83–86}

School teaching kitchens domain. Evidence from 5 qualitative and 9 quantitative studies pertained to this domain. In the qualitative studies, youth participants in nutrition-related cooking education programs or the programs' teachers expressed satisfaction with the programs in general (e.g., viewing them as fun and engaging).^{63–67} Two qualitative studies also found evidence that health-focused cooking activities were feasibly integrated with other academic topics.^{66,67}

Seven quantitative studies assessed the impact of cooking education programs on dietary behaviors; 5 found significant increases in the consumption of targeted items such as vegetables (2 studies directly tied curricula to changes in the school cafeteria).^{89–91,95,96} Six of these studies also reported dietary-related psychosocial outcomes (e.g., improved fruit and vegetable preferences, cooking self-efficacy); all had significant findings.^{89–94}

Educational signage, wayfinding, and marketing domain. We identified 8 qualitative and 7 quantitative studies relevant to this domain.

School staff, parents, and students participating in the qualitative studies identified healthy food marketing and food labeling as acceptable strategies to address healthy eating in schools ($n = 6$),^{73,74,76–79} and students in 1 study indicated that advertising in the school triggered the purchase of unhealthy foods.⁶³ School cafeteria staff in 1 qualitative study reported that labeling strategies were easy to implement, but they did not perceive that food labeling influenced student choices.¹⁴⁷

Two quantitative studies assessed the impact of school cafeteria labeling strategies on student food choice and consumption. One of these studies labeled vegetables with attractive names and found significant improvements in their selection and consumption.¹²³ The other study labeled items with a traffic light system and found that servings of items with moderate nutritional quality increased but that servings of items with the lowest and highest nutritional quality did not change.¹⁴⁷ A cross-sectional study found that branded snack logos were significantly associated with increased intake of candy and salty snacks, but sugar-sweetened beverage logos had only a marginally significant association with intake of these beverages.¹²⁰

Three studies evaluated communication campaigns that included substantial print materials. One study targeted low-fat milk consumption and found that students increased selection without increasing waste.¹²² The other 2 studies had mixed results. A cross-sectional study assessed associations between self-reported exposure to school communication campaigns and change in dietary behaviors across 21 middle schools. Increased exposure to some, but not all, campaign

messages was associated with dietary changes (e.g., exposure to “water rather than added-sugar beverages” messages was associated with significant improvement in dietary behaviors, but exposure to “high-quality rather than low-quality food” messages was not).¹¹⁹ An intervention with a sizable social marketing campaign to promote healthy a la carte food choices slightly increased sales of promoted items in the first year of implementation but not in the second.¹²¹

Integrated healthy food community and dining domains. No studies provided design-specific evidence related to the integrated healthy food community domain, and we found only 1 qualitative study relevant to the dining domain, an ethnographic study of 11 primary schools in the United Kingdom. That study indicated that overcrowding in the cafeteria contributed to students' negative social experiences.⁷⁵

Aesthetics of healthy food environments and integrated healthy food education facilities domains. Two qualitative studies reported that parents and school staff suggested improving the aesthetics of dining facilities (e.g., adding murals) to improve dietary behaviors.^{70,76} Another study found that students rated cafeteria aesthetics poorly but did not feel that this affected their eating choices.⁷¹

A cross-sectional study found a significant positive association between self-reported use of school-based health centers and dietary quality.¹⁴⁶ A school-based intervention implemented a family diabetes program that included cooking preparation and demonstration; parents' self-reported consumption of fruits or vegetables improved, but children's and parents' weight did not.¹⁵⁰ Two

