DISCUSSION PAPER

Systems Thinking for Public Health

A Case Study Using U.S. Public Education

Elizabeth Ashby, MS, National Academies of Sciences, Engineering, and Medicine; **Charlie Minicucci, BS,** National Academies of Sciences, Engineering, and Medicine; **Julie Liao, PhD,** National Academies of Sciences, Engineering, and Medicine; **Danilo Buonsenso, MD, PhD,** Fondazione Policlinico Universitario Agostino Gemelli IRCCS; **Sebastián González-Dambrauskas, MD,** LARed: Red Colaborativa Pediátrica de Latinoamérica; **Rafael Obregón, PhD,** UNICEF; **Matt Zahn, MD,** Children's Hospital of Orange County; **William Hallman, PhD,** Rutgers University; and **Chandy John, MD, MS,** Indiana University School of Medicine

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ABSTRACT | *The initial response to the COVID-19 pandemic in the United States largely focused on addressing the immediate health consequences from the emergent pathogen. This initial focus often ignored the related impacts from the pandemic and from mitigation measures, including how existing social determinants of health compounded physical, social, and economic impacts on individuals who have historically been marginalized. The consequences of decisions around closing and reopening primary and secondary (K–12 in the United States) public schools exemplify the complex impacts of pandemic mitigation measures. Ongoing COVID-19 mitigation and recovery efforts have gradually begun addressing indirect consequences, but these efforts were slow to be identified and adopted through much of the acute phase of the pandemic, mirroring the decades-long neglect of contributors to the overall health and well-being of populations that have been made to be vulnerable.*

A systems approach for decision making and problem solving holistically considers the effects of complex interacting factors. Taking a systems approach at the start of the next health emergency could encourage response strategies that consider various competing public health needs throughout different sectors of society, account for existing disparities, and preempt undesirable consequences before and during response implementation. There is a need to understand how a systems approach can be better integrated into decision making to improve future responses to public health emergencies. A wide range of stakeholders should contribute expertise to these models, and these partnerships should be formed in advance of a public health emergency.

Introduction

In September 2021 the National Academies of Sciences, Engineering, and Medicine hosted a workshop titled "Towards a Post-Pandemic World: Lessons from COVID-19 for Now and the Future." (NASEM, 2022) In this article, select workshop participants further explore the application of systems thinking in evaluating COVID-19 mitigation measures.

Systems Thinking in Public Health

A systems science approach to outbreak response planning is a useful tool for broadening strategic thinking to consider critical factors driving the short- and long-term consequences of crisis response measures, including how such decisions will impact health disparities (Bradley et al., 2020). A conceptual framework, systems thinking accounts for the relationship between individual factors within a scenario as well as their contributions to the whole, and can facilitate the synthesis of response plans that match the scale and complexity of the problem at hand (Trochim et al., 2006).

Specifically for public health, a systems approach "applies scientific insights to understand the elements that influence health outcomes; models the relationships between those elements; and alters design, processes or policies based on the resultant knowledge" (Kaplan et al., 2013). Complex and interconnected risk factors collectively influenced health outcomes in the COVID-19 pandemic. Response to an evolving public health emergency requires a

systems approach that can weigh disparate needs and account for systemic inequities to quickly generate solutions while remaining adaptable as new data emerges.

In this article, we use the issue of K–12 public school closures in the United States to illustrate the need for systems approaches in public health situations. Mapping tools, such as causal loop diagrams, can show the complexity of interconnected factors and their use should be prioritized to guide evidence-based decisions in complex and evolving circumstances. This article argues for the adoption of a systems science approach to outbreak decision making that:

- addresses the inherent complexity of societal impacts during public health emergencies,
- accounts for social determinants of health, and
- includes perspectives from a wide range of stakeholders.

COVID-19 Decision Making and Unintended Consequences

At the start of the COVID-19 pandemic, policy decisions and responses were enacted quickly to contain the spread of disease. However, the public health implications of COVID-19 extend beyond the disease itself, as the pandemic exacerbated disparities in health outcomes closely correlated with social determinants of health and structural inequalities (Karmakar et al., 2021; Liao and De Maio 2021; Webb Hooper et al., 2020). While strong infection control measures, such as lockdowns and school closures, were considered essential when COVID-19 was an emergent disease, these responses resulted in unintended consequences that were not prioritized in the early decision-making process (Turcotte-Tremblay et al., 2021).

This trade-off may have been necessary at the time, given the rapid disease spread and lack of data about the disease to guide initial decisions. However, as the potential for containment or eradication of COVID-19 dimmed, decision makers were slow to update mitigation measures based on evolving knowledge and accounting for the broader population health needs. The COVID-19 response stemmed largely from concern about acute infections, reflecting a mindset that was more focused on medical response than broader public health impacts.

Biological factors (e.g., age or comorbidities such as hypertension, diabetes, lung disease, or immunodeficiencies) and social determinants of health (e.g., disparities stemming from marginalized socioeconomic status, lack of access to housing and transportation, race and ethnicity, and language and literacy barriers) interact to affect health and well-being (WHO, 2023; Gao et al., 2021). While awareness of biological risk factors for severe illness grew rapidly and mitigation measures were enacted to protect individuals at risk, consideration for social risk factors in COVID response plans were not equally prioritized (Laylavi, 2021).

For example, while the federal government heavily invested in the development of vaccines and anti-viral treatments early in the pandemic (Lalani et al., 2023), expanded unemployment support to address pandemic-related job losses and educational support for students during school closures were deprioritized and debated at length in government. This inaction slowed critical support for populations disproportionately impacted by pandemic spread-related closures.

The neglect of programs that would create a social safety net for the populations most marginalized is not specific to the pandemic, but is an exacerbation of systematic neglect over decades (Mody et al., 2022; Dorn et al., 2020; Saenz and Sparks, 2020). Even when educational support programs were rolled out, they were implemented inconsistently and did not specifically consider the additional needs of populations that have been made to be vulnerable and that were more likely to be disproportionately impacted by school closures and loss of income due to pandemic restrictions (Wright, 2021).

Officials did not give significant attention to the secondary impacts of the COVID-19 pandemic as the pandemic progressed. While these social disparities existed before the onset of COVID-19, decisions made in response to the pandemic widened many of these gaps.

There have been earlier calls to apply a systems approach to improve public health outcomes, and many examples exist to illustrate the strength of a systems approach in successfully addressing complex public health challenges (Kaplan et al., 2013; Honoré et al., 2011). The example of public school closures demonstrates how the social impacts of mitigation measures widened existing disparities. The example also highlights the need for holistic, systems-based approaches in addressing future public health crises.

