WORK IN PROGRESS AND LESSONS LEARNED

Community- based systems dynamics for Reproductive Health:

An Example from Urban Ohio, USA

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Submitted 28 October 2020, revised 28 December 2021, accepted 18 February 2022.

ABSTRACT:

Background: Health outcomes, risk factors, and policies are complexly related to the reproductive health system. Systems-level frameworks for understanding and acting within communities through community-engaged research are needed to mitigate adverse reproductive health outcomes more effectively within the community.

Objectives: To describe and share lessons learned from an ongoing application of a participatory modeling approach (community-based system dynamics) that aims to eliminate racial inequities in Black-White reproductive health outcomes.

Methods: The community-based system dynamics approach involves conducting complementary activities, workshops, modeling, and dissemination. We organized workshops, co-developed a causal loop diagram of the reproductive health system with participants from the community, and created materials to disseminate workshop findings and preliminary models.

Lessons Learned: Many opportunities exist for cross-fertilization of best practices between community-based system dynamics and community-based participatory research. Shared learning environments offer benefits for modelers and domain experts alike. Additionally, identifying local champions from the community helps manage group dynamics.

Conclusions: Community-based system dynamics is well-suited for understanding complexity in the reproductive health system. It allows participants from diverse perspectives to identify strategies to eliminate racial inequities in reproductive health outcomes.

KEYWORDS:

Reproductive History, Community health partnerships, Health disparities, Community-based system dynamics, Midwestern United States

Introduction

Pregnancy, abortion, and infant and maternal outcomes, which we collectively label as "reproductive health outcomes", are associated with a complex set of risk factors. Additionally, these reproductive health outcomes are affected by a diverse set of current and historical social, economic, and political forces. The dynamics of the reproductive health system, which encompass the interactions between risk factors, policies, and outcomes, remain under-researched. The reproductive health system is complex because health outcomes are affected by multiple risk factors at several levels of organization. As a result, this complexity should be considered when designing and implementing policies to address reproductive health outcomes.

At the individual level, risk factors for reproductive health outcomes include lack of access to prenatal care (1), limited transportation options for prenatal visits (2), lack of sex education in schools (3), and lack of access to and use of contraception (4). Policies related to the maternity/paternity leave (5) and health insurance coverage at the institutional level (e.g., employers) also affect reproductive health outcomes. At the federal and state level there are additional policies (e.g., Medicaid (6)) that affect reproductive health outcomes. At the community and interpersonal level, several risk factors and policies have been associated with reproductive health outcomes including high-police contact (7), material and physical environment (8), structural racism/historical redlining (9), and social networks (10). Additionally, inter-level feedback also occurs (e.g. intergenerational transmission of poor reproductive health outcomes (11)). Most studies of the reproductive health system focus on only one or two factors of interest. Few studies focus on the nonlinear relationships and interactions between such factors and levels.

In this manuscript, we describe how we established partnerships and used a participatory modeling approach, which is rooted in systems science, to understand the dynamics, feedbacks, and nonlinearities in the reproductive health system. The project we describe is a work-in-progress and we share lessons learned regarding the approach we took rather than scientific findings, which we plan to describe at the end of the project.

Systems-level frameworks for understanding and acting within communities through community-engaged research are needed to mitigate adverse reproductive health outcomes more effectively within the community. While several such frameworks exist (e.g. the Preconception Stress and Resiliency Pathways Model (12) and the Perinatal Periods of Risk (13)), the lack of a modeling component within these frameworks makes it difficult to explain and predict the impact of interventions. Including a modeling component, especially one that is informed and co-developed by community partners who design and implement interventions in real-world settings, offers several advantages. First, the model itself can serve to highlight boundaries for the community partners in terms of the set of modifiable risk factors they can address given the reproductive health outcomes of interest to their organization. As such, the co-creation of the model underscores the specific role of each participant in affecting one or more outcomes, risk factors, or policies that may be collectively identified by community partners. Second, the model can be used to guide data collection/sharing because community partners may see the value of providing and using data for shared decision-making based on insights from the co-developed model. Lastly, in contrast to models based on a single stakeholder's role and input (e.g., health care system develops a prediction model for risk of preterm birth), a community that co-creates a model may be more likely to use the model for taking actions through policy development,

"What if?" scenario analysis, and asking new questions together based on the diverse perspective that is captured in the model.

Community-based system dynamics is an approach that brings community partners together in the process of understanding and changing systems. Sometimes the goal from the outset, is to transform the system as a long-term goal of the community partners. At other times, this approach lends itself to learning about the system or figuring out how to coordinate within the system. The community-based system dynamics approach is ideal for public health practice because it allows decision-makers to understand the complexity in a system where multiple risk factors may be operating at multiple levels of organization. The community-based system dynamics approach also provides the community of decision-makers with policy simulation models (14) for improving their understanding of the system and for evaluating the potential impact of interventions before implementing interventions in real-world settings. Within the field of systems science the community-based system dynamics approach has been used to understand and address challenges in health systems research at large (15), including chronic diseases, (16), and obesity (17). Within the area of reproductive health, systems science studies have included assessments of policy options for infant mortality in Ohio (18), neonatal health in Uganda (19), gestational diabetes in Australia (20), maternal and neonatal survival in Honduras (21), and health-seeking behavior of pregnant women in Pakistan (22). These studies have been limited in scope to specific outcomes (e.g., gestational diabetes in (20)), specific group model building scripts (e.g., parameter value elicitation in (18)), or focused mainly on reporting the results of a simulation model (22). Missing from the literature are descriptions of implementing the community-based system dynamics approach to transform the reproductive health system. Such descriptions exist in studies for multiple social, welfare, health and healthcare outcomes, and

public health systems research (20, 23-26) but, to the best of our knowledge, not for the reproductive health system. The reproductive health system differs from public health systems because of its focus on risk factors and policies associated specifically with reproductive health outcomes as described above. We sought to fill this gap in knowledge by focusing on the reproductive health system in urban Ohio.

