Boundary Objects for Group Model Building to Explore Oral Health Equity

Susan S. Kum, MPH
Department of Geography, University at Buffalo, The State University of New York,
Buffalo, NY 14261, USA
susankum@buffalo.edu

Hua Wang, PhD
Department of Communication, University at Buffalo, The State University of New York,
Buffalo, NY 14260, USA
huawang23@buffalo.edu

Zhu Jin, MS
Department of Geography, University at Buffalo, The State University of New York,
Buffalo, NY 14261, USA
zhujin@buffalo.edu

Weiai Wayne Xu, PhD, MA
Department of Communication, University at Buffalo, The State University of New York,
Buffalo, NY 14260, USA
weiaixu@buffalo.edu

Janet Mark, MA
School of Dental Medicine, University at Buffalo, The State University of New York,
Buffalo, NY, USA 14214, USA
janetmar@buffalo.edu

Mary E. Northridge, PhD, MPH
Department of Epidemiology and Health Promotion, New York University College of Dentistry,
New York, NY 10010, USA
men6@nyu.edu

Carol Kunzel, PhD
Section of Population Oral Health, College of Dental Medicine, Columbia University,
New York, NY 10032, USA
ck60@columbia.edu

Stephen E. Marshall, DDS, MPH
College of Dental Medicine and Mailman School of Public Health, Columbia University,
New York, NY 10032, USA
sm15@columbia.edu

Sara S. Metcalf, PhD, MS
Department of Geography, University at Buffalo, The State University of New York,
Buffalo, NY 14261, USA
smetcalf@buffalo.edu

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Abstract

This paper describes the nature and utility of boundary objects that were developed as a means of facilitating team collaboration in group model building workshops. Assembled on an NIH-funded grant, the team is charged with integrating social and systems science approaches to promote oral health equity for older adults. The project was designed to conduct group model building workshops in parallel with efforts to collect qualitative data about factors that hinder or facilitate access to and utilization of oral health care. The modeling team takes a portfolio approach to incorporate different methods of systems science—including system dynamics, agent-based modeling, geographic information science, and social network simulation—in models that help to explore challenges to oral health equity for older adults.

Introduction

As a structured process engaging various stakeholders, group model building is commonly used by the system dynamics community for collaborative problem identification and problem solving (Vennix 1996, Hovmand 2014). The present contribution reports on group modeling building workshops with a multi-disciplinary research team of social scientists, systems scientists, epidemiologists, biostatisticians, and oral health practitioners across three research universities, collaborating on an oral health equity project. As a subunit of the larger research team, the modeling team is responsible for facilitating the group model building workshops and developing the systems science models that comprise our portfolio. Beyond the modeling team, most members of the research team had minimal to no prior knowledge about systems science modeling and no prior experience with a group model building process.

To engage the entire team in the modeling process, the modeling team developed novel boundary objects to facilitate discussion. Black (2013, p.76) defines a boundary object as "a representation—perhaps a diagram, sketch, sparse text, or prototype—that helps individuals collaborate effectively across some boundary, often a difference in knowledge, training, or objective." For groups with members with different domain expertise, boundary objects are useful for coordinating knowledge and objectives, and for developing a shared vocabulary about the problem. This paper highlights the nature and utility of boundary objects that have emerged from our group model building workshops.

This research builds upon a long-standing collaborative effort to meet the oral health needs of older adults in largely underserved, racial and ethnic minority communities through the ElderSmile community-based oral health outreach program (Marshall et al. 2009). With an orientation toward healthy aging, the purpose of this research is to integrate social science and systems science approaches to promote oral health equity for older adults. The ecological model underpinning our research highlights factors at the individual, interpersonal, and community scales that influence oral health and related health outcomes (Northridge et al. 2012). In this framework, the oral health of older adults reflects the lifelong accumulation of advantages and disadvantages experienced at multiple scales, from the micro-scale of the mouth to the macro-scale of society. According to this framework, factors at the community scale, such as access to health and dental care services, and factors at the interpersonal scale such as health behaviors and oral hygiene activities, can be important points for interventions of oral health outcomes for older adults, such as tooth loss, dental caries, and periodontal disease. Model formalizations attempt to evaluate interventions at the community scale (e.g. referrals to treatment and financing treatment), interpersonal scale (e.g. peer and familial support and practitioner-patient relationships), and individual scale (e.g. general health screenings in dental settings).