Public School Closures and Remote Learning: A Case for Applying Systems Thinking to Improve Health Outcomes during Future Disease Outbreaks

The issue of school closures during the pandemic serves as a case study for how factors affecting health were not holistically considered during decision making. School closures can exacerbate social and health disparities, with long-lasting consequences (NASEM, 2020). Many students rely on school systems for adequate nutrition, safety, supervision, and socioemotional and cognitive development (Van Lancker and Parolin, 2020).

In addition, substantial evidence shows that remote learning is an inadequate and unequitable substitute for in-person learning and does not completely mitigate learning losses during school closures (Agostinelli et al., 2022; Engzell et al., 2021; Bettinger and Loeb, 2017).

Furthermore, school closures may have a greater impact on students in underserved communities. Systemically disadvantaged students (e.g., those who are experiencing poverty or are from racial or ethnic minority communities) are less likely to have access to the technology or broadband internet that is necessary

for remote learning. They are less likely to have parents who are able to work from home and supervise them and often encounter other barriers to achieving learning goals (Smith and Reeves, 2020). Students with special educational needs have had disproportionate learning losses and have limited access to other supportive resources otherwise provided through schools while schools are closed (Hurwitz et al., 2021; Nelson and Murakami, 2020).

Importantly, education access and achievement are associated with improved health outcomes, and the above-mentioned educational disparities may translate to worsened health disparities among the different communities (Dorn et al., 2021; Zajacova and Lawrence, 2018).

The decision making surrounding school closures is complex (Allen, 2021; World Bank Group Education, 2020). While decision makers now know that K–12 public school children have reduced physical risk to severe disease outcomes from COVID-19 compared to adults, school closures were implemented early in the pandemic, when this risk was unknown and there was limited time for decision making. Students experienced related impacts from pandemic mitigation measures, and some have suffered mentally, emotionally, and developmentally as a direct result of school closures specifically (Viner et al., 2022; Engzell et al., 2021).

However, decisions about school closures and transitions to remote learning at the start of the COVID-19 pandemic generally focused on physical health risk factors (e.g., preventing transmission and mortality) rather than holistic evaluations of children's multifaceted developmental needs (e.g., socialization in cognitive and emotional development; Viner et al., 2022). Factors such as public fear and parental pressure may have also affected decisions both to close and reopen schools. Many under-resourced schools may have also had limited ability to facilitate a safe return to in-person learning. The many factors affecting school closure decisions further demonstrates the overall need for a systematic, context-specific model for decision making in future emergencies.

Widespread school closures lasted well into 2021, despite early and repeated warnings about the potential costs to student well-being (Allen, 2021; Kaffenberger, 2021; Balingit and Meckler, 2020) and evidence that with adequate interventions, in-person schooling could be made safe (Alonso et al., 2022; Rotevatn et al., 2022; Head et al., 2021).

Furthermore, school closures were experienced unequally. A nationwide study by Parolin and Lee (2021) found a correlation between school closures in fall 2021 and the racial and ethnic composition of the student body, with nearly 70 percent in-person attendance in schools with a high majority of White students and more than 70 percent closure among schools with large proportions of non-White students. This difference was observed across the United States and within local metro areas.

For example, in Los Angeles County, schools with the highest proportion of racial and ethnic minority students stayed closed at higher rates and for longer durations than schools with the highest proportion of White students (see *Figure 1*). Many factors could have contributed to this observation, including governance, demographic distribution in urban and suburban areas, differences in resource availability in public schools (including school health services), and differences in transmission rates due to population density.

A separate study by Grossmann et al. (2021) also suggested that other outside factors, such as political pressure and strength of teachers unions, may have had significant influence over school closure decisions. A diversity of factors impact student well-being; thus, a systems approach would support informed decision making in school closure policies.

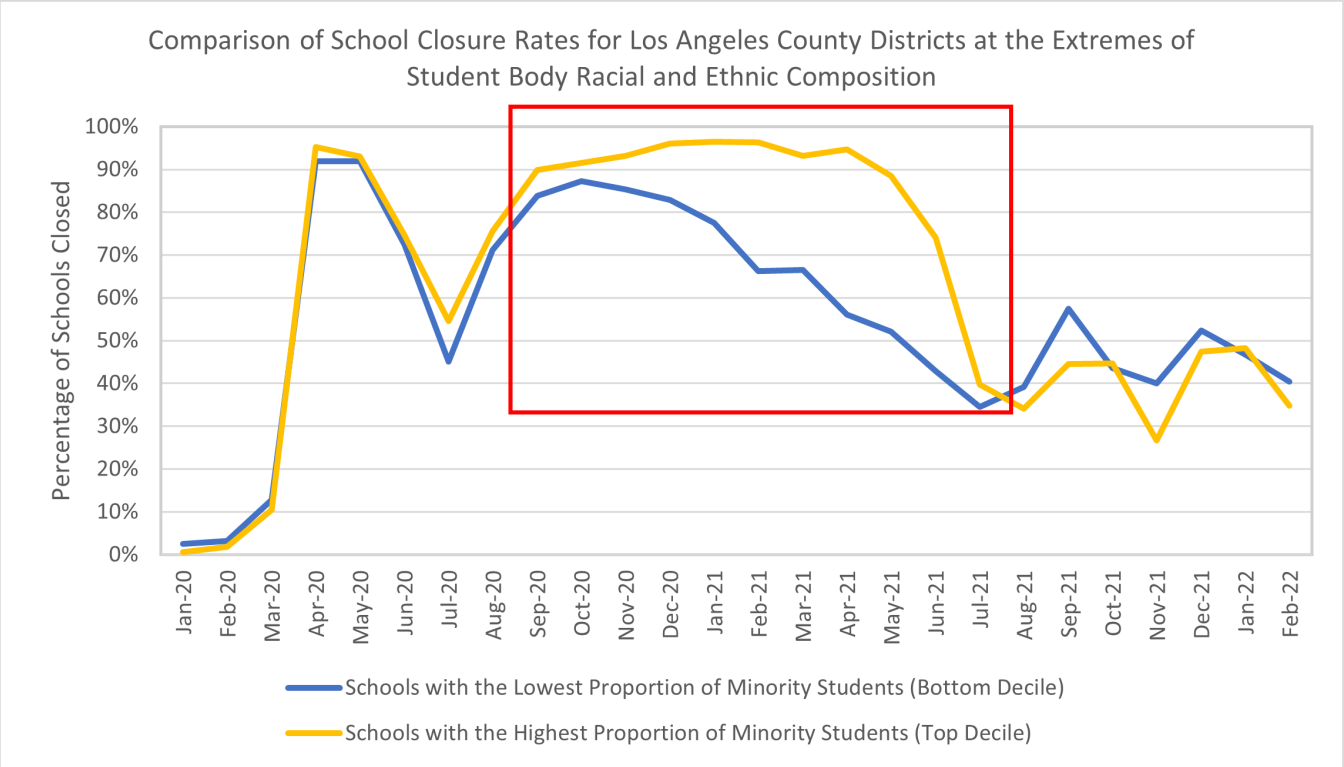
Multiple factors must also be accounted for in remediation plans, not just initial decision making, in response to a public health crisis. In July 2021, the Center on Reinventing Public Education (CRPE, 2022) evaluated published plans from 100 major US school districts on spending the more than $43 billion allocated from the Elementary and Secondary School Emergency Relief Fund. While most districts included learning loss and social, emotional, and mental health as key target areas for remediation, only about 30 percent of schools accounted for special needs, equity, and community engagement in their remediation plans (see *Figure 2*). This data revealed that many school districts have attempted to address pandemic-related health outcomes, but these efforts can be further improved with a more holistic approach to decision making regarding public education and student health.