We applied the community-based system dynamics approach in urban Ohio because of the racial disparities that exist in the state within several reproductive health outcomes (21, 22). Additionally, our team is based in Ohio and had a large existing network of community partners for successfully applying this new approach in the context of reproductive health. Compared to the US national average, Ohio ranks poorly in several reproductive health outcomes, including preterm birth (rank 33/50), infant mortality (rank 41/50), and maternal mortality (rank 21/50) (21). Prevalence of each of these outcomes among Black women in Ohio is almost double that among White women (% live births that were preterm among Black women: 17.2%, White women 11.0%; infant mortality rate among Black infants 13.6 per 1000 live births, White infants 6.3 per 1000 live births)(27, 28). Additionally, people in Ohio are increasingly facing limited access to contraception and abortion services in a legislative landscape that is rapidly changing and remains uncertain at the state and federal level (23). In light of these inequities and challenges, patient advocates, reproductive justice-focused community-based organizations, local/state health and Medicaid departments, and healthcare providers, have been collaborating in Ohio since 2012 to design, implement, evaluate and scale (from local to statewide) intervention/prevention strategies for reducing racial disparities in pregnancy, infant, birth, and maternal outcomes (29). These collaborative efforts have included statewide initiatives, such as the Ohio Collaborative for Preventing Infant Mortality and the Ohio Equity Institute. One

outcome of these efforts in Ohio has been a culture of collaboration, data sharing, and community engagement. This is important because Ohio has an ever-changing and restrictive legislative landscape towards contraception and abortion (23). We applied the community-based system dynamics approach through the lens of the reproductive justice field (30, 31). Reproductive justice highlights the social, economic, and political inequalities within reproductive healthcare and how people experiencing multiple, intersecting forms of oppression face immense barriers to care. The reproductive justice lens supports the application of community-based system dynamics because it connects the dots between multiple types of risk factors (e.g., proximal/distal, individual/neighborhood), outcomes (e.g., pregnancy, infant and maternal), and policies (e.g., institutional, public, insurance).

Methods

Recruiting Participants from the Community and Forming the Partnership

We recruited participants for group model building workshops from the community. For this project, we defined community as the group of individuals whose work addresses risk factors, policies, and outcomes associated with the reproductive health system in urban Ohio. Group model building workshops were typically half-day meetings involving facilitated group discussions and scripted activities led by the project team. We identified potential participants through various methods that included the professional networks of two project authors (AH, AN), the project team's interactions with attendees of statewide meetings organized by the Ohio Collaborative for Preventing Infant Mortality, and membership lists of workgroups that project authors participated in, such as the Health Equity Advisory Working Group, which was

organized by the Health Policy Institute of Ohio, and LARC Access Ohio (LARC stands for long-acting reversible contraception), which was organized by the Ohio Better Birth Outcomes initiative. We sought a diversity of perspectives (see Categories and Examples in Table 1) from potential participants during the recruitment process. We collected information about potential participants: name, job title or position, name of the organization they worked for or represented, seniority level at the organization, and the perspective we thought they would present during the group model building workshops based on their job title and organization. The subset of participants whom we invited to participate was selected by the project team based on the following considerations: i) offering multiple perspectives and backgrounds during the workshops, and ii) high likelihood of adopting workshop findings within their organization or the people served by their organization.

We initially invited 38 people to participate in the group model building workshops, out of which 22 people accepted the invitation. Ultimately, 18 people attended the first workshop (Table 1). People who declined the invitation or did not respond to the initial invitation email were proportionally more likely to be the ones who could have provided the provider, patient, or scholarly organization perspective at the workshops. “Proportionally” here refers to the number of people who declined the invitation divided by the number of people from a given perspective who were invited to participate. We did not ask the four invitees, who initially accepted the invitation to participate but were unable to participate in the first workshop, why they were unable to participate. These four participants voluntarily offered that they either had clinical responsibilities or that they were not available to attend all of the group model building workshops. Some invitees who declined the invitation suggested other relevant people from their

organizations; we invited those people and subsequently had 18 participants at the first group model building workshop.

We formed a partnership with community partners who attended the group model building workshops. The basis for the partnership was taking part in the group model building workshops, identifying potential datasets for the project team to review, and providing feedback in between workshops on various workshop outputs (e.g., policy simulation dashboard). We aimed to keep the total number of workshop participants between 15 and 20 people based on best practices from other community-engaged researchers who have applied the community-based system dynamics approach (14). The partnership lasted from the first workshop, which was held in February 2019 to the last workshop, which was held in May 2020. We held a total of five workshops over the course of the partnership. Participation across the workshops ranged from 11 to 18 people because some participants were unavailable due to commitments such as childcare, vacation, and work-related activities. Some members of the project team have remained in touch with some of the participants even though the partnership was formally ended in May 2020. To ensure equitable access and participation, we offered to reimburse participants for travel costs to attend workshops. We paid a per diem amount to participants who were not paid by their organization to attend the workshops as part of their regular work responsibilities.

Group model building workshop participants offered a range of perspectives and came from different professional backgrounds and types of organizations (Table 2). They represented community organizations (n=9), local public health departments (n=6), state health/healthcare agencies (n=2), and one each from healthcare organizations, patient advocates, providers, and scholarly organizations. Geographically, participants were from either a major urban center in

Ohio (n=7), a medium-sized city (n=7), or statewide organizations (n=4). Most of the participants did not know of each other prior to the start of the partnership because they worked in different geographic regions of Ohio and had different roles within their organizations (Table 2). The rest of this section describes the community-based system dynamics approach, which consisted of a Core Modeling Team. The Core Modeling Team's objective was to organize each group model building workshop, facilitate the development of a system dynamics model, and disseminate outputs and insights from the series of workshops and related modeling activities. This project was approved by the Ohio State University Institutional Review Board (Approval # 2018H0113).