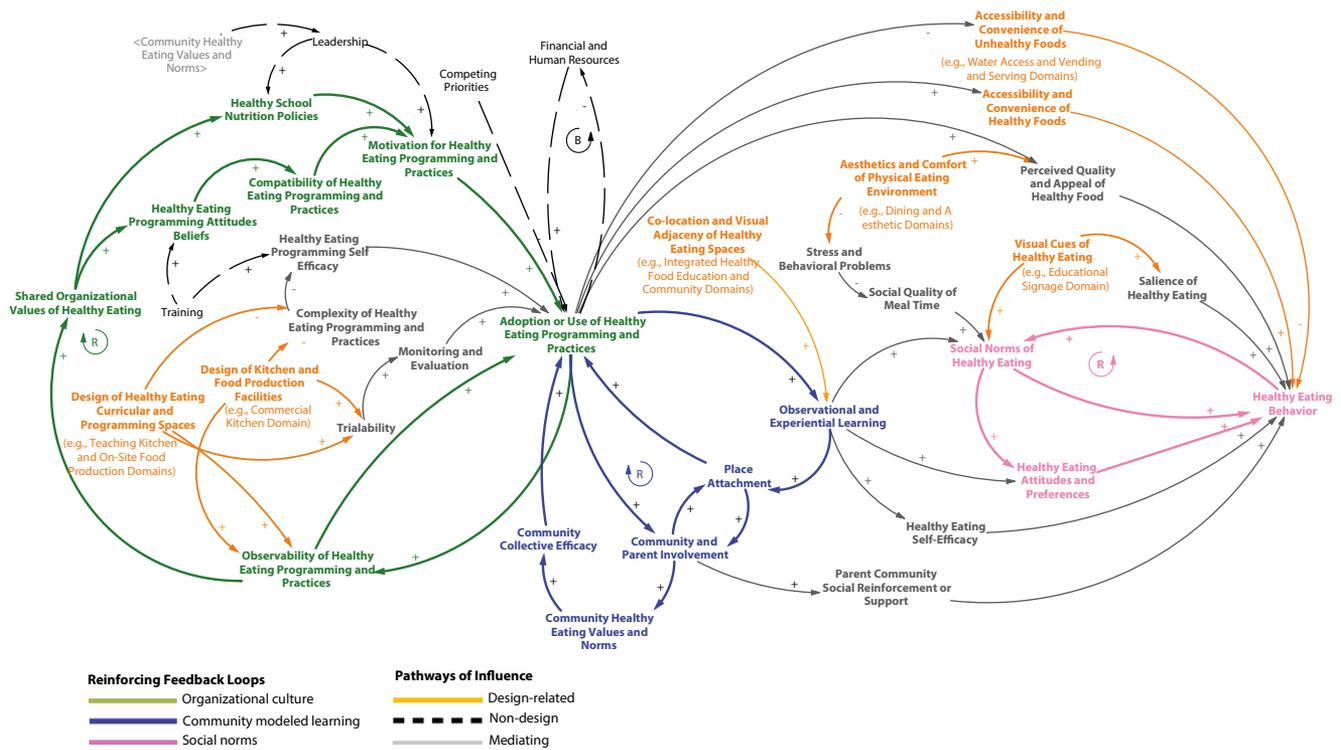
qualitative studies indicated that parents were favorable toward school programs that involved them in cooking preparation activities with their children.^{87,150}

Commercial kitchen domain. We found zero quantitative and 14 qualitative studies relevant to this domain.^{49–62} Each of these studies reported that a lack of appropriate kitchen facilities and equipment hindered schools' ability to provide meals with high nutritional quality and appeal. For example, a recent nationally representative survey of US food services directors found that 88% of respondents needed 1 or more pieces of new equipment to help them meet the recently updated Department of Agriculture dietary guidelines for school meals.⁵²

Causal Loop Diagram

The HEDGs and reviewed studies draw upon theories from multiple disciplines and across ecological levels. Causal loop diagramming provides a visualization of the multiple and interacting pathways influencing healthy eating in the socioenvironmental context of the school (i.e., a school's complex system for addressing healthy eating; Figure 3). This visualization elucidates feedback loops that can either reinforce or diminish changes in the system and variables that can either trigger or block these feedback loops.

A school's complex system for addressing healthy eating comprises reinforcing feedback loops that involve 3 spheres of influence: (1) organizational culture, (2) community-modeled learning, and (3) social norms (respectively indicated in green, blue, and pink in Figure 3). Organizational culture consists of mutual reinforcement between the observability of and the use of healthy-eating



Note. Items and arrows in orange show design-related influences. The 3 reinforcing loops (letter “R” circled by looping arrows) represent organizational culture (green), community-modeled learning (blue), and social norms (pink). A plus sign is used to signify that a change in one variable causes the second variable to change in the same direction, a negative sign is used to signify that a change in one variable causes the second variable to change in the opposite direction. The letter “B” circled by a looping arrow indicates a balancing loop.

FIGURE 3—Causal loop diagram of a school's complex system for addressing healthy eating.

programming, and observability is additionally connected to shared organizational values that subsequently shape motivation and implementation of healthy-eating programming and practices. Community-modeled learning comprises several feedback loops, which indicate the potential for healthy-eating programming and use of observational and experiential learning techniques to improve place attachment and parent and community outreach. Improvements to place attachment and community outreach could shape positive healthy-eating–related community values and collective efficacy that in turn improve school use of healthy-eating programming. Finally, social norms, eating behavior, and attitudes and

preferences positively reinforce each other. HEDG domains and strategies influence healthy eating through multiple paths (indicated in orange in Figure 3). Strategies associated with several HEDG domains (e.g., integrated healthy food education and community facilities) address the colocation and visual proximity of healthy-eating spaces and features, which can influence observational learning. Domains such as serving and educational signage are associated with many physical environment strategies with direct or proximal influence on children's healthy-eating behaviors (i.e., visual cues, aesthetics, and accessibility of healthy and unhealthy foods) and potential triggers of the social norms–reinforcing loop.