Specific project aims and hypotheses have been articulated at the individual, interpersonal, and community scales to frame our modeling work. In preparing for the group model building workshops, team members were asked to specify which factors are critical for shaping oral health equity at the community, interpersonal, and individual scales. To do so, we revisited our project aims and hypotheses, which are as follows:

1. To understand how urban minority senior center attendees utilize services such as health and dental care at the community scale to enhance their oral health.
   Hypothesis: Urban minority senior center attendees successfully navigate the built environment and capitalize on the social context of their communities to gain access to health and dental care to improve their oral health.
2. To identify how factors at the interpersonal scale enhance care-seeking behaviors and improve the oral health outcomes of urban minority senior center attendees.
   Hypothesis: Urban minority senior center attendees are buffered against stressors, encouraged to adopt positive health behaviors, and socially integrated, thus leading to enhanced care-seeking behaviors and improved oral health outcomes such as tooth retention and periodontal health.
3. To examine the cultural acceptability of screening for hypertension and diabetes in the dental setting at the individual scale for urban minority senior center attendees.
   Hypothesis: For urban minority senior center attendees, screening for hypertension and diabetes in the dental setting is culturally acceptable.
4. To model the knowledge gained about factors at the community, interpersonal, and individual scales for urban minority senior center attendees in Aims 1, 2, and 3 to enhance community- and clinic-based oral health service delivery and improve oral health outcomes.
   Hypothesis: Enhanced understanding of factors at multiple scales that impact urban minority senior center attendees will improve oral health outcomes via program enhancements, familial and peer support, and expanded screening for related health outcomes such as hypertension and diabetes.

As part of a comprehensive qualitative data collection effort, these aims and hypotheses are being explored through key informant interviews with directors and staff members of senior centers, and focused groups with urban-dwelling, racial and ethnic minority senior center attendees. As our work proceeds, these interviews and focused groups will be used to: extricate factors associated with utilization of health and dental care; establish the influence of familial, peer, and other social relationships in care-seeking behaviors; and assess the appropriateness of screening for hypertension and diabetes in dental settings.

Group Model Building

The group model building (GMB) activities undertaken in our project are designed to bring our portfolio of models closer in line with the knowledge gained from our qualitative data collection and the knowledge held by members of the research team about oral health equity in general and the ElderSmile program in particular. A GMB workshop is held annually for each of the five years of the research grant. Our annual GMB workshops are designed to engage members of the entire research team in all stages of the modeling process. These five stages are in keeping with the description of the modeling process outlined by Sterman (2000). The emphasis of each workshop is summarized in Table 1 below.

Table 1. Group model building workshops aligned with steps in the modeling process

Workshop	Dates	Primary Modeling Step	Emphasizing	Memorable Adage
GMB1	May 16, 2013	Problem Definition	reference modes	Model the problem, not the system.
GMB2	April 24-25, 2014	Dynamic Hypothesis	causal map	Close the loop.
GMB3	May 26-27, 2015	Model Formulation	stocks, flows, agents	Nature only integrates.
GMB4	2016	Model Testing	confidence building	All models are wrong. Some are useful.
GMB5	2017	Scenario Analysis	policy tests	What if?

This section summarizes the first two of five GMB workshops. As noted in Table 1, the first workshop (GMB1) was held in May 2013, and the second workshop (GMB2) was held in April 2014. The third workshop (GMB3) was held in May 2015, and findings are currently being synthesized. The modeling team developed primers containing the agendas and descriptions of workshop activities for GMB1 and GMB2. Primers were distributed to the research team two weeks prior to the workshops. Participation from the overall research team in the GMB workshops included 18 people (5 of whom were the modeling team members) in GMB1 and 16 people (6 of whom were the modeling team members) in GMB2. A total of 12 team members participated in both GMB1 and GMB2, with 22 total participants. GMB1 was held prior to the qualitative data collection and thus served to construct a collective *prior* problem definition and dynamic hypothesis. A survey was administered before GMB1 to collect team members' perspectives on the importance of factors from the ecological model, and to identify scenarios that might be worth exploring with models. The survey provided a way to gauge the priorities and expectations of team members, as well as to help team members to begin thinking about key problem variables and potential scenarios. GMB2 was held while the key informant interviews and focused groups were underway.