Students' well-being and long-term health outcomes are not the only considerations in deciding when best to resume in-person learning. Plans for safe and sustainable resumption of in-person learning also need to consider the needs and concerns of other stakeholders, such as parents, school staff (including nurses and health human resources), and public officials. For example, federal school reopening strategies included practices to safeguard the well-being of educators and other school staff (Department of Education, 2021). Other concerns include the need for data to understand and mitigate transmission dynamics within classrooms and in the local community, especially with the emergence of new viral variants (Honein et al., 2021). These complexities further underline the need for a holistic decision-making strategy that accounts for different needs and dynamics as information unfolds during a public health emergency such as the COVID-19 pandemic.

Using Systems Thinking to Redefine Strategies for Public Health Preparedness

Implementing a systems approach to public health planning requires tools, trained experts, and collaboration with stakeholders. Causal loop diagrams (CLDs) are analytical tools used to

FIGURE 1 | Average Monthly School Closure Rates for Los Angeles County Public Schools by Race and Ethnicity



SOURCE: Los Angeles Almanac. 2020. *Ethnic distribution of pupils by school districts: Los Angeles County: School year 2019–2020.* Available at: http://www.laalmanac.com/education/ed05.php (accessed January 13, 2023).
NOTE: Each series comprises the 10 percent of school districts with the highest and lowest proportions of minority students. The red box highlights a stark difference in school closures between the two groups during the 2020–2021 academic year.

Figure 1 was developed with data from the California Department of Education via the Los Angeles Almanac (2020) and depicts the disparity between closure rates for schools in Los Angeles County, represented by the proportion of a district's ethnic minority students. Schools were considered closed if the district saw a greater than 50 percent decline in foot traffic in 2020 over the same month in 2019, when schools were still open, according to the US School Closure and Distance Learning Database's use of anonymized mobile phone location data (Parolin and Lee, 2021).

School student counts and ethnic compositions are as reported for the 2019–2020 school year by the California Department of Education via the Los Angeles Almanac (2020). Proportions are averaged across all the districts selected. The lowest percent minority district set includes the 10 percent of Los Angeles County districts with the highest proportion of non-minority students (n = 8; all more than 45 percent White). This set covers about 115 schools educating over 87,000 students (about 5.9 percent of the Los Angeles County total). No closure data were available for one small district (Hermosa Beach City; 1,378 students; 67.5 percent White) and one independent school (Hughes-Elizabeth Lakes Union Elementary; 196 students; 64.8 percent White). They were excluded and replaced by two districts further down the scale.

The highest percent minority district set includes the 10 percent of Los Angeles County districts with the largest proportion of minority students (n = 9; though two separate parts of one district were tracked separately: all more than 98 percent minority). This set covers about 125 schools educating over 93,000 students (about 6.3 percent of the Los Angeles County total). Of note, closure data for Lennox School District (13,818 students; 0.7 percent White) were unavailable for the first half of 2021. It is not included in the averaged value on the graph for those months.

A similar analysis (data not shown) was conducted for the top and bottom quartiles (instead of decile) and showed a similar, though less pronounced, difference between the two series. Chartered public schools were excluded from this analysis.

map a complex set of factors and forces in a system. They can be used to analyze interplay between factors or develop response strategies. CLDs are gaining attention in public health spheres and can be developed for various purposes, including for influencing policy and practice and for system dynamics modeling (Baugh Littlejohns et al., 2021).

Several CLDs have been developed to demonstrate the variety and interconnectedness of issues related to COVID-19, including mitigation measures. In a series of workshops, Sahin et al. (2020) gathered a group of subject matter experts in various fields (e.g., public health, social science, systems thinking) to develop a CLD that maps the unintended impacts of COVID-19 mitigation measures on socioeconomic systems (see *Figure 3*). One of the loops shows that social distancing will likely decrease virus transmission but also has negative, lasting mental health consequences (loop B3). Sahin et al. (2020) note there is a "a high risk of catastrophic social order demise" if enacted policies do not account for impacts on society.

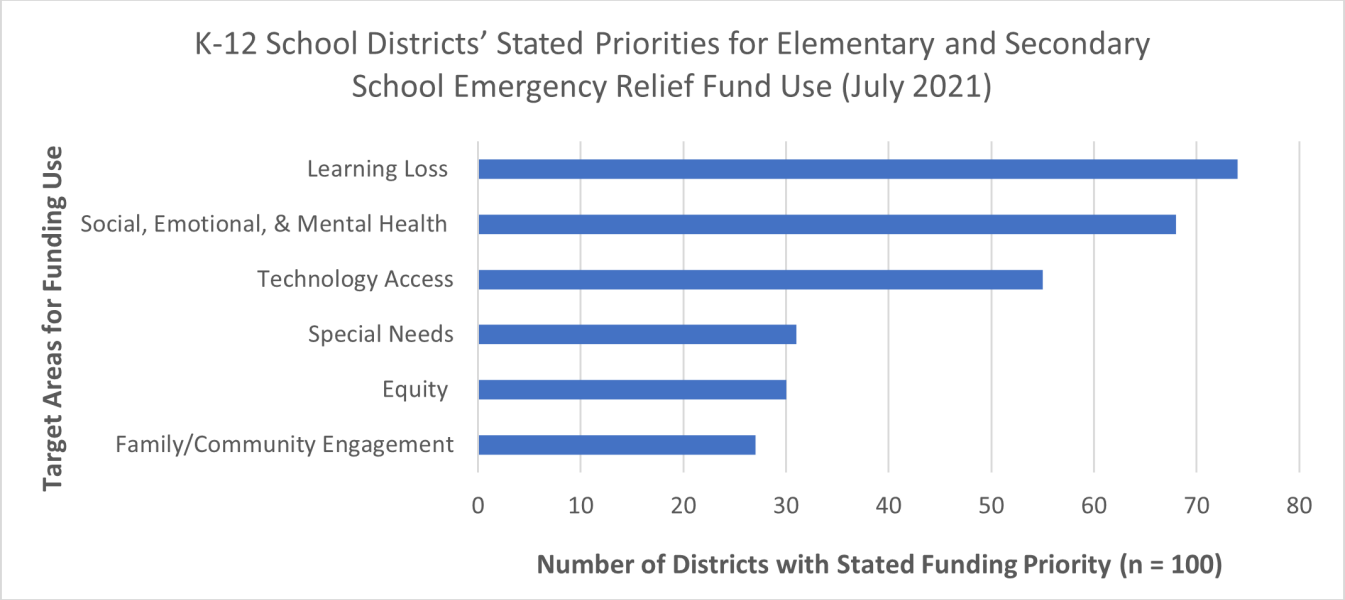
Tools such as CLDs can facilitate understanding of varying factors within a public health system, a view that is needed to enact holistic solutions. This model captures the severity of social consequences, which were largely overlooked throughout the pandemic.