Implementing changes to these physical features demands relatively few resources and little effort for the school (e.g., moving a vending machine). However, factors such as lack of parental and community support for healthy eating may diminish the impact of such changes. By contrast, HEDG domains such as the teaching kitchen and on-site food production do not directly influence children's healthy-eating behaviors, but may be involved in diffusion of innovation concepts to influence adoption and use of healthy-eating programming and practices. Implementing and maintaining changes to these physical features (e.g., establishing a school garden) involve relatively greater resources and effort from schools.

These features, though, are triggers of organizational culture and community-modeled learning reinforcing loops with significant potential to facilitate and improve school adoption and use of healthy-eating programming and practices long term. It is important to consider factors such as financial and human resources, competing priorities, and leadership because they may diminish impact.

DISCUSSION

We found evidence that a range of physical factors contribute to creating supportive healthy-eating school environments. Our results supported strategies associated with 9 of the 10 HEDG spatial domains and offered no evidence

of negative effects. The extent of evidence varied, and we found strengths and weaknesses related to each domain. Complex interrelationships of factors across multiple levels influence healthy-eating outcomes in schools, and a systems lens offers insight into the role of physical design and potential synergistic influences to consider for future school-based interventions and research.

The largest bodies of evidence pertained to the serving and water access and vending machine domains. This included mixed findings from cross-sectional studies, but supportive evidence from longitudinal and experimental studies has accumulated. Several of the studies reported outcomes from sales data (which may not directly translate to consumption) and plate waste analyses (which do not measure dietary intake outside the school setting).

Evidence for positive influence from the teaching kitchen and on-site food production domains was promising but inconclusive. More studies found significant impacts on healthy-eating–related psychosocial outcomes (e.g., preference for vegetables) than on healthy-eating behavior, especially for gardening programs. These strategies have only been applied with elementary and middle school students, and it is unknown whether similar programs with older students would be effective. Several qualitative studies indicated that although gardening programs are viewed favorably, they face significant barriers to implementation and maintenance beyond the need for physical space.

The extent of evidence for strategies related to the commercial kitchen and educational signage, wayfinding, and marketing domains was moderate, with

limited studies but some significant findings. We found no quantitative evidence regarding the commercial kitchen domain, but a preponderance of qualitative evidence indicated that adequate kitchen facilities are important to achieving the standards set by school meal nutrition guidelines. Studies pertaining to the educational signage, wayfinding, and marketing domain produced both qualitative and quantitative evidence, but the pool of studies was small. The use of communication campaigns and visual media materials as 1 strategy in multicomponent interventions is common, but it is rarely identifiable as an active component in existing literature.¹⁵¹

Few studies explored the domains of dining and aesthetics of healthy food environments or provided significant findings. As indicated in Figure 3, factors of aesthetics and comfort may affect eating behaviors through the perceived quality and appeal of healthy food. However, these factors may also reduce stress and behavioral issues that affect social interactions that encourage healthy eating. It is increasingly recognized that school mealtimes should promote positive experiences, and some schools have engaged students to improve the visual appeal and comfort of the cafeteria environment (e.g., student murals).^{152,153} The evidence for these approaches is limited, however, and their contribution to interconnected behavioral, academic, and healthy-eating outcomes remains unclear.

Evidence related to the domains of integrated healthy food education facilities and integrated healthy food community was also limited. Strategies from these domains aim to improve schools' capacity for community and parent outreach to encourage healthy

eating and to increase opportunities throughout the school day and environment for healthy-eating education. Systematic reviews indicate that school-based interventions that involve parents and community are more likely to succeed than those that target only students,¹⁵⁴⁻¹⁵⁶ and several studies have found that appropriate equipment and materials improve institutionalization and maintenance of interventions that address healthy eating.^{157,158} The rationales for the importance of these domains are strong, but research has not yet explored or tested physical environment strategies designed to address these important aspects of school-based healthy-eating interventions.