Although the overall design of this group model building effort aligns each workshop to a stage in the modeling process, it should be noted that Table 1 indicates the primary focus of each workshop and does not preclude progress in other stages of the modeling process. Indeed, as depicted in Table 2 below, the schedule for each group model building workshop allotted time for different steps of the modeling process. For example, as consistent with step 5 of the modeling process, models enable the team to ask "What if?" scenarios about the effects of changes in health policy and programs on health outcomes. We found that scenarios emerged easily in discussion and further encouraged asking "What if?" scenarios through designated portions of the workshops. In this way the group model building process employed by the research team is iterative, in that important steps in the modeling process are revisited. The agenda items outlined in Table 2 provide an overview of the structure of the first two workshops and indicate the time that was dedicated to each portion of the agenda.

Table 2. Agenda items for group model building workshops GMB1 and GMB2

GMB1 Schedule	GMB2 Day 1 Schedule	GMB2 Day 2 Schedule
Introduction (30 min). Roles, problem orientation, review project hypotheses.	Introduction (30 min). Roles, problem review, summary of GMB1.	
Problem definition (1 hr). Identify reference modes (trends over time) for factors that impact oral health equity and select a key "problem variable" from which to develop a causal map.	Student-led discussion (30 min). Discussion of the causal mapping process.	Student-led discussion (30 min). Time map demonstration and discussion.
Causal mapping (1 hr). Collectively construct a causal map starting with the key "problem variable" identified.	Hands-on exercise (1 hr). Work with physical representation of causal map developed during GMB1. Edit the structure and add variables that help to tell the stories associated with each feedback loop.	Hands-on exercise (2 hrs). Continue to work with the causal map as developed on day 1. Add or amend according to group discussion. Prioritize and name feedback loops.
Lunch break	Lunch break	Lunch break
Portfolio review (1 hr 15 min). Present, demonstrate, and discuss the existing portfolio of models. Highlight differences between agent-based and stock-flow model forms as well as possibilities for model hybridity. Demonstrate the "time map" ElderSmile reference mode.	Hands-on exercise (1 hr 30 min). Identify feedback loops developed in morning session. Add or amend according to continued group discussion. Incorporate new insights that have emerged from interview and focused group observations.	Student-led discussion (30 min). Presentation and discussion of the latest simulation models in our portfolio.
Scenario development (1 hr). Collectively brainstorm scenarios to explore with existing and forthcoming models.		Review (1 hr 30 min). Collectively brainstorm scenarios to explore with existing and forthcoming models. Review and discuss potential forms of model implementation in the context of our portfolio.

GMB1 was a one-day workshop that involved problem definition, causal mapping, portfolio review, and scenario development. The first activity was identifying trends over time for factors that impact oral health equity and selecting a key *problem variable*. The second activity was collectively constructing a causal map with the key problem variable identified in the previous activity. For the third activity, the existing portfolio of models were presented and discussed. For the fourth activity, a list of potential scenarios was recorded and refined through group discussion. Existing models were presented and potential scenarios were discussed to stimulate thinking on what might be interesting to explore in future models.

GMB2 was a two-day workshop that involved a review of GMB1, causal mapping, and portfolio review. Whereas GMB1 was organized around activities designed to provide an introduction to the modeling process and an orientation to the extant model portfolio, the focus of GMB2 was the causal map, particularly in identifying and defining feedback loops. Therefore, the objectives of GMB2 were to: review, modify, and add to the causal map from GMB1; provide team members the opportunity to practice identifying causal relationships and feedback loops; collectively decide which variables and feedback loops were central to our research problem; and demonstrate and discuss new models and revisions to the existing models. Also, as several of the interviews and focused groups had been conducted and transcripts shared and read, incorporation of new insights from these activities was encouraged.

The approach to systems science employed by the research team accommodates multiple methods, guiding the development of both agent-based and traditional system dynamics models (Metcalf et al. 2013). The research team has developed a portfolio of conceptual, statistical, spatial, and simulation models that utilize the rich information streams associated with this research project. A review of the model portfolio is therefore included in each workshop so as to refine the purpose and scope of the models.

Boundary Objects

As a theoretical construct, the boundary object has been applied to group model building to describe the purpose of a system dynamics model and also to consider the effectiveness of group model building. From a modeling perspective, a boundary object is "a socially constructed artefact for building trust and agreement" (Scott et al. 2014 p. 4, citing Zagonel 2002). For boundary objects to be useful, they must be modifiable and readily perceptible representations that embody the dependencies among resources and goals of group members (Black and Andersen 2012). Examples of boundary objects in system dynamics include reference modes (behavior over time graphs), causal maps (causal loop diagrams), and stock-flow diagrams of model structure. These system dynamics representations meet the criteria of being concrete and therefore readily perceptible, and being modifiable in response to feedback from the team. Through the construction of boundary objects, group members can have conversations where knowledge is shared, expectations are expressed, and points of contention are addressed (Black 2013).

