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Perspective

Leveraging Complex Systems Science to Advance Sexual and Gender Minority Youth Health Research and Equity

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Abstract

Over the past two decades, sexual and gender minority (SGM) youth health inequities have remained the same or widened, highlighting the need for new approaches to foster health equity. Complex systems science (CSS) techniques must be added to our armamentarium because of the following: CSS techniques can model cyclical feedback loops inherent in the relationships between SGM youth health outcomes and their multilevel causes, thereby enhancing the integration of real-world complexity in scientific models; and CSS can simulate multiple hypothetical interventions, thereby identifying future interventions with great potential impact. We describe four promising CSS techniques for advancing SGM youth health equity.

Keywords: complex systems science, public health, sexual and gender minority health, systems modeling

Introduction

Sexual and gender minority (SGM) youth (e.g., lesbian, gay, bisexual, and transgender people younger than 18 years), compared with their cisgender heterosexual peers, experience greater inequities in preventable negative health outcomes, such as substance use, mental health issues, sexually transmitted infections, and violence victimization.[1–4] Over the past several decades, many of these inequities have either remained unchanged or grown larger.[5–8] Researchers have identified drivers of these inequities at the structural, organizational, familial, interpersonal, and intrapersonal levels of the social ecological model[9,10]; however, few evidence-based interventions expand their focus beyond these intrapersonal variables, and therefore do little to address multiple drivers and efficaciously reduce SGM youth health inequities.[11]

Complex systems science (CSS) is an approach that examines how collective patterns (such as population-level health inequities) are derived from ever-evolving interrelationships among the individual parts of the system (such as how people dynamically interact with each other and their environment). CSS uses a diverse set of methodological tools (such as agent-based models, social network analysis, group-model building, and system dynamics modeling) that allow researchers to investigate complex mechanisms of health (such as bidirectional relationships and feedback loops present across multiple social ecological levels) that are often constrained or prohibited in more traditional epidemiologic and statistical modeling techniques.[12–14] We argue that CSS techniques can advance SGM youth health equity and must be added to our armamentarium because of the following: (1) CSS can model cyclical feedback loops inherent in the relationships between SGM youth health outcomes and their multiple multilevel causes, thereby enhancing the integration of real-world complexity in our scientific models; and (2) CSS allows for the simulation of hypothetical interventions at multiple points within the system, thereby informing the design of interventions with the most potential impact. Although the importance of CSS has been discussed in the context of racial and ethnic minority health inequities,[14] this article outlines the need for and benefits of

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adopting a CSS approach to better understand and reduce persistent and substantial SGM youth health inequities. We chose to focus on youth to highlight the potential of CSS in promoting multilevel preventive health interventions.

Complex Features of SGM Youth Inequities

Several complex features of SGM youth health inequities make them difficult to study and challenging to eliminate. First, SGM youth health is influenced by factors or variables *across* multiple social ecological levels (i.e., individual, interpersonal, familial, school, and structural factors).[15] The multilevel drivers of inequities impact SGM youth health through myriad, likely interconnected, pathways. Each pathway can be envisioned as its own reciprocal system of drivers that work in tandem, creating feedback loops across social ecological levels. For example, the role of SGM youth substance use is influenced by individual levels of stress, a function of SGM youth interpersonal discrimination, and violence.[1] Stress, discrimination, and violence are all in turn influenced by SGM youth policies.[16] Thus, to effectively reduce SGM youth substance use, we must intervene in these feedback loops at several levels simultaneously.

A second complex feature of SGM youth inequities is the multiplicity of mechanisms at work *within* each social ecological level.[17] For example, multiple intrapersonal dimensions, including anxiety, stress, and self-esteem, interact with each other and reinforce poor mental health outcomes.[18] In this example, health outcomes are fed back into the system as inputs, creating bidirectional linkages and feedback loops. Although research often investigates the independent effects of a single factor on a single health outcome, the bidirectional feedback loops between such factors are not well studied or understood. In addition, no single mechanism (at any level of the social ecological model) appears able to account for all that we know about SGM youth health inequities. For example, sexual orientation-inclusive antibullying policies are associated with reduced risk of suicide attempts for sexual minority youth, but they do not eliminate inequities between sexual minority and heterosexual youth.[19]

A third complex feature is the diversity of actors (''actors'' in CSS generally refers to people and places) and diversity in actors' characteristics, goals, rules, constraints, and contexts that affect SGM youth health outcomes at the individual and population levels. These actors include friends, family members, schools, health care providers, government agencies, media, and key decision makers. Each of these actors has different goals, motivations, constraints, sources of information, modes of decision-making, and types of connection to other actors and to SGM youth. Interventions can affect each actor differently, and each actor, as well as each intervention, has a different sphere of potential influence as an agent of change. Research and interventions that fail to consider the diversity, or heterogeneity, of these actors cannot leverage potential synergies. Interventions also run the risk of being ineffective if they are counteracted by other actors' behaviors.