The community-based system dynamics approach

Core Modeling Team: The Core Modeling Team was responsible for designing and conducting each group model building workshop (see below). It consisted of individuals from the project team who were domain experts in contraception and abortion (AN) and social determinants of health and birth outcomes (SSJ) along with an expert in systems modeling with general expertise in perinatal epidemiology (AH). The Core Modeling Team held practice sessions prior to the first two workshops and led the facilitated exercises during each workshop.

Group model building (GMB) workshops: The format for each workshop was a set of activities involving facilitated discussions using pre-specified scripts. We held all workshops in person except the third and fifth workshops, which were held online. A brief description of each workshop is provided in Table 3. The activities for each workshop were based on established and in-development scripts (32) as well as new scripts (including "Key Stakeholders", "Data

Sources", and "Decisions and Communicating the Model"). See Supplementary Material for details on the Key Stakeholder script. We also developed a facilitation guide for each workshop, which included a minute-by-minute agenda with step-by-step instructions for each activity, instructions on how to arrange the room, and the roles and responsibilities of each member of the group model building facilitation team. The group model building facilitation team consisted of Core Modeling Team members and helpers for logistical and technical support including note-takers.

Each workshop had a range of goals, from creating the problem statement to identifying relevant policies, to developing and revising the causal loop diagrams. The helpers on the group model building facilitation team documented the outputs of each activity during the workshops, including notetaking during facilitated discussions and taking pictures of diagrams drawn by workshop participants on whiteboards or paper. These outputs of each workshop were "digitized" so that they could be retained as the products of the workshop and easily shared with participants in subsequent workshops. In the next section, we describe and give examples of the outputs from each workshop.

System dynamics modeling: We translated multiple diverse, co-created, and implicit mental models of the reproductive health system, which were outputs generated by participants during the group model building workshops, into a single explicit model—the causal loop diagram. A causal loop diagram is a visual representation of the variables and the links between them that show all the relationships that matter given the problem statement. We used the STELLA software (33) to create digital versions of the causal loop diagrams, which were later converted into a computer simulation model, specifically a system dynamics model. Although

we are currently in the process of finalizing the system dynamics model, we used a draft version of it to develop an interactive policy simulation dashboard. We obtained feedback from participants on the design and layout of the dashboard during the last group model building workshop. Once the system dynamics model is finalized by our team we will provide participants and other stakeholders access to the policy simulation dashboard, which they can use to predict the impact of various types of policies on reproductive health outcomes.

Dissemination We used several strategies to help group model building participants disseminate information about the community-based system dynamics approach and make use of the outputs that were co-developed during the partnership. First, we wrote a short primer on the community-based system dynamics approach for a general audience. Second, we shared examples of web-based applications for visualizing and sharing workshop outputs, such as the interactive causal loop diagram and interactive policy simulation dashboard (34, 35). Draft versions of these interactive products are currently available upon request from the authors. The final causal loop diagram is provided in the Supplement Material in PDF format. Third, we summarized group model building activities and outputs into a two-page document that participants could share within their organizations and with external collaborators and stakeholders. Lastly, given the complexity of the final causal loop diagram that was developed by participants, we offered to mail them a poster-sized version of the final causal loop diagram.

Results: A summary of the five group model building workshops

In this section, we describe the process and engagement activities related to each group model building workshop rather than what participants said about the reproductive health

system. Our rationale for the emphasis on workshop process and engagement activities is to identify lessons learned from applying the community-based system dynamics approach to understand the complexity of the reproductive health system. In subsequent manuscripts, we plan to describe what we learned about the reproductive health system and insights from the system dynamics model that was co-developed with workshop participants.

Workshop #1: Before this workshop, the project team developed a draft problem statement: *"How do contextual factors, norms, and policies in urban Ohio impact access to and use of reproductive health services (e.g., contraception, abortion, prenatal care, birth care), pregnancy, and maternal and child health?"* We used a facilitation guide to conduct the workshop. Initial workshop activities were focused on participants getting to know each other and the Core Modeling Team. Several activities aided in achieving this objective. The process of sharing "hopes and concerns" (Table 4) allowed participants to become comfortable with each other and the workshop format, providing a solid foundation for collaboration in subsequent activities. We led participants through an activity to collectively develop a problem statement that identified key issues within the reproductive health system in urban Ohio. The draft problem statement (described above) was revised by the participants to the following: "*How do social determinants of health, biases, attitudes, cultural norms, laws, and policies in urban Ohio impact access to and use of reproductive and other health services (e.g., contraception, abortion, prenatal care, birth care), pregnancy, and maternal and child health?*" This problem statement served as a boundary object for the partnership because participants could refer to it as they worked through facilitated group-based activities for the rest of the first and subsequent group model building workshops.

After finalizing the problem statement, the workshop facilitators led several activities that focused on identifying the most important policies and interventions related to the reproductive health system. First, participants identified 35 key stakeholders relevant to the problem statement and described the level of power and interest of these stakeholders to act on the stated problem (Fig. 1 and Supplementary Materials Table S1). Second, participants identified 27 different policies that were relevant to the problem statement (Table 5). Third, participants generated illustrations, which are known as graphs-over-time in the system dynamics literature(36), of the hoped, expected, and concerning trends for each of the outcomes identified in the problem statement (Fig. 2 and section in Supplementary Materials titled "Full list of variables in the Graphs-over-Time exercise"). Finally, the Core Modeling Team did a short presentation for participants on System Dynamics models and explained how such models were going to be developed, calibrated, and validated based on outputs of workshop activities throughout the partnership. This demonstration gave participants an idea of a tangible deliverable of the partnership.

Workshop #2: The goal of this workshop was to build upon outputs from workshop #1 and begin converging on a co-created causal loop diagram based on the problem statement. Therefore, before the workshop, the Core Modeling Team sketched out examples of causal loop diagrams that would be shown to participants during the workshop and developed a facilitation guide for the workshop. The facilitation guide for this workshop was kept flexible in terms of the roles and responsibilities of project team members because we did not know how the participants would want to develop causal loop diagrams (e.g., option #1: separating into multiple smaller groups to develop multiple causal loop diagrams, which would be eventually consolidated into a

single causal loop diagram, or option#2: remaining together as a larger group and developing a single causal loop diagram). Also, we did not know how long the causal loop diagram activity would take in practice because it was a group-based activity in which managing participant input equitably was going to be critical for reducing bias due to group thinking and perceived or real power dynamics between the group of participants.