Here we present the boundary objects introduced and developed during our first two GMB workshops. These boundary objects have been useful for fostering communication and shared understanding across disciplines. GMB1 and GMB2 emphasized the problem definition and dynamic hypothesis steps in the modeling process. The main objectives of these two steps are setting the time horizon and time units, and defining the endogenous, exogenous, and excluded variables related to the problem. In effect, the boundaries of the problem are being negotiated. Reference modes and causal maps have served as important boundary objects in crossing the different disciplinary boundaries of our research team to collectively agree on the boundaries of our research problem.

Reference Modes

Each team member was asked to draw reference modes as behavior over time graphs and then present explanations of his/her sketches to the rest of the group. The time horizon could be represented as calendar time or age across the lifespan. After each presentation, adjustments to the sketches were made, as appropriate. There were some initial difficulties in capturing the intended narratives in some of the sketches, but for the most part, these were resolved in group discussions. Sketches were posted on the conference room walls and organized from micro to macro scales and clustered by topics (Figure 1). The reference modes provided indications of the domain expertise, experiences, and priorities of the team members. After all of the reference modes were presented and posted, team members voted for the key problem variable by placing stickers on the reference mode sketches (each team member was given three stickers). This hands-on activity also served to help team members to become better acquainted with one another, as this was the first face-to-face all-team meeting.

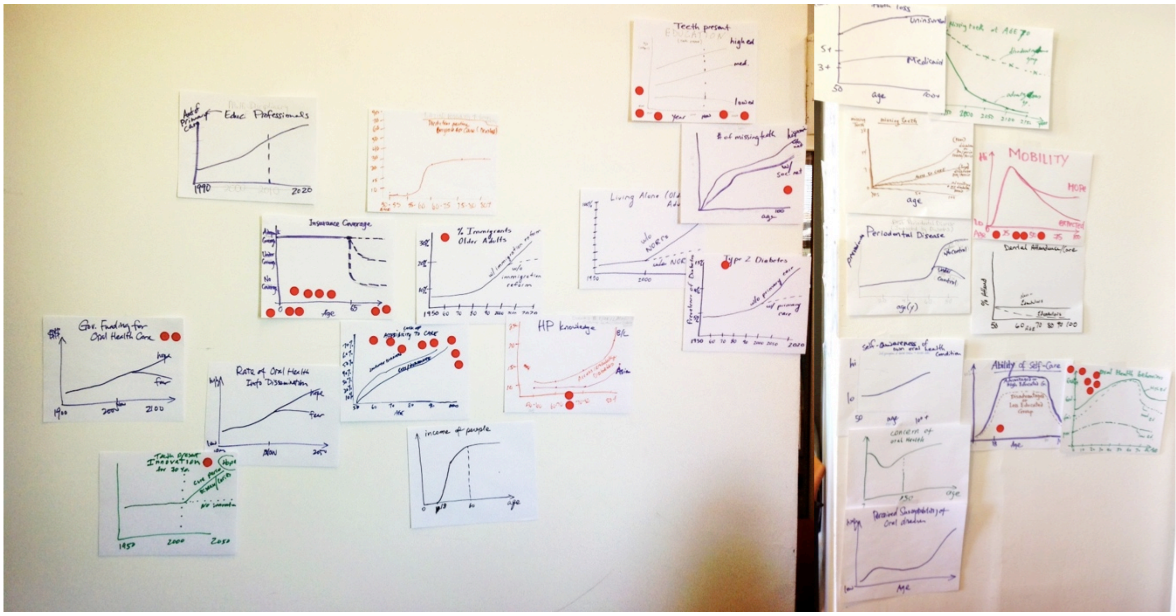

Figure 1. Reference modes arranged on walls

The reference mode for the variable *number of affordable oral health service providers* (Figure 2) received the most votes from the team as a central factor that facilitated or hindered oral health equity for older adults. This was used as the starting point for a causal map. For clarity, however, the variable was deconstructed into two separate components: *number of oral health providers* (an indicator of availability) and *affordability of oral health care*. Both of these components were seen to affect *oral health care accessibility* in the resultant causal map.