Leveraging CSS to Advance SGM Youth Health Inequities Research

CSS is a rapidly developing, interdisciplinary field whose adherents study the nature of systems, or a group of interacting or interrelated entities that form a unified whole.[20] CSS can provide language and methods for studying the multilevel drivers and feedback mechanisms of SGM youth health inequities that tend to be studied in disciplinary silos. As shown in Table 1, complex systems have an additional array of properties or features, such as nonlinearity and emergence, that also pertain to the study of SGM youth health in important ways.[21–24]

Modeling SGM youth health inequities as a complex system

Currently, quantitative research on SGM youth health predominantly uses statistical modeling frameworks, in which researchers typically test hypotheses using participant-reported data. Qualitative research on SGM youth health primarily uses interviews and focus group discussions to better understand phenomena. Both these techniques—statistical modeling and interviews/focus groups—have led to numerous advances in the field, and we posit that CSS modeling techniques can help advance the field further.[20] Notably, the use of CSS analytic techniques often requires a shift in data collection as well. For example, data collection may be at the individual level as well as the groups in which they are embedded, such as neighborhoods or cities, and be collected using self-report, administrative data sets, or smartphone data, among other methods.

To better understand complex phenomena, complex system scientists use different kinds of analytic techniques (Table 2).[25–33] For example, the most widely used CSS technique in the study of SGM youth health is social network analysis. Social network analysis is salient for mapping and measuring relationships and flows between people or groups of people, and has been used to study how peer relationships serve as risk or protective factors in the field of SGM youth health.[28] However, social network analysis is limited in its ability to capture many of the complex features of SGM youth health inequities, such as multiple levels of influence and multiple mechanistic drivers.

There are several other qualitative and quantitative CSS analytic techniques that can help elucidate the complexity of SGM youth health inequities (Table 2).[30–33] Qualitatively, group model building is a technique that has stakeholders create causal loop diagrams that visually capture the relationships and feedback loops among multilevel drivers of SGM youth health inequities. These causal loop diagrams help to make implicit mental models more explicit, thereby revealing our assumptions about the cyclical relationships embedded in the system. Subsequently, the results from group model building sessions can inform the design and testing of more quantitative, computational modeling techniques such as system dynamics models and agent-based models. Unlike system dynamics models, agent-based models can capture individual agent-level insights by incorporating heterogeneity, adaptation, or emergence. These types of simulation models can further help us understand the complexity of SGM youth health inequities and test plausible hypotheses about an SGM youth health driver to see whether they produce similar or different dynamics from the real behavior of the system.[31,32]

Identifying intervention points in the complex system to reduce SGM youth health inequities

In addition to better modeling the complexity of SGM youth health inequities, researchers can use CSS tools to

Table 1. Complex System Features and Their Applications in Sexual and Gender Minority Youth Health Research