During the workshop, facilitators from the Core Modeling Team reviewed digitized versions of each of the outputs from workshop #1. Next, we conducted a variable elicitation activity where participants were asked to generate an initial list of variables that in their mind were related to the outcomes of interest (e.g., infant survival, a person receiving sex education in high school). Participants generated an initial list of 49 variables. When given the two options about how to develop a causal loop diagram, the consensus among participants was to split up into smaller groups (option #1 from above). Thus, we split up participants into four groups and facilitated a "connection circles" activity based on the problem statement. A "connection circle" is a simplified version of causal loop diagrams where variables of interest are placed around a circle and arrows are drawn to show the relationships that matter between variables. After drawing their "connection circles", each group transitioned to developing and refining a causal loop diagram for the remainder of the workshop. Participants reviewed the digitized materials from workshop #1 to help them develop causal loop diagrams (e.g., reviewing the policy levers identified in workshop #1 to identify relationships that matter, directionality, and type of relationship between variables in the causal loop diagram). After the workshop, the Core Modeling Team digitized each group's causal loop diagram (Supplementary Material Fig. S1). Also, the Core Modeling Team consolidated each group's causal loop diagrams into a single

causal loop diagram by combining variables that were worded similarly or referred to the same variable or variables based on a common theme (Table 6). The consolidated causal loop diagram was digitized so it could be presented to participants for their feedback in the next workshop.

Workshop #3: This workshop took place virtually because the goal of the workshop was to validate the consolidated causal loop diagram through a shorter facilitated discussion compared to previous workshops. This was an important goal to achieve prior to using the causal loop diagram to start developing the system dynamics model. Notably, when the consolidated causal loop diagram was presented to participants for feedback, participants initially rejected it as being too simplistic and failing to account for the rich complexity in each group's causal loop diagram from workshop #2. This important turning point in the community engagement process was evidence of a misalignment between the mental models of the Core Modeling Team and the participants. After the workshop, the Core Modeling Team revised how they combined each group's causal loop diagram based on feedback received during the workshop.

Workshop #4: Before the workshop, the project team printed out a poster-size version of the revised consolidated causal loop diagram and developed the workshop facilitation guide with the primary goal of re-aligning the mental models and frames of reference between participants and the Core Modeling Team. During the workshop, participants were asked to mark up the poster with the causal loop diagram with any changes in terms of additional variables and relationships. The act of a workshop facilitator handing a writing instrument to participants and offering them the opportunity to make changes on the diagram was emblematic of transferring power and ownership of the causal diagram from the Core Modeling Team back to the workshop participants. In addition, we conducted demonstrations of a very simple system dynamics model

based on the revised causal loop diagram and a web-based interactive policy simulation dashboard. These demonstrations allowed participants to clearly comprehend how the Core Modeling Team planned to convert the final causal loop diagram and other outputs from the group model building workshops into a practical set of tools for understanding the complexity of the reproductive health system. Also, offering participants and their stakeholders with decision-making tools to evaluate the impact of different policies on reproductive health outcomes was expected to achieve the long-term goals of the project, which was to transform the reproductive health system in urban Ohio.

Participants spent a substantial part of the workshop reviewing a list of data sources for variables needed to develop, calibrate and validate the system dynamics model and having discussions to reach a consensus about how to categorize data sources that would be used to build the model (see "Categorization of data sources" in Supplementary Materials). Participants also raised questions about how the project team, especially the modelers, would incorporate structural and institutional racism into the various deliverables of the partnership, including the causal loop diagram and, subsequently, the system dynamics model and the policy simulation dashboard. Ultimately, participants reached a consensus that each of these three deliverables should focus on Black people of reproductive age and the risk factors and policies that are associated with their reproductive health outcomes.

Workshop #5: This workshop took place several months after workshop #4 and was the last workshop in the partnership. The delay in conducting workshop #5 was due to two reasons: limited availability of participants and delays in the development of the system dynamics model and the policy simulation dashboard. Underlying both of these reasons was the pivot that many

of the participants, Core Modeling Team members, and other project members made towards state and local COVID-19 pandemic response and recovery efforts. When the workshop was eventually held, the model and dashboard were still being tested and refined but our team had made enough progress such that both deliverables were available for feedback from participants during the workshop. In keeping with best practices during the pandemic, this workshop was held virtually.

During this final workshop, participants were once again able to see the final causal loop diagram as it was revised following previous discussions. We also used this time to offer specific suggestions to participants for using the causal loop diagram to explain the complex nature of urban Ohio's reproductive health system to their stakeholders, such as how to interpret the interactive causal loop diagram, identifying feedback loops, and reviewing data sources for the policy simulation model. Additionally, the Core Modeling Team described the process of how the project team used the variables and policy levers that were identified by the participants during workshop #1 to build the causal loop diagram that was finalized by participants in workshop #4 to develop the near-final version of the system dynamics model. Finally, we previewed a working version of the policy simulation dashboard to elicit feedback on which elements to keep or change, as well as the usability of the dashboard.

After the workshop, the modelers within the project team have continued to refine and update the system dynamics model and the policy simulation dashboard. Simultaneously, we have created content for a project website that will eventually include background materials on the group model building workshop process, sample facilitation guides that we used during each workshop, digitized versions of outputs from each workshop (e.g., causal loop diagram, power

vs interest graph), and a short writeup on the problem statement and racial gaps within infant mortality and other reproductive health outcomes in Ohio.