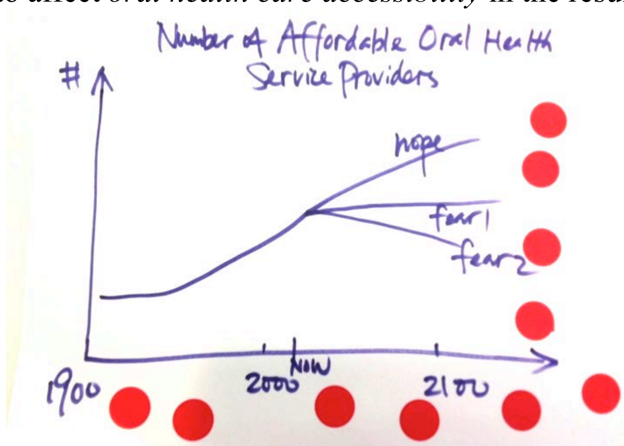

Figure 2. Reference mode with most votes

Spatially-explicit Reference Mode

The concept of the reference mode was further elaborated in GMB1 with the introduction of an interactive *time map* to provide a spatially-explicit reference mode appropriately scaled to the senior centers that are affiliated with the ElderSmile oral health outreach program. The ElderSmile TimeMap is a spatially contextualized trend illustrating the schedule of preventive health screening events held by the ElderSmile community-based oral health outreach program at different senior centers throughout Northern Manhattan (Kum et al, in press). It was developed by the modeling team to facilitate constuction of spatial reference modes that reveal patterns in program participation in time and space. As an individual-based means of rendering reference modes spatially explicit, this approach is complementary to the possibilities explored by BenDor and Kaza (2012) for depicting reference modes in space as well as time.

At the aggregate scale of ElderSmile operation, earlier analyses showed an oscillatory pattern (Metcalf et al 2011, 2013). However, at the scale of individual senior centers, the ElderSmile TimeMap reveals a variety of trends for particular centers. Indeed, some of the centers had only held one ElderSmile event, rendering characterization of a trend difficult. Figure 3 shows a screenshot of the web-based ElderSmile TimeMap[1] highlighting participation trends for ElderSmile events at the selected center. The GIS-based construction of the ElderSmile TimeMap paralleled the GIS-based simulation model development in the AnyLogic platform, and the earliest version of the TimeMap was constructed as a model in AnyLogic.