To further demonstrate their potential, we have created an example CLD that highlights components that could inform a more complex CLD addressing public education issues for children (see *Figure 4*). This illustrative CLD integrates several of the factors that have been discussed in this article (e.g., children's physical health, mental and emotional health, family stressors). While not developed with the intent of immediate application, this example CLD could be modified and used for decision making.

An analysis of COVID-19 CLDs by Strelkovskii and Rovenskaya (2021) concluded that these tools can "draw the attention of policy makers to areas where unintended and unwanted effects may be anticipated"; they identified CLDs as useful tools for highlighting the diverse impacts of the pandemic. Their analysis also found that, while there have been numerous calls to apply systems thinking approaches to the impacts of COVID-19, there are few examples of practical applications. The authors highlighted that there have been relatively few examples of CLDs developed for COVID-19, and these have been developed for purposes other than influencing decision making.

As with many aspects of the COVID-19 pandemic, there is an opportunity to develop tools, such as CLDs, that are more actionable and policy related. The means of developing the CLD are also critical to its use. Such development should include an interdisciplinary group of experts to capture the multiple layers of a complex system. Stakeholder and community participation in developing CLDs represent a step toward developing tools that are more comprehensive and that may be more actionable from a policy standpoint (Baugh Littlejohns et al., 2021). Collaborative groups that include experts, community members, and policy makers can be better poised to develop a dynamic model that can be useful in depicting complex social, physical, and economic relationships. These nuanced models could serve as critical tools for weighing the impacts of mitigation measures

FIGURE 2 | Public School Priorities for Elementary and Secondary School Emergency Relief Fund Use



SOURCE: Data accessed from: Center on Reinventing Public Education. 2022. *2021–2022 School District Plans Database*. Available at: https://crpe.org/pandemic-learning/tracking-district-actions/ (accessed October 17, 2023).

in a public health emergency, and developing system models in advance will facilitate immediate action at the onset of an emergency.

While providing substantial benefits, developing CLDs also presents challenges. Because systems are inherently complex, it is difficult to capture all relevant factors in a diagram while maintaining the detail that is needed to be useful. Also, translating a CLD into action can be challenging, as evidenced by the lack of actionable CLDs that address the impacts of the COVID-19 pandemic. Despite these challenges, CLDs remain a useful tool for providing a decision-making framework in complex situations with interconnected factors.