The project website, which remains a work-in-progress, will eventually include explainer videos describing the community-based system dynamics approach and tutorial videos that show stakeholders, such as participants in this project, decision-makers who work with those participants, and the people served by participants' organizations, how to disentangle the complex set of relationships in the reproductive health system in Ohio, and how to use the policy simulation dashboard for evaluating the impact of one or more policies to close the racial gap in reproductive health outcomes. We also remain engaged with some of the participants (e.g., a health commissioner of a county health department and an administrator at a healthcare system) who have asked the project team to present the findings of this project to their organizations and develop versions of the system dynamics model and the policy simulation dashboard to fit the specific needs of their organizations and the communities they serve in Ohio.

Conclusions and Lessons Learned

Lessons learned

We learned several lessons from using the community-based system dynamics approach to understand the complexity of the outcomes, policies, and factors in the reproductive health system. The first set of lessons was related to the structural aspects of the approach. The structure of the Core Mapping Team would ideally have included a local champion from the set of community participants who took part in the group model building workshops. The local champion would have been able to advocate on behalf of workshop participants in a more timely

and effective manner. Additionally, the compensation structure for participants could have been made more equitable and transparent to reduce the likelihood of participants feeling singled out for requesting compensation during the workshop. We also learned how to efficiently structure workshops. While we made our workshops half-day-long commitments with two or more months in between each workshop, it may have been better to have workshops that were shorter in length and less spaced out. This would have provided more opportunities for engagement and, consequently, reduced the chances of misalignment between the mental models of the Core Modeling Team and the participants. We learned a major lesson in workshop #3 where we had to correct a misalignment between the Core Modeling Team and participants in a timely manner. We also had to be humble about admitting our mistakes as academics, which was critical in regaining the trust of the community participants. This is an important lesson when using the community-based systems approach, where there are many components where misalignment can occur. It is critical to correct misalignments quickly since each set of activities builds upon each other. In other words, not addressing misalignment earlier on between the Core Modeling Team and the participants can potentially derail the whole project in the long term.

The second set of lessons learned was related to the process aspects of the community-based systems dynamics approach. This first workshop illustrated the critical role participants played in co-developing and face validating each deliverable of the partnership. During the first workshop, some of the processes worked well (e.g., room layout, duration of each workshop activity, providing coffee-infused chocolates during the late afternoon period) and some did not (e.g., taking a long time to transfer text from whiteboard to PowerPoint, hard to find parking at a university campus for participants, and complicated instructions for some workshop activities).

Our team took what we learned from the first workshop (e.g., simplifying instructions and practicing giving instructions to participants, finding an off-campus workshop location with easier access and parking) and applied it to future workshops. Another lesson learned was the importance of regularly presenting co-created boundary objects (e.g., lists of policies and key stakeholders, the power vs. interest graph, list of variables and data sources) to participants. This was especially important because of the long gaps between workshops. We had to convert the last workshop to be online because of the long delay between workshops #4 and #5 due to the COVID-19 pandemic. At the start of workshop #5, we summarized the various outputs participants had co-created from all previous workshops before doing a demo of the policy simulation dashboard. Some activities in the community-based system dynamics approach were more suitable in online format than others. For example, it would not have been practical nor effective to conduct workshops #1 and #2 in an online format. In workshop #1, participants were still getting to know each other and the Core Modeling Team. In workshop #2, several activities required group participation and drawing out connection circles and causal loop diagrams, which are not easy to do in an online format.

The last set of lessons is related to cultural aspects of the community-based system dynamics approach. These cultural aspects can be divided into lessons applicable for researchers in general and lessons applicable for researchers seeking to do community-engaged research. For the former group, we learned that modelers and non-modelers need to set aside ample time to practice facilitating exercises for the group model building workshops and must be intentional in learning about concepts, nuances, and norms of each domain involved in the project. This was an important lesson for us because it helped educate modelers and non-modelers on the Core

Modeling Team about the appropriate language (e.g., pregnant people instead of pregnant women) and the local context (e.g., social, political, and religious factors) before facilitating group model building workshops. Learning this language and context can help modelers build better models for public health practice. Unfortunately, limited opportunities exist for learning and applying systems science methods in public health practice within current public health education programs (37, 38). This limitation can be addressed by experimenting with different pedagogies where modelers and non-modelers collaborate in community-engaged research projects using approaches, such as community-based system dynamics, that uniquely combine qualitative methods and quantitative methods. For example, modelers in this project had to lean in and learn about reproductive justice principles.

For researchers seeking to conduct community-engaged research a major lesson learned was to follow best practices for the community-based participatory research (39) and where possible adapt them while applying the community-based system dynamics approach. The group model building workshops were analogous to a Community Advisory Board, which is commonly set up in community-based participatory research. The workshops brought together the Core Modeling Team and community participants over the course of the partnership to develop the problem statement, drive the research forward, and keep the community (as defined for this project) engaged in the research. Although similarities between community-based participatory research and community-based system dynamics exist (40), we learned that highlighting these similarities in introductory emails that we sent to workshop participants and then segueing into details of the community-based system dynamics approach was a useful way to show participants the value of the community-based system dynamics approach.

Strengths of the community-based system dynamics *approach*

One major strength of the community-based system dynamics approach is that it centers on the complex nature of the reproductive health system and allows for a more holistic approach to addressing issues of inequity in both reproductive health policies and outcomes. For example, if a health commissioner wanted to know which policy or set of policies may close the gap in Black-White infant mortality rates by addressing risk factors related to structural racism, then the health commissioner could use the causal loop diagram to identify specific factors related to both structural racism and infant mortality and focus on evidence-based interventions and policies that holistically address those specific factors.

Another strength of the community-based system dynamics approach is that it can provide participants with data, models, and communication tools to share their vision of an equitable and fair reproductive health system with other stakeholders within their spheres of influence. Since the community-based system dynamics approach is grounded in the experience of community members working within the reproductive health system (e.g., hospitals, community health systems, public health) and/or, in some cases, having themselves experienced racial inequities as they sought reproductive health services, the various deliverables from the community-based system dynamics approach will more accurately reflect the lived experiences of participants and their communities. During the first two workshops, the lived experience of participants was evident in their responses to questions that we asked during the facilitated exercises. Additionally, we heard participants talk about their own experiences with pregnancy, birth, infant care, and seeking contraception as they drew the connection circles and causal loop

diagrams to fully capture the relationships between risk factors, policies, and outcomes in the reproductive health system.