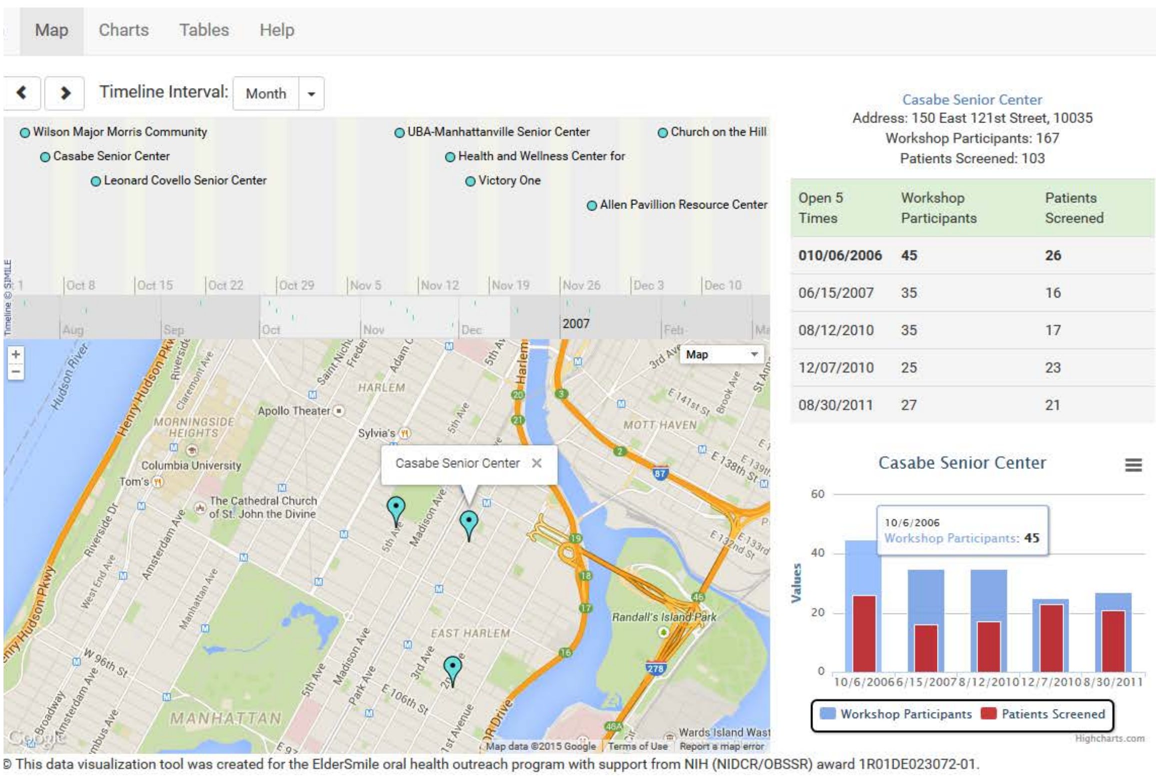

Figure 3. The ElderSmile TimeMap[1]

As an interactive tool, demonstration of the TimeMap enriched the group model building process by enabling the research team to visualize and summarize data about participation in the ElderSmile oral health outreach program that are contextualized by both time and place. Discussions at the group model-building workshops about these spatial reference modes have led to conversations about the operations and challenges of the ElderSmile outreach program. These conversations have been helpful for adjusting assumptions about reference modes used for previously built simulation models in the portfolio of the research team.

Work on the ElderSmile TimeMap has been instrumental in fostering communication between team members, particularly those involved in oral health outreach activities and those

[1] http://www.acsu.buffalo.edu/~smetcalf/resources/timemap.html

involved with constructing models. The TimeMap enabled the modeling team to provide a compelling example of how observations from the ElderSmile community-based outreach program were transformed into visual spatial trends that could be customized to meet the needs of the program. These benefits were realized in addition to its utility for informing model development as originally intended. Additional considerations for model structure become apparent when considering the spatial context of participation trends.

The ElderSmile TimeMap has been refined through an iterative feedback process with further team discussions guiding its extension. As an emergent product of the collaborative modeling process, the TimeMap is an apt example of a virtual boundary object that reflects the collective input of different team members.

Causal Maps

Although the reference mode for *number of affordable oral health service providers* (see Figure 2) received the most votes during GMB1, the team did not reach a consensus designating it as the key problem variable. Upon discussion, the team agreed that oral health equity is central to our research program, and that oral health at the individual and population scales are key outcomes. Accordingly, oral health was drawn in the center of the map (see Figure 4) to ensure its endogeneity. From the beginning, the group sought to reach agreement about the central problem, and the causal map reflects this consensus. Our first collaborative casual map as a team evolved at GMB1 on a whiteboard, as shown in Figure 4.

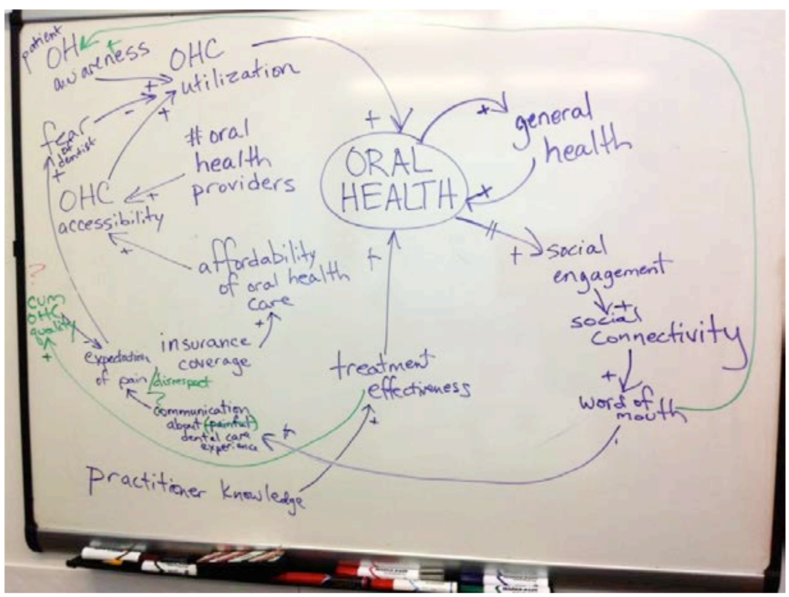

Figure 4 Causal map drawn during GMB1

As the causal map was being constructed on the whiteboard during GMB1, Vensim was being used to create a digital version (Figure 5). In the digital version, the unabbreviated variable names are used and organized spatially to make a distinction between endogenous and exogenous variables. For example, the endogenous variable *patient oral health awareness* is depicted within a reinforcing feedback loop involving *word of mouth* in Figure 5, rather than its position at the upper left of the whiteboard sketch in Figure 4. And the exogenous variable *insurance coverage* is depicted at the right edge of the causal map in Figure 5, in contrast to its location in the center left of Figure 4 above.