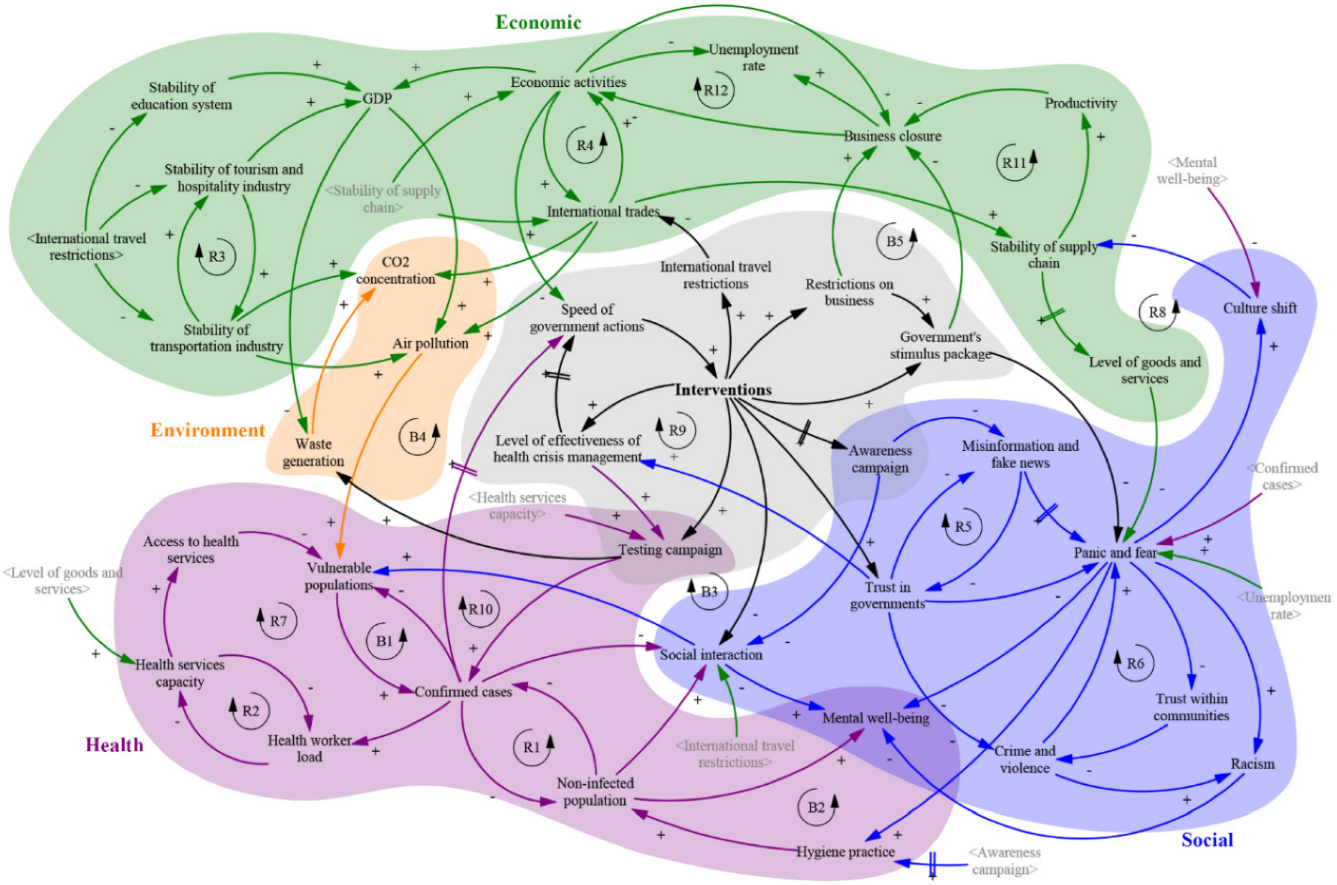
Conclusion

The U.S. response strategy to the COVID-19 pandemic suffered from a lack of a holistic and systems-oriented approach to decision making. This paper outlines the complexities that should have been considered in making the shift to fully remote learning in K–12 schools during COVID-19. There is a need to integrate diverse perspectives from interdisciplinary experts, stakeholders, and community members in developing models that influence decision making. In the example of school closures, educators, parents, school health leaders, and community leaders are relevant stakeholders for public health decisions that affect health outcomes in schools.

Systems approaches facilitate more comprehensive assessments to inform decision making, and CLDs are a valuable tool that can be used for response planning. Time is of the essence in a public health emergency, especially when there is minimal information about an emerging threat. Systems models can be built to respond to an emerging threat and developed as information is gained.

We assert that using CLDs as part of a systems approach can improve the transparency, inclusiveness, and credibility of the decision-making process during future public health emergencies. Systems thinking, and tools such as CLDs, should be prioritized in future public health emergencies.

FIGURE 3 | Causal Loop Diagram Demonstrating Impacts of COVID-19 Pandemic Mitigation Measures



SOURCE: Sahin, O., H. Salim, E. Suprun, R. Richards, S. MacAskill, S. Heilgeist, S. Rutherford, R. A. Stewart, and C. D. Beal. 2020. Developing a preliminary causal loop diagram for understanding the wicked complexity of the COVID-19 pandemic. *Systems* 8(2):20. https://doi.org/10.3390/systems8020020.

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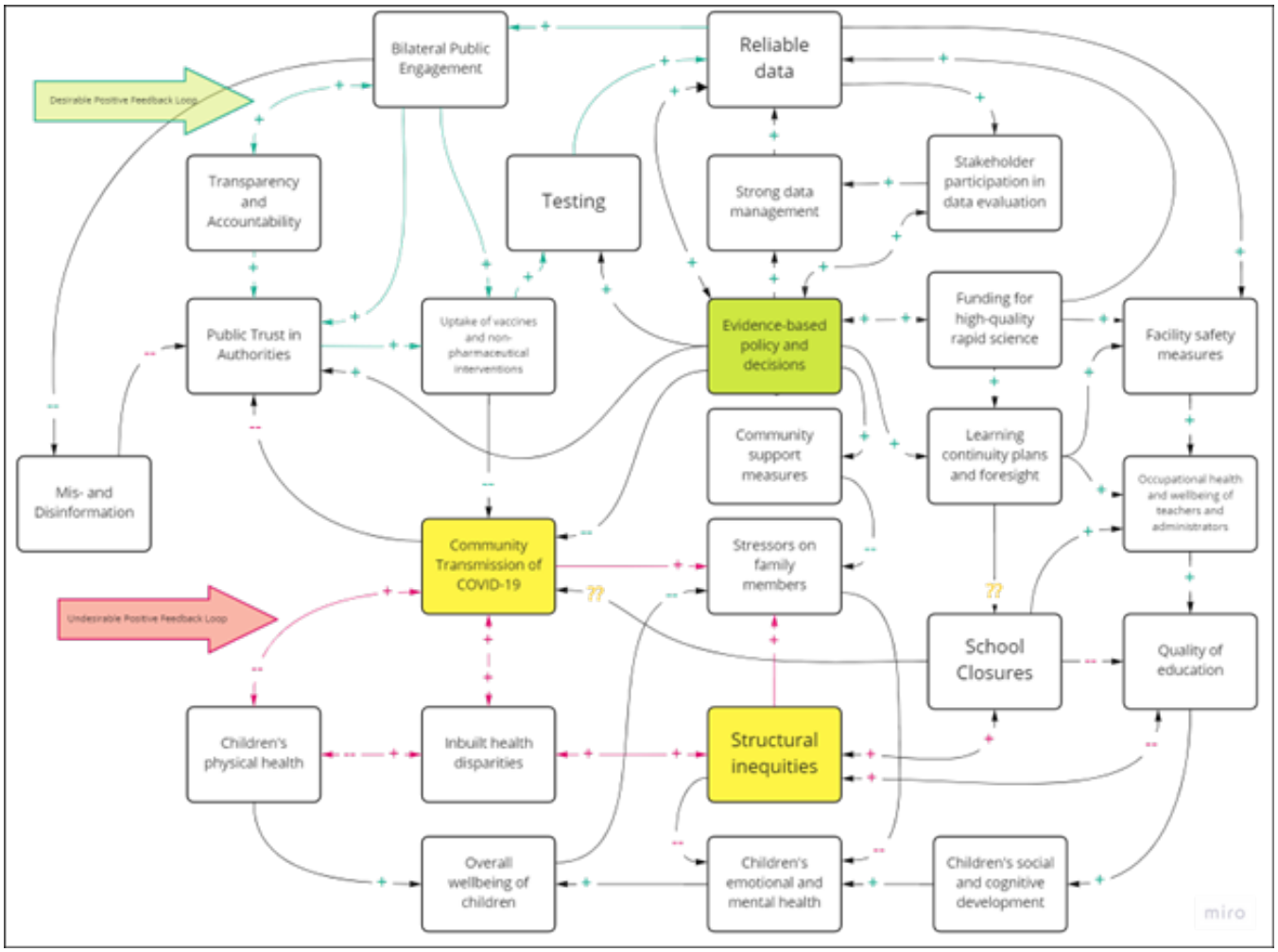
FIGURE 4 | Causal Loop Diagram to Inform Systems Thinking in Public Education Response to COVID-19