Lastly, bringing together diverse participants for engagement in the group model building workshops was a useful process. Namely, these workshops provided a space for connections, thought development, and support among workers in the reproductive health system who might not otherwise have met. These benefits of the community-based system dynamics approach are not very different from the strengths of a traditional community-based participatory research approach but there are real differences in terms of the greater emphasis on systems thinking, identification of feedback loops, and use of simulation models to evaluate and compare policies through "What if?" analyses.

Limitations and weaknesses of the community-based system dynamics approach

Despite these strengths of the community-based system dynamics approach, there are several weaknesses as well. First, selection bias is a risk given that the list of potential participants was developed based on the personal networks of researchers within the reproductive health system. A non-diverse pool of participants may skew outputs from group model building workshops. Our research team was purposeful in the selection of participants and invited stakeholders from across the reproductive health and broader healthcare advocacy spectrum, though we do recognize that some groups may not be as representative as possible. For example, we only had one participant directly representing the lay public. However, many other participants represented organizations that either directly or indirectly worked with the lay public. In addition, our project defined "community" in such a way that the goal of the

participant recruitment process was to capture people in official roles who could change things and not the lay public, which may still have an important and relevant perspective to offer but one that we did not adequately capture given the scope of this project.

Second, we were only able to include one layperson (i.e., a patient advocate) which may limit the utility of our model to only people and organizations included in the modeling process. Another limitation was that several organizations declined to participate including those who would have offered the perspective of providers, patients, and scholarly organizations (Table 1). By not having these stakeholders our model of the reproductive health system could potentially be biased toward the participants' organizations and the people they served in their community.

Third, our implementation of the community-based system dynamics approach was limited to risk factors, outcomes, and policies, which were described by community participants, even though additional factors, outcomes, and policies outside of the reproductive health system may also be relevant to the problem statement. The community-based system dynamics approach is limiting in this way because it requires that boundaries be set for the scope of the system being studied and, eventually, modeled because it is unlikely that any single model can encompass everything we know to be part of the reproductive health system.

Lastly, the community-based system dynamics approach is most suitable for in-person settings thus public health emergencies and disasters (e.g., global pandemics) can be disruptive to the implementation of in-person activities. Such disruptions may have unintended consequences for outputs from workshops due to lack of participation by participants who may have been more impacted than others and limited opportunities for Core Modeling Team

members to practice activities together before workshops. Thus, the effectiveness of online versions of scripted activities that are commonly used for group model building workshops remains unknown.

Conclusions

In this manuscript, we have described how we established partnerships and provided a description for implementing the community-based system dynamics approach to gain a systems-level understanding of the reproductive health system through a reproductive justice lens. Our project is a response to calls for systems-level community-engaged and practice-oriented approaches in the maternal and child health and public health literature (21, 38, 41-43). By viewing the reproductive health system as a dynamic system made up of multiple parts that interact together, and by partnering with community participants in order to understand and explicitly identify those parts and their interactions, the community-based system dynamics approach has the potential to transform our understanding of how to bring about changes in the reproductive health system to, for example, close the Black-White infant mortality gap.

Acknowledgments: We thank each person from across Ohio who participated in the group model building workshops. Thank you for sharing your experiences and insights for this project. We thank Lisa Frazier for her assistance in identifying group model building participants and providing insights on communicating systems science to community stakeholders.

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Table 1. Categories for the different perspectives (as judged by project authors only) that potential partners would bring o the group model building workshop. Examples of the type of organizations are based on the project author's understanding. The number of participants invited from each category is provided along with the number of invitations that were declined and reasons are given for declining the invitation.

Category	Examples of types of organizations	Number invited	Number declined	Reasons for declining invitation (number of people who gave this reason)
Community organizations	Reproductive justice-oriented community-based organizations, patient advocacy groups	15	6	Unable to attend(5), Unable to attend but recommended replacement who accepted invitation (1)
Local public health	City or county health departments	9	2	Accepted invitation initially but later declined to attend (2)
Healthcare organizations	Hospitals, Federally Qualified Health Centers	1	0	Not applicable
State organizations	State health department,	5	2	Unable to attend (2)

	Medicare/Medicaid department			
Providers	Lactation consultants, midwifes, doulas	4	3	Unable to attend but interviewed by Core Modeling Team(1), Unable to attend due to clinical responsibilities(1), Unable to attend(1)
Scholarly organizations	Universities, colleges	1	0	Not applicable
Patients	Women of reproductive age, patient advocates	2	1	Unable to attend(1)
Healthcare organizations (Catholic)	Catholic hospitals	1	1	Unable to attend(1)

Table 2. Description of group model building workshop participants

Stakeholder type	Professional title*	Institution
Community organizations	Project management	Health care access organization
Local public health	Nursing leader	Health department A
Local public health	Nursing leader	Health department B
Local public health	Maternal and child health leader	Health department C
Healthcare organizations	Nursing leader	Local hospital A
Local public health	Community health leader	Health department D
Local public health	Nursing leader	Health department E
Community organizations	Social worker	Local hospital B
Healthcare Providers	Maternal and child health leader	Health department F
Community organizations	Maternal and child health leader	Local hospital B
Local public health	Executive leader	Health department G
Community organizations	Community organizer	Reproductive justice organization A
Community organizations	Maternal and child health leader	Infant health organization A
Scholarly organizations	Maternal and child health analytics lead	State healthcare department
Community organizations	Executive leader	Religious coalition
Patients	Patient advocate leader	Reproductive rights advocacy organization
Community organizations		

Stakeholder type	Professional title*	Institution
	Executive leader	Reproductive justice organization B
Community organizations	Doula and program leader	Reproductive justice organization
State agencies	Program leader	State health equity agency
Community organizations	Community outreach leader	Infant health organization B
State agencies	Nursing lead	State health department

*We modified the actual professional title of the participant in order to maintain their privacy.