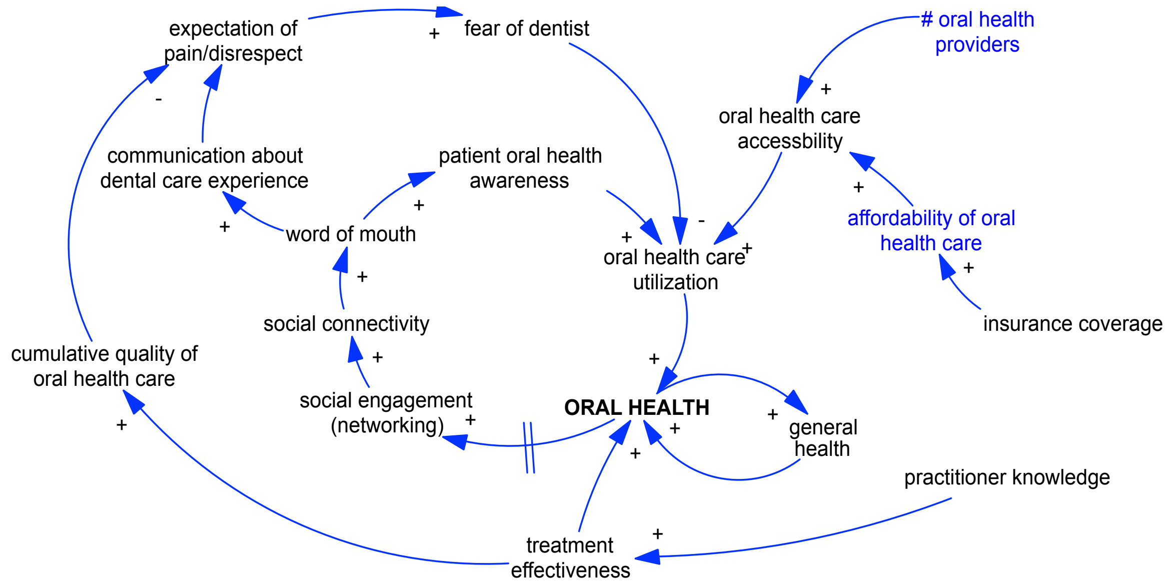

Figure 5. Digital causal map from GMB1

The digital representation in Figure 5 was presented to the entire team in follow-up discussions after the workshop. This causal map from GMB1 was used as a starting point for GMB2. This representation was reviewed and used at GMB2 to explain core concepts such as feedback loops and delays. The causal map was projected on a screen during the GMB2 workshop (Figure 6). Participants were introduced to a physical representation of this map (Figure 7) that was constructed using circular cards and color-coded connections. In GMB2, the digital representation of the causal map was used to remind the team members of the variables and relationships that had been agreed upon previously, as well as to reinforce understanding about the dynamic hypothesis and causal maps.

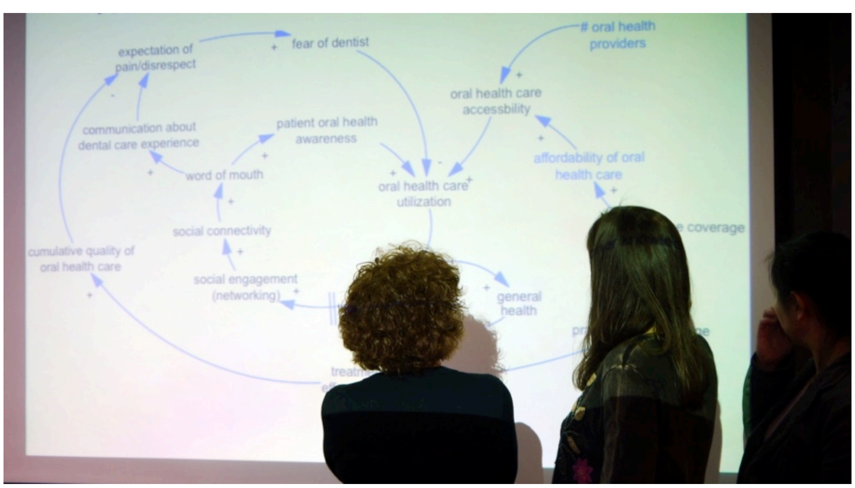

Figure 6. Reviewing the GMB1 causal map during GMB2

To address the difficulties and limitations of drawing out causal maps on the white board and creating causal maps real-time in Vensim, physical materials—index cards and pipe cleaners—were used to develop a physical representation of the causal map (Figure 7). A primary motivation for using physical materials was to stimulate more active engagement from the team members.