SOURCE: Bradley, D. T., M. A. Mansouri, F. Kee, and L. M. T. Garcia. 2020. A systems approach to preventing and responding to COVID-19. *eClinicalMedicine* 21:100325. https://doi.org/10.1016/j.eclinm.2020.100325; Walsh, S., A. Chowdhury, V. Braithwaite, S. Russell, J. M. Birch, J. L. Ward, C. Waddington, C. Brayne, C. Bonell, R. M. Viner, and O. T. Mytton. 2021. Do school closures and school reopenings affect community transmission of COVID-19? A systematic review of observational studies. *BMJ Open* 11(8):e053371. https://doi.org/10.1136/bmjopen-2021-053371; Centers for Disease Control and Prevention (CDC). 2022. *Operational Guidance for K-12 Schools and Early Care and Education Programs to Support Safe In-Person Learning.* Available at: https://www.cdc.gov/coronavirus/2019-ncov/community/schools-childcare/k-12-childcare-guidance.html (accessed October 17, 2023); Alonso, S., M. Català, D. López, E. Álvarez-Lacalle, I. Jordan, J. J. García-García, V. Fumadó, C. Muñoz-Almagro, E. Gratacós, N. Balanza, R. Varo, P. Millat, B. Baro, S. Ajanovic, S. Arias, J. Claverol, M. F. de Sevilla, E. Bonet-Carne, A. Garcia-Miquel, E. Coma, M. Medina-Peralta, F. Fina, C. Prats, and Q. Bassat. 2022. Individual prevention and containment measures in schools in Catalonia, Spain, and community transmission of SARS-CoV-2 after school re-opening. *PLOS ONE* 17(2):e0263741. https://doi.org/10.1371/journal.pone.0263741; and Head, J. R., K. L. Andrejko, Q. Cheng, P. A. Collender, S. Phillips, A. Boser, A. K. Heaney, C. M. Hoover, S. L. Wu, G. R. Northrup, K. Click, N. S. Bardach, J. A. Lewnard, and J. V. Remais. 2021. School closures reduced social mixing of children during COVID-19 with implications for transmission risk and school reopening policies. *Journal of the Royal Society Interface* 18(177):20200970. https://doi.org/10.1098/rsif.2020.0970.

NOTE: Generated by authors using Miro online whiteboard. The green box indicates a hypothetical decision maker's position in the system. Yellow boxes highlight central aspects of the system that a decision maker might attempt to affect directly. Plus and minus signs indicate positive or negative causal relationships. Green symbols indicate a desirable causal relationship, red symbols indicate an undesirable causal relationship, and question marks indicate relationships of unknown nature as a result of knowledge gaps (in the case of school closures impacting transmission) or key decisions that have yet to be made (e.g., whether learning continuity plans choose to encourage or discourage school closures). Colored arrows highlight examples of positive feedback loops in the system: green arrows denote a loop of desirable causal relationships that decision makers may want to reinforce, and red arrows denote one that may be targeted for disruption.

Despite the widely acknowledged usefulness of CLDs, there are few examples of CLDs that were applied during the COVID-19 pandemic to influence decision making. Partnerships between public health experts and decision makers should be developed in advance of public health emergencies, so they will be poised to respond immediately. Further, perspectives from the economic and social sectors should also be sought, to understand the complex impact of emergencies, including the impacts of mitigation measures. Increased stakeholder engagement can result in tools that are more actionable and effective.

A commitment to incorporate systems thinking will require broadening the preparedness planning approach for public health decision making, emphasizing the inclusion of physical and related impacts, and securing buy-in from decision makers (Zięba, 2021; Klement, 2020). This type of thinking would also require training, so the public health workforce can learn to design and implement these methods.

References

1. Agostinelli, F., M. Doepke, G. Sorrenti, and F. Zilibotti. 2022. When the great equalizer shuts down: Schools, peers, and parents in pandemic times. *Journal of Public Economics* 206:104574. https://doi.org/10.1016/j.jpubeco.2021.104574.
2. Allen, J. G. 2021. We learned our lesson last year: Do not close schools. *The New York Times,* December 20. Available at: https://www.nytimes.com/2021/12/20/opinion/omicron-schools-do-not-close.html (accessed October 17, 2023).
3. Alonso, S., M. Català, D. López, E. Álvarez-Lacalle, I. Jordan, J. J. García-García, V. Fumadó, C. Muñoz-Almagro, E. Gratacós, N. Balanza, R. Varo, P. Millat, B. Baro, S. Ajanovic, S. Arias, J. Claverol, M. F. de Sevilla, E. Bonet-Carne, A. Garcia-Miquel, E. Coma, M. Medina-Peralta, F. Fina, C. Prats, and Q. Bassat. 2022. Individual prevention and containment measures in schools in Catalonia, Spain, and community transmission of SARS-CoV-2 after school re-opening. *PLOS ONE* 17(2):e0263741. https://doi.org/10.1371/journal.pone.0263741.
4. Azevedo, J. P. W. D., F. H. Rogers, S. E. Ahlgren, M.-H. Cloutier, B. Chakroun, G.-C. Chang, S. Mizunoya, N. J. Reuge, M. Brossard, and J. L. Bergmann. 2010. *The state of the global education crisis: A path to recovery.* Washington, DC: World Bank Group. Available at: http://documents.worldbank.org/curated/en/416991638768297704/The-State-of-the-Global-Education-Crisis-A-Path-to-Recovery (accessed October 18, 2023).
5. Balingit, M., and L. Meckler. 2020. Schools close over coronavirus threat, raising concerns about disruption. *The Washington Post,* March 9. Available at: https://www.washingtonpost.com/local/education/schools-close-over-coronavirus-threat-raising-concerns-about-disruption/2020/03/09/ea74e528-622b-11ea-acca-80c22bbee96f_story.html (accessed October 17, 2023).
6. Baugh Littlejohns, L., C. Hill, and C. Neudorf. 2021. Diverse approaches to creating and using causal loop diagrams in public health research: Recommendations from a scoping review. *Public Health Reviews* 42. https://doi.org/10.3389/phrs.2021.1604352.
7. Bettinger, E., and S. Loeb. 2017. Promises and pitfalls of online education. *Evidence Speaks* 2(15):1–4. Available at: https://www.brookings.edu/research/promises-and-pitfalls-of-online-education/ (accessed October 17, 2023).
8. Bradley, D. T., M. A. Mansouri, F. Kee, and L. M. T. Garcia. 2020. A systems approach to preventing and responding to COVID-19. *eClinicalMedicine* 21:100325. https://doi.org/10.1016/j.eclinm.2020.100325.
9. Center on Reinventing Public Education. 2022. *2021–2022 School District Plans Database.* Available at: https://crpe.org (accessed October 13, 2023).
10. Department of Education. 2021. *ED COVID-19 handbook: Strategies for safely reopening elementary and secondary schools, Vol. 1.* Washington, DC. Available at: https://www2.ed.gov/documents/coronavirus/reopening.pdf (accessed October 17, 2023).
11. Dorn, E., B. Hancock, J. Sarakatsannis, and E. Viruleg. 2021. *COVID-19 and education: The lingering effects of unfinished learning.* Chicago, IL: McKinsey and Company. Available at: https://www.mckinsey.com/industries/education/our-insights/covid-19-and-education-the-lingering-effects-of-unfinished-learning (accessed October 17, 2023).
12. Dorn, E., B. Hancock, J. Sarakatsannis, and E. Viruleg. 2020. *COVID-19 and learning loss—disparities grow and students need help.* McKinsey and Company, December 8. Available at: https://www.mckinsey.com/industries/public-and-social-sector/our-insights/covid-19-and-learning-loss-disparities-grow-and-students-need-help (accessed October 17, 2023).
13. Engzell, P., A. Frey, and M. D. Verhagen. 2021. Learning loss due to school closures during the COVID-19 pandemic. *Proceedings of the National Academy of Sciences* 118(17):e2022376118. https://doi.org/10.1073/pnas.2022376118.
14. Gao, Y. D., M. Ding, X. Dong, J. J. Zhang, A. Kursat Azkur, D. Azkur, H. Gan, Y. L. Sun, W. Fu, W. Li, H. L. Liang, Y. Y. Cao, Q. Yan, C. Cao, H. Y. Gao, M. C. Bruggen, W. van de Veen, M. Sokolowska, M. Akdis, and C. A. Akdis. 2021. Risk factors for severe and critically ill COVID-19 patients: A review. *Allergy* 76(2):428–455. https://doi.org/10.1111/all.14657.
15. Grossmann, M., S. Reckhow, K. O. Strunk, and M. Turner. 2021. All states close but red districts reopen: The politics of in-person schooling during the COVID-19 pandemic.