Table 3. Overview of each Group Model Building workshop.

Workshop #	Date (duration in minutes)	Purpose	Objectives	Activities
1	February 2019 (300 minutes)	Listen to participants.	1. Practice systems thinking 2. Know the purpose of the project 3. Define the problem and its boundary space 4. Sketch out a preliminary causal loop diagram for the problem 5. Become comfortable with other participants	• Hopes and Concerns[1*] • Key Stakeholders[2] • Policy Levers[1] • Variables Over Time[1] • Concept Model and Live Demo
2	March 2019 (300 minutes)	Create a model.	1. Know basics of a System Dynamics model 2. Expand on the preliminary SD model 3. Identify data sources and initial values for model parameters	• Variable Elicitation[1] • Connection Circles[1] • Causal Loop Diagram after

			4. Define criteria for model calibration and validation 5. Identify policies/interventions to evaluate using the model.	Connection Circle[1] • Policy Levers with Current Model[1]
3	April 2019 (120 minutes)	Translate model to action.	1. Determine the validity of model outcomes under each policy scenario.	• Model Review and Feedback[1] • Data Sources and Decisions[2]
4	May 2019 (300 minutes)	Translate model to action.	1. Interpret model outcomes by referring to dynamical features of the problem 2. Develop a plan for implementing the SD model in reproductive health planning and policy initiatives 3. Explain Community-Based System Dynamics approach to leadership of their organization and community members.	• Model Review and Feedback[1] • Data Sources and Decisions[2] • Demo of Web-Based Model Application and Feedback on Web App Interface[2] • Communicating the Model[2]

Notes: [1]Established scripts. [2]Scripts in development or developed by our project team. [*]This script is better known as Hopes and Fears but was changes to Hopes and Concerns by mutual agreement of the Core Modeling Team.

Table 4. High-level summary of hopes and concerns expressed by group model building participants

Hopes	**Concerns**
Treating health as a human right and not as a privilege	Ideas are too broad and data is too hard to acquire so people don't use it
Being able to change the work of the participant's organization	Don't address forgotten groups
Come away with new ideas and actionable steps	Ignore health disparities
Reduce infant mortality among black babies	Stigma around reproductive health and abortion still exits
Solve problems through cultural practices	The laws constantly change so data quickly become irrelevant
Develop policy and norms to change reproductive health	There are barriers to services that require buy-ins from other key groups
	Institutional racism
	Continue to remain siloed and results won't be transferred to other institutions or put into practice

Table 5. Categories of policy levers with examples of policies under each category. See Supplementary Materials for full list of policies in each category.

Macro-level Policy	**School education**
- Guaranteed (no bans) birth/postpartum doula support - All managed care treat contraceptives as preventative care and all women have the right to this care from the start of menstrual cycle until menopause - Scientific-based medical counseling for abortion patients	- Reproductive health education is a mandated, comprehensive, culturally, gender, and sexuality inclusive course in middle school and high school - Reproductive life plan is implemented with all school-aged teens aged 13-19 years. - Comprehensive sex education is a requirement in all Ohio schools
Community-level Policy	**Healthcare provider education**
- Sealing of housing evictions after a certain amount of time - Allocate more money to support community health workers (CHWs) - Incarcerated women to have all their reproductive needs taken care of, both pregnant + non-pregnant women	- Comprehensive contraceptive method training for providers - Trauma informed care trainings - Require all medical staff (nurses, doctors, medical assistants, front desk staff) + healthcare students (nursing, medical, etc.) to undergo implicit bias + cultural competency trainings
Individual-level policies	
- Free early childcare for everyone	

- Paid maternity, paternity and domestic partner leave for 1 year
- Strengthening working conditions for pregnant women

Table 6. Common themes based on factors included in causal loop diagram developed independently by each group in the second group model building workshop.

Theme	Group 1	Group 2	Group 3	Group 4
Relationships	Grassroots community engagement	Positive support networks	Family formation Healthy relationships Family formation decision Attachment to adults	Abusive relationship Partner involvement Social capital Social network
Abortion, contraception, and access	Quality of care, Access to and use of reproductive healthcare	Abortion Access to healthcare coverage	Abortion Receipt of quality reproductive healthcare Early intervention	

			Infant health + LBW/PTB Maternal/Paternal health (Mental + Physical) Postpartum depression Increase breastfeeding	Infant mortality Maternal mortality, Maternal morbidity
Politics	Politics/policy/term length	Favorable political climate		
Economics	Local economy	Income		Job benefits (PTO, FMLA, healthcare) Government subsidized benefits
Health literacy,	Provider education, Provider recruitment		Provider training	Prenatal education

providers education		Healthcare knowledge/ competency	Diversify workforce development	Reproductive coercion
			Autonomy Stress	Racism Stress
Stress, stigma, racism	Attitude (acceptability)	Stigma (cultural, mental health, etc.)		Company culture, Clinician cultural bias