Overall, findings showed that the physical environment, as delineated through the HEDG spatial domains, plays an important role in school-based healthy-eating interventions. Public health experts and authorities recommend a comprehensive approach to addressing healthy eating in schools: nutrition education combined with supportive social, policy, and physical environment changes are needed to create population-level impact.² Approaches to transforming school food culture, such as the Berkeley Unified School District's School Lunch Initiative in California and Food for Life Partnership in England, have reported success.^{62,159} Some studies have identified the influence of physical environment changes in these approaches. For example, a significant dining and cafeteria space renovation in 1 of the Berkeley Unified School District's middle schools during the initiative's third year bolstered improvements in student attitudes regarding the quality of the school's healthy meals.¹⁵⁹

Our causal loop diagram helps clarify multiple influences and interrelationships that contribute to healthy-eating outcomes in the context of a school system and elucidates the potential role of physical space and design (Figure 3). In a school system, adoption and use of healthy-eating programming and practices are central to driving change, which may face major barriers (e.g., competing priorities, insufficient financial resources). If such barriers can be overcome, however, the design of curricular and food production physical spaces can trigger potentially powerful reinforcing feedback loops. In particular, improvements in the observability of healthy-eating programming and practices function in reinforcing loops that include elements of organizational change (e.g., organizational values and policies), which are important factors for sustainability.

Limitations

We reviewed studies with a range of research designs and sample sizes, and our narrative-based method did not quantitatively rank or weigh evidence according to design strength, nor did we assess the magnitude of effect sizes. We did not consider variation in findings arising from factors such as ethnicity and socioeconomic status that may influence generalizability. The qualitative studies were not coded by multiple independent researchers, which may reduce reliability of thematic findings.

We did not review quantitative studies for evidence of fidelity, which could influence interpretation of results. However, a strength of our review was that we assessed both quantitative and qualitative studies. Quantitative studies provide important information

regarding impact, but qualitative studies have implications for effective application and implementation of strategies.

Conclusions

The HEDGs were developed as testable hypotheses,⁹ and further work is needed to accumulate evidence and to refine or expand new strategies. Increased experimental and practice-based evaluation of cooking and gardening programs is needed to further knowledge related to the teaching kitchen and on-site food production domains. This research should not only focus on evidence related to dietary behaviors, but also assess potential methods for assisting schools to integrate the curricula with regular practice and to overcome structural and resource barriers. Research is also needed to build a stronger base for the educational signage, wayfinding, and marketing domain, and future studies should test and determine the most relevant and effective messages, which may vary across population subgroups (e.g., by age and race/ethnicity).

Qualitative research is needed to explore how features related to the aesthetics and dining domains affect healthy eating; these can then be tested through deductive quantitative methods to strengthen evidence. Finally, integrated healthy food education facilities and community domain strategies need refinement and expansion. These domains have strong rationales but limited evidence, and research should consider community-engaged and human-centered design approaches noted for their potential to explore new and creative solutions.¹⁶⁰

The causal loop diagram also provides important information for future research and for

evaluation of healthy-eating interventions. The whole-building and sustainable design fields are moving toward performance-based approaches,⁸ which require monitoring and establishment of performance indicators. Indicators for schools should include eating behavior and should also consider factors such as food service staffs' perceptions of the complexity of food preparation and students' stress levels. Furthermore, these should be considered in light of the overall system (e.g., differences in financial resources or leadership may influence outcomes and comparisons across schools). As data on these indicators accumulate, they can be combined with research evidence to refine the causal loop diagram and translate it into computational models. Computational models would allow for quantitative simulation to improve understanding of the potential impact of different intervention combinations.

Ours was the first review to consolidate evidence regarding physical environment influences on healthy eating across the entire school setting. Research shows that architecture and design can contribute to healthy-eating outcomes. Our findings can be used to enhance research on and practice of architecture and design for healthy eating and to explore integration with policy and social environment approaches. In a systems approach, a school's physical environment can play an important role in addressing the complex issue of healthy eating. ■

About the Authors

At the time of the study, Leah Frerichs, Jeri Brittin, Amy L. Yaroch, Mohammad Siahpush, Melissa Tibbits, and Terry T.-K. Huang were with the College of Public Health, University of Nebraska Medical Center, Omaha. Dina Sorensen is with VMDO Architects, Charlottesville, VA.

Matthew J. Trowbridge is with the School of Medicine, University of Virginia, Charlottesville.

Correspondence should be sent to Leah Frerichs, PhD, Post-Doctoral Research Associate, University of North Carolina at Chapel Hill, Center for Health Equity Research, 323 MacNider Hall; CB 7240, 333 S Columbia St, Chapel Hill NC 27599-7240 (e-mail: leahf@unc.edu). Reprints can be ordered at <http://www.ajph.org> by clicking the "Reprints" link.

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Contributors

T. T.-K. Huang supervised the study. All authors conceptualized and designed the study and critically revised and approved the article. L. Frerichs led collection, analysis, and interpretation of review articles. J. Brittin and D. Sorensen provided critical review and theoretical expertise from architecture and design perspectives. M. J. Trowbridge, A. L. Yaroch, and T. T.-K. Huang provided critical review and theoretical expertise from obesity prevention and nutrition perspectives.

Human Participant Protection

No protocol approval was required because no human participants were involved.

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