Educational Researcher 50(9):637–648. https://doi.org/10.3102/0013189x211048840.

16. Head, J. R., K. L. Andrejko, Q. Cheng, P. A. Collender, S. Phillips, A. Boser, A. K. Heaney, C. M. Hoover, S. L. Wu, G. R. Northrup, K. Click, N. S. Bardach, J. A. Lewnard, and J. V. Remais. 2021. School closures reduced social mixing of children during COVID-19 with implications for transmission risk and school reopening policies. *Journal of the Royal Society Interface* 18(177):20200970. https://doi.org/10.1098/rsif.2020.0970.
17. Honein, M. A., L. C. Barrios, and J. T. Brooks. 2021. Data and policy to guide opening schools safely to limit the spread of SARS-CoV-2 infection. *JAMA* 325(9):823–824. https://doi.org/10.1001/jama.2021.0374.
18. Honoré, P. A., D. Wright, D. M. Berwick, C. M. Clancy, P. Lee, J. Nowinski, and H. K. Koh. 2011. Creating a framework for getting quality into the public health system. *Health Affairs* 30(4):737–745. https://doi.org/10.1377/hlthaff.2011.0129.
19. Hurwitz, S., B. Garman-McClaine, and K. Carlock. 2021. Special education for students with autism during the COVID-19 pandemic: "Each day brings new challenges." *Autism* 26(4):889–899. https://doi.org/10.1177/13623613211035935.
20. Kaffenberger, M. 2021. Modelling the long-run learning impact of the Covid-19 learning shock: Actions to (more than) mitigate loss. *International Journal of Educational Development* 81:102326. https://doi.org/https://doi.org/10.1016/j.ijedudev.2020.102326.
21. Kaplan, G. S., G. W. Bo-Linn, P. Carayon, P. J. Pronovost, W. B. Rouse, P. P. Reid, and R. S. Saunders. 2013. Bringing a systems approach to health. *NAM Perspectives*. Discussion Paper, National Academy of Medicine, Washington, DC. https://doi.org/10.31478/201307a.
22. Karmakar, M., P. M. Lantz, and R. Tipirneni. 2021. Association of social and demographic factors with COVID-19 incidence and death rates in the US. *JAMA Network Open* 4(1):e2036462–e2036462. https://doi.org/10.1001/jamanetworkopen.2020.36462.
23. Klement, R. J. 2020. Systems thinking about SARS-CoV-2. *Frontiers in Public Health* 8. https://doi.org/10.3389/fpubh.2020.585229.
24. Lalani H. S., S. Nagar, A. Sarpatwari, R. E. Barenie, J. Avorn, B. N. Rome, and A. S. Kesselheim. 2023. US public investment in development of mRNA covid-19 vaccines: Retrospective cohort study. *BMJ* 380:e073747. doi:10.1136/bmj-2022-073747.
25. Laylavi, F. 2021. Social vulnerability to COVID-19: Preliminary indicators and research agenda. In *COVID-19 pandemic, geospatial information, and community resilience,* edited by A. Rajabifard, G. Foliente, and D. Paez. Boca Raton, FL: CRC Press. pp. 87–99. https://doi.org/10.1201/9781003181590
26. Liao, T. F., and F. De Maio. 2021. Association of social and economic inequality with coronavirus disease 2019 incidence and mortality across US counties. *JAMA Network Open* 4(1):e2034578–e2034578. https://doi.org/10.1001/jamanetworkopen.2020.34578.
27. Los Angeles Almanac. 2020. *Ethnic distribution of pupils by school districts: Los Angeles County: School year 2019–2020.* Available at: http://www.laalmanac.com/education/ed05.php (accessed January 13, 2023).
28. Mody, A., C. Bradley, S. Redkar, B. Fox, I. Eshun-Wilson, M. G. Hlatshwayo, A. Trolard, K. H. Tram, L. M. Filiatreau, F. Thomas, M. Haslam, G. Turabelidze, V. Sanders-Thompson, W. G. Powderly, and E. H. Geng. 2022. Quantifying inequities in COVID-19 vaccine distribution over time by social vulnerability, race and ethnicity, and location: A population-level analysis in St. Louis and Kansas City, Missouri. *PLOS Medicine* 19(8):e1004048. https://doi.org/10.1371/journal.pmed.1004048.
29. NASEM (National Academies of Sciences, Engineering, and Medicine). 2020. *Reopening K-12 schools during the COVID-19 pandemic: Prioritizing health, equity, and communities.* Washington, DC: The National Academies Press. https://doi.org/10.17226/25858.
30. NASEM. 2022. *Toward a post-pandemic world: Lessons from COVID-19 for now and the future: Proceedings of a workshop.* Washington, DC: The National Academies Press. https://doi.org/10.17226/26556.
31. Nelson, M., and E. Murakami. 2020. Special education students in public high schools during COVID-19 in the USA. *Journal of the Commonwealth Council for Educational Administration & Management* 48(3):109–115. Available at: https://cceam.net/wp-content/uploads/2020/10/ISEA-2020-48-3.pdf#page=115 (accessed October 13, 2023).
32. Parolin, Z., and E. K. Lee. 2021. Large socio-economic, geographic and demographic disparities exist in exposure to school closures. *Nature Human Behaviour* 5(4):522–528. https://doi.org/10.1038/s41562-021-01087-8.
33. Rotevatn, T. A., P. Elstrøm, M. Greve-Isdahl, P. Surén, T. K. B. Johansen, and E. Astrup. 2022. School closure versus targeted control measures for SARS-CoV-2 infection. *Pediatrics* 149(5):e2021055071. https://doi.org/10.1542/peds.2021-055071.
34. Saenz, R., and C. Sparks. 2020. *The inequities of job loss and recovery amid the COVID-19 pandemic.* University of New Hampshire Carsey School of Public Policy, August 11. Available at: https://carsey.unh.edu/publication/inequities-job-loss-recovery-amid-COVID-pandemic (accessed October 17, 2023).