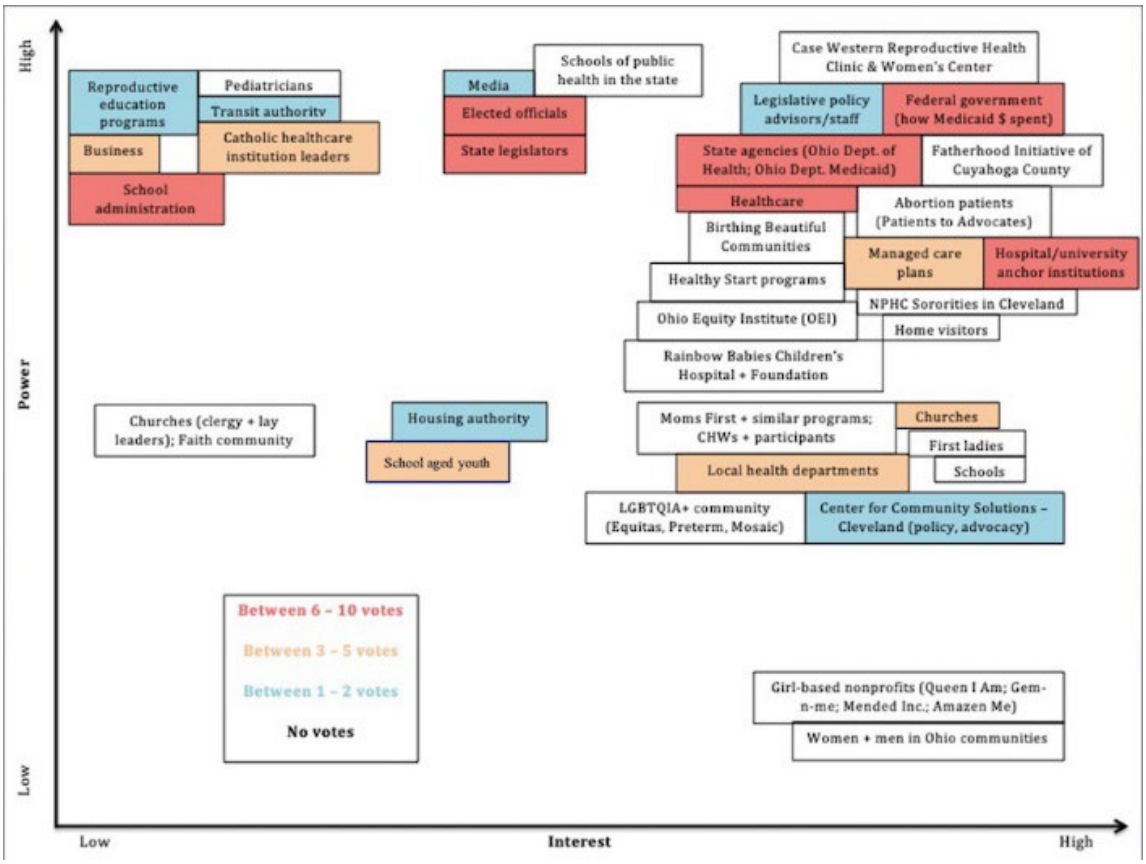

Figure 1. Digitized version of power vs. interest graph with key stakeholders color coded by type of stakeholders.

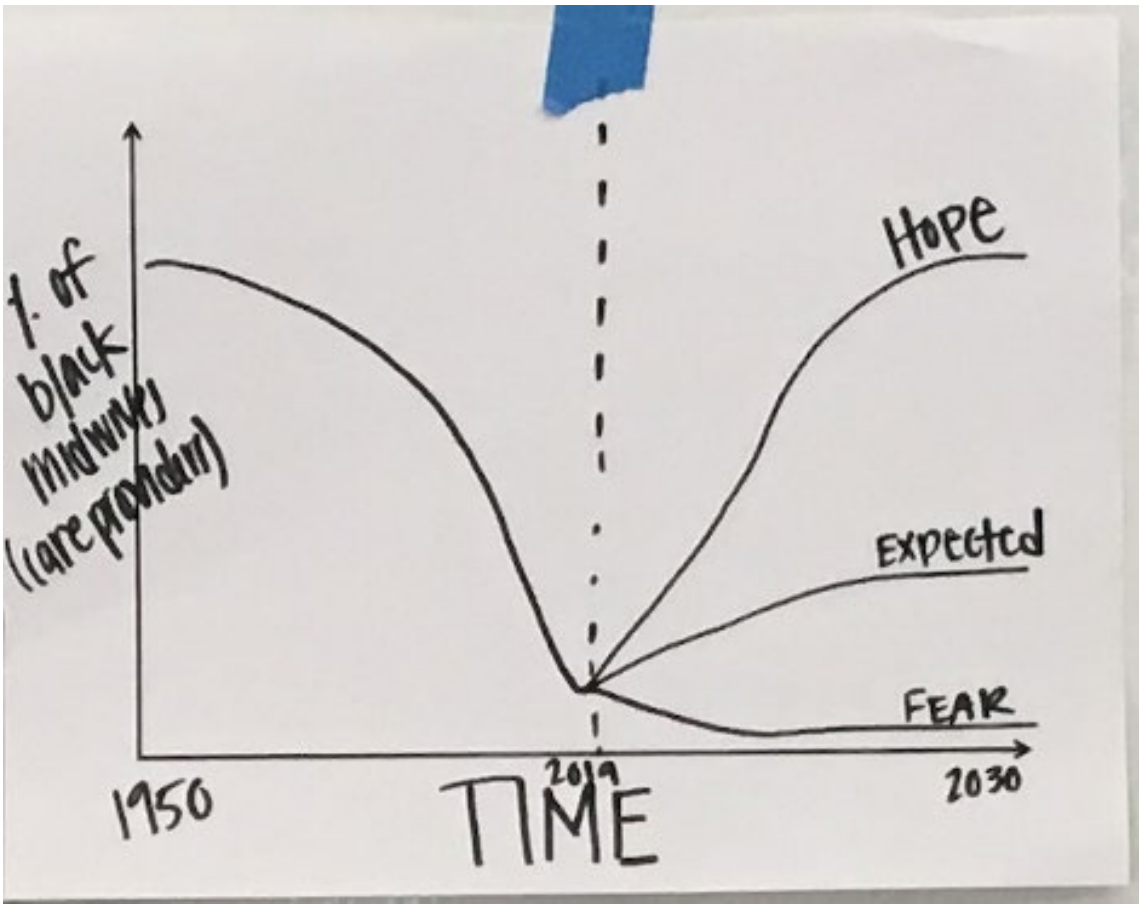

Figure 2. Example of a Graph-over-Time as drawn by a participant in a group model building workshop. The graph shows the participant's view of the expected (status quo), hoped, and feared trend in the percent of black midwives/care providers in Ohio.