Feature	*Description of the feature*	*Applications in extant SGM youth health research*
Multilevel	Complex systems generally consist of multilevel variables that span micro-, individual-level behavior to macro-, community-level behavior.	Research often examines individual- and higher social ecological-level exposures (e.g., school-level or policy-level). This research often examines the impact/association of the higher level exposure on an individual-level outcome but does not examine how individual-level behaviors impact higher level behaviors/exposures.
Heterogeneity	Substantial diversity in actors' characteristics, goals, rules, and constraints at each level.	SGM youth research often incorporates agents with heterogeneous individual-level characteristics (e.g., sexual orientation, gender, race/ethnicity, age) and some research incorporates actors with heterogenous school-level characteristics (e.g., presence of a gay/straight alliance, presence of inclusive sexual education) or state-level characteristics (e.g., structural stigma, gay marriage legality, housing rights).
Nonlinearity	Small actions can have large consequences. A change in the size of the input does not produce a proportional change in the size of the output.	SGM youth research often uses statistical modeling that assumes linearity, however, statistical interaction terms are sometimes explored and tested. For example, research may examine the statistical interaction among several demographic characteristics and a health outcome such as quality of life, or how multiple forms of discrimination statistically interact to affect outcomes.
Stochasticity	Outcomes and system behaviors are, unpredictable, sometimes random and uncontrollable, and many times unknowable in advance.	SGM youth research often assumes uncertainty or error in regression models. Research often recognizes that only a proportion of the variance in outcome (e.g., R^2) is explained by variables in the statistical model.
Dynamicism	Interactions within, between, and among systems are often changing. Past behavior of the system affects future behavior of the system.	A large proportion of SGM youth research is cross-sectional, and therefore static in nature. However, longitudinal research and serial cross-sectional research are starting to grow.
Interdependence	Complex systems usually contain many interdependent and interacting actors, connected across different levels with feedback and nonlinear dynamics.	In cross-sectional SGM youth research, researchers will often control for the nonindependence of school or familial clusters. In longitudinal research, researchers will often control for nonindependence of observations within individuals. However, rarely does SGM youth health research examine the bidirectional interactions between agents, except in the rare instances of social network analyses.
Feedback	Feedback, also known as feedback loops, is a closed chain of causal connection. For example, a change in one variable X affects change in another variable Y; subsequently, the change in variable Y affects change in variable X. Feedback loops result in either amplification (positive feedback) of both variables or balancing (negative feedback) of both variables.	SGM youth health research often assumes a cyclical relationship between variables, although some longitudinal research examines the bidirectionality of associations between variables. One example looks at the overlap and separation of SGM youths' experiences and their relationships with their parents; the reinforcement of these experiences creates a feedback loop, where parental affirmation or discouragement feeds into SGM youths' other experiences.[23]
Emergence	Occurrence of unexpected phenomena—patterns of collective behavior that form in the system are difficult to predict from separate understanding of each individual element.	Rarely does SGM youth health research examine emergence because dynamicism and feedback loops are often not incorporated into statistical modeling.
Adaptation and self-organization	Interacting elements and agents respond and adapt to each other; emergent behavior is a function of ongoing adaptation among both interacting elements and the responsive relationships interacting agents have with their environment.	It is rare for research to examine how collective behavior emerges and changes over time or is sensitive to initial conditions. SGM youth emergent behaviors are often rooted in emergent identities; upon coming out, reactive adaptations due to multiple oppressive systems may influence an adolescent's identity and subsequent behaviors.[24] However, these behaviors are rarely contextualized as an ongoing adaptation, and it is difficult to track changes to initial conditions in SGM youth health research.

SGM, sexual and gender minority.

TABLE 2. COMPLEX SYSTEMS SCIENCE ANALYTIC TECHNIQUES AND THEIR APPLICATIONS IN SEXUAL AND GENDER MINORITY YOUTH HEALTH RESEARCH

Analytic technique	*Description of the technique*	*Example research question(s)*	*Related applications in extant SGM youth health research*
Social network analysis	Analysis of social structures using networks and graph theory by mapping and measuring relationships among any types of connected entity (e.g., people, groups, organizations). One of its main goals is to understand a community by mapping the relationships that connect them as a network.	Does victimization starting at age 9 differ by sexual orientation, whereby youth who report a sexual minority status by age 15 indicate higher self, teacher, and primary caregiver reported victimization?[25] Do students' experiences in their GSAs over the school year predict positive development or thriving in the form of higher relative levels of hope at the end of the school year? Do GSA experiences promote resilience by attenuating the link between victimization and lower relative levels of hope among 366 student members of 38 GSAs?[26]	A few studies have examined how social networks serve as risk or protective factors among SGM youth. Stigmatization, aggression, and homophobic behaviors within high school peer networks increase mental health inequities and perpetuate victimization.[26,27] One such factor is homophobic name-calling, which predicts lower levels of self-esteem and affects how gender minority youth self-identify.[28] Among Black young MSM, social network analysis has linked health risk behaviors to social venues.[29] These social clusters serve as a nexus for youth to engage in health risk behaviors, including drug use and condomless sex.[29] Social networks may also serve to guard SGM youth. Homophilous friendships and school diversity are two protective factors that mitigate negative social influences and lessen health risk behaviors.[25,30]
Group model building	A participatory systems modeling method that involves stakeholders in the process of conceptualizing, formulating, testing and validating, analyzing, and implementing system models. One of its main goals is to build the capacity of stakeholders to think systemically as well as create consensus around a topic or issue.		To our knowledge, this technique has not been used in health research with SGM youth; however, it could help researchers and community partners to analyze where in their system an intervention or policy may have the most impact. In addition, because this technique is participatory in nature, it could be useful for understanding the multilevel drivers among marginalized groups whose experiences are underrepresented in research literature.
System dynamics modeling	A mathematical approach to understand the nonlinear behavior of complex systems using an array of modeling techniques such as stock and flow diagrams and causal loop diagrams. One of its main goals is to visualize and understand complex issues.		To our knowledge, this technique has not been used in SGM youth health research; however, it could help researchers and community partners to analyze where in their system an intervention or policy may have the most impact.