35. Sahin, O., H. Salim, E. Suprun, R. Richards, S. MacAskill, S. Heilgeist, S. Rutherford, R. A. Stewart, and C. D. Beal. 2020. Developing a preliminary causal loop diagram for understanding the wicked complexity of the COVID-19 pandemic. *Systems* 8(2):20. https://doi.org/10.3390/systems8020020.
36. Smith, E., and R. V. Reeves. 2020. *Students of color most likely to be learning online: Districts must work even harder on race equity.* Brookings Institution, September 23. Available at: https://www.brookings.edu/blog/how-we-rise/2020/09/23/students-of-color-most-likely-to-be-learning-online-districts-must-work-even-harder-on-race-equity/ (accessed October 17, 2023).
37. Strelkovskii N., and E. Rovenskaya. 2021. Causal loop diagramming of socioeconomic impacts of COVID-19: State-of-the-art, gaps and good practices. *Systems* 9(3):65. https://doi.org/10.3390/systems9030065.
38. Trochim, W. M., D. A. Cabrera, B. Milstein, R. S. Gallagher, and S. J. Leischow. 2006. Practical challenges of systems thinking and modeling in public health. *American Journal of Public Health* 96(3):538–546. https://doi.org/10.2105/AJPH.2005.066001.
39. Turcotte-Tremblay, A.-M., I. A. Gali Gali, and V. Ridde. 2021. The unintended consequences of COVID-19 mitigation measures matter: Practical guidance for investigating them. *BMC Medical Research Methodology* 21(1):28. https://doi.org/10.1186/s12874-020-01200-x.
40. Van Lancker, W., and Z. Parolin. 2020. COVID-19, school closures, and child poverty: A social crisis in the making. *The Lancet Public Health* 5(5):e243–e244. https://doi.org/10.1016/S2468-2667(20)30084-0.
41. Viner, R., S. Russell, R. Saulle, H. Croker, C. Stansfield, J. Packer, D. Nicholls, A.-L. Goddings, C. Bonell, L. Hudson, S. Hope, J. Ward, N. Schwalbe, A. Morgan, and S. Minozzi. 2022. School closures during social lockdown and mental health, health behaviors, and well-being among children and adolescents during the first COVID-19 wave: A systematic review. *JAMA Pediatrics* 176(4):400–409. https://doi.org/10.1001/jamapediatrics.2021.5840.
42. Walsh, S., A. Chowdhury, V. Braithwaite, S. Russell, J. M. Birch, J. L. Ward, C. Waddington, C. Brayne, C. Bonell, R. M. Viner, and O. T. Mytton. 2021. Do school closures and school reopenings affect community transmission of COVID-19? A systematic review of observational studies. *BMJ Open* 11(8):e053371. https://doi.org/10.1136/bmjopen-2021-053371.
43. Webb Hooper, M., A. M. Nápoles, and E. J. Pérez-Stable. 2020. COVID-19 and racial/ethnic disparities. *JAMA* 323(24):2466–2467. https://doi.org/10.1001/jama.2020.8598.
44. WHO (World Health Organization). 2023. *Social determinants of health.* Available at: https://www.who.int/health-topics/social-determinants-of-health#tab=tab_1 (accessed October 13, 2023).
45. World Bank Group Education. 2020. *The COVID-19 pandemic: Shocks to education and policy responses.* Washington, DC: World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/33696/148198.pdf (accessed October 17, 2023)
46. Wright, A. 2021. "It's patchwork": Rural teachers struggle to connect in pandemic. *Stateline,* March 3. Available at: https://www.pewtrusts.org/en/research-and-analysis/blogs/stateline/2021/03/03/its-patchwork-rural-teachers-struggle-to-connect-in-pandemic (accessed October 17, 2023).
47. Zajacova, A., and E. M. Lawrence. 2018. The relationship between education and health: Reducing disparities through a contextual approach. *Annual Review of Public Health* 39(1):273–289. https://doi.org/10.1146/annurev-publhealth-031816-044628.
48. Zięba, K. 2021. How can systems thinking help us in the COVID-19 crisis? *Knowledge and Process Management* 29(3):221–230. https://doi.org/https://doi.org/10.1002/kpm.1680.

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Author Information

Elizabeth Ashby, MS, is Associate Program Officer, National Academies of Sciences, Engineering, and Medicine. **Charlie Minicucci, BS,** is Research Associate, National Academies of Sciences, Engineering, and Medicine. **Julie Liao, PhD,** is Program Officer, National Academies of Sciences, Engineering, and Medicine. **Danilo Buonsenso, MD, PhD,** is Pediatric Infectious Disease Physician, Department of Woman & Child Health & Public Health, Fondazione Policlinico Universitario Agostino Gemelli IRCCS. **Sebastián González-Dambrauskas, MD,** is Founder and Chair, LARed: Red Colaborativa Pediátrica de Latinoamérica and Adjunct Professor, Departamento de Pediatría y Unidad de Cuidados Intensivos de Niños, Universidad de la República. **Rafael Obregón, PhD,** is Country Representa-

tive, Paraguay, UNICEF. **Matt Zahn, MD,** is Pediatric Infectious Disease Physician, Children's Hospital of Orange County. **William Hallman, PhD,** is Professor and Chair, Department of Human Ecology, School of Environmental and Biological Sciences, Rutgers University. **Chandy John, MD, MS,** is Professor of Pediatrics, Indiana University School of Medicine.

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Correspondence

Questions or comments should be directed to Charlie Minicucci at charles.minicucci@yale.edu.

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