(*continued*)

TABLE 2. (CONTINUED)

Analytic technique	*Description of the technique*	*Example research question(s)*	*Related applications in extant SGM youth health research*
Agent-based modeling	A computational modeling process that simulates the actions and interactions of heterogeneous and autonomous agents. One of its main goals is to understand the effects of individual behavior on the system as a whole by modeling interactions of agents in their environment.	Can referral networks among HIV testing and LTC providers have the potential to reduce time from diagnosis to linkage to care?[31] What are the impacts of different PrEP prioritization strategies among Black and Latino MSM in the United States?[32]	This technique has been utilized primarily in SGM youth research to examine HIV outcomes among young MSM. A recent study used agent-based modeling to test two LTCs, which can help youth living with HIV to engage in timely care despite systemic barriers.[31] This is particularly pertinent for non-Hispanic Black youth and young MSM, as HIV prevalence is disproportionately higher among these populations.[33] Similar studies have used agent-based modeling to identify network-level mechanisms to further understand racial/ethnic disparities in HIV spread among Black and Latino MSM.[32] For example, agent-based modeling has been used among adults to examine the impact of various PrEP prioritization strategies on HIV transmission among Black and Latino MSM.[32]

GSAs, gender-sexuality alliances; LTCs, linkage to care interventions; MSM, men who have sex with men; PrEP, pre-exposure prophylaxis.

advance SGM youth health equity policy and interventions. Current research on policy and interventions for improving SGM youth health has (1) relied heavily on observational data and/or experimental trials[11]; (2) focused largely on HIV with limited evidence-based interventions on mental health, substance use, and violence victimization[33]; and (3) rarely focused on examining the effects of interventions on multiple health outcomes among SGM youth.[6,11] CSS can help advance SGM youth health equity intervention research in multiple ways. Causal loop diagramming can qualitatively identify the primary driving mechanisms through which SGM youth health inequities are reinforced, and then can become the targets for future interventions. More quantitative CSS techniques, such as system dynamics models, can simulate the effects of a hypothetical intervention as well as potential intervention combinations for maximal effect on SGM youth health equity. In addition, agent-based models can explicitly be used to simulate where interventions should be placed geographically and how widely the interventions have to be disseminated to achieve certain levels of SGM youth health equity. These simulations can be used to plan and test future experimental trials, as well as to help researchers, public health decision makers, and program implementers identify dissemination and implementation challenges.[34]

Conclusion

Several attributes of complex systems—the number of ecologic levels involved, the multiplicity of mechanisms implicated, and the substantial diversity of relevant actors—are relevant to the study of SGM youth health. Therefore, CSS approaches are warranted in SGM youth health (as we have illustrated) and may also enhance the field of SGM health research more broadly. CSS techniques—such as agent-based modeling, social network analysis, group-model building, and system dynamics modeling—are promising methodological tools for future research and have the ability to inform effective interventions and policies that foster SGM health equity.

Authors' Contributions

T.R.M. is the primary author of this article, and co-led the writing and thinking. E.N.F. contributed to generating the necessary citations and reviewing the literature to support the text. C.M. and J.G.B. reviewed the article and contributed to thinking around complexity theory, editing as necessary. R.W.S.C. is the senior author of this article and organized meetings and co-led the writing and thinking. All coauthors reviewed and approved the article before submission.

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