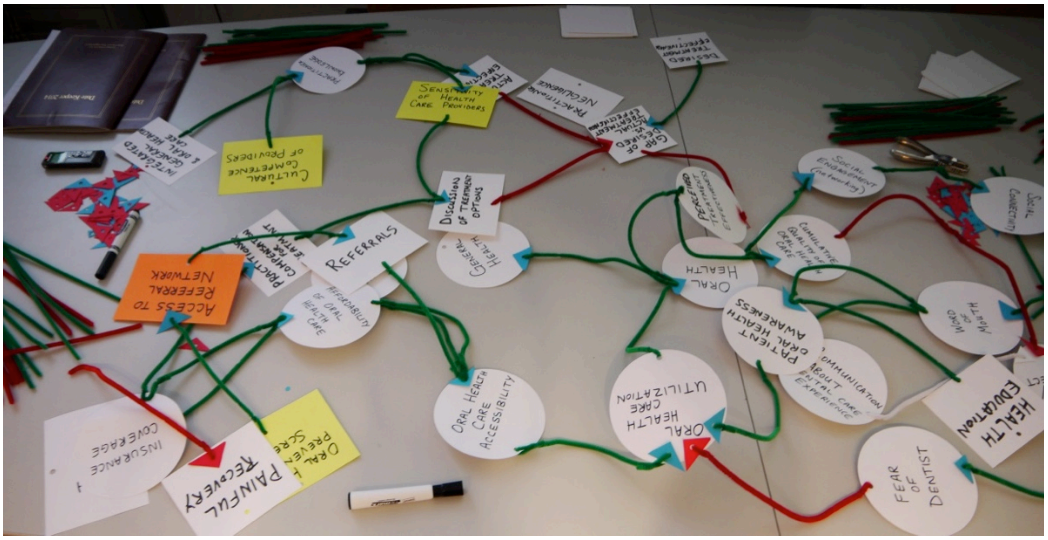

Figure 7. Constructing and extending the causal map with physical materials

The index cards represent the variables, and the pipe cleaners represent the links, where red indicates negative causal relationships and green indicates positive causal relationships. Corresponding colored triangles signify the directionality of each arrow. Different forms of index cards were used to make the following distinctions. Circular index cards were used for variables already included in the GMB1 causal map. Color-coded rectangular index cards were used for variables extracted from our ecological model, with color indicating the scale (as per the legend in Figure 8). White rectangular index cards represented variables newly introduced in GMB2.

Where the discussion involved conflicting viewpoints about a particular portion of the causal map, specifically around treatment, the use of a physical representation was particularly helpful in moving the discussion forward, because alternative views and examples were simply recorded for reference on the opposite side of index cards. Another exercise undertaken with the physical representation was to work through the causal map and to identify feedback loops using large foam boards labeled *B* and *R*for balancing and reinforcing loops, respectively.

A digital version of the map was updated in Vensim alongside the physical model during the causal map construction process of GMB2. To accomplish this task, three modeling team members collaborated in the roles of observer, modeler, and reviewer to verify that the digital causal map aligned with the physical representation. These team members were responsible for updating the digital representation of the causal map in real time as the physical version was being modified. GMB2 participants could therefore translate the structure and trace changes that were hard to identify in the physical version.

During the construction of the causal map with physical materials, modeling team members documented the process by taking photographs and recording brief notes explaining the changes to the causal map. These photographs and notes, along with audio recordings of the activities, aided the modeling team members in verifying the digital version in Vensim. After the group model building workshop, the photographs and notes served as post-hoc references for finalizing the digital causal map.

The digital representation of the causal map developed from the physical boundary object is shown in Figure 8. This representation of the causal map was stylized to match the physical representation for improved comprehensibility. Just as in the physical representation, certain variables were ascribed to specific scales (community, interpersonal, and individual) in keeping with the ecological model that frames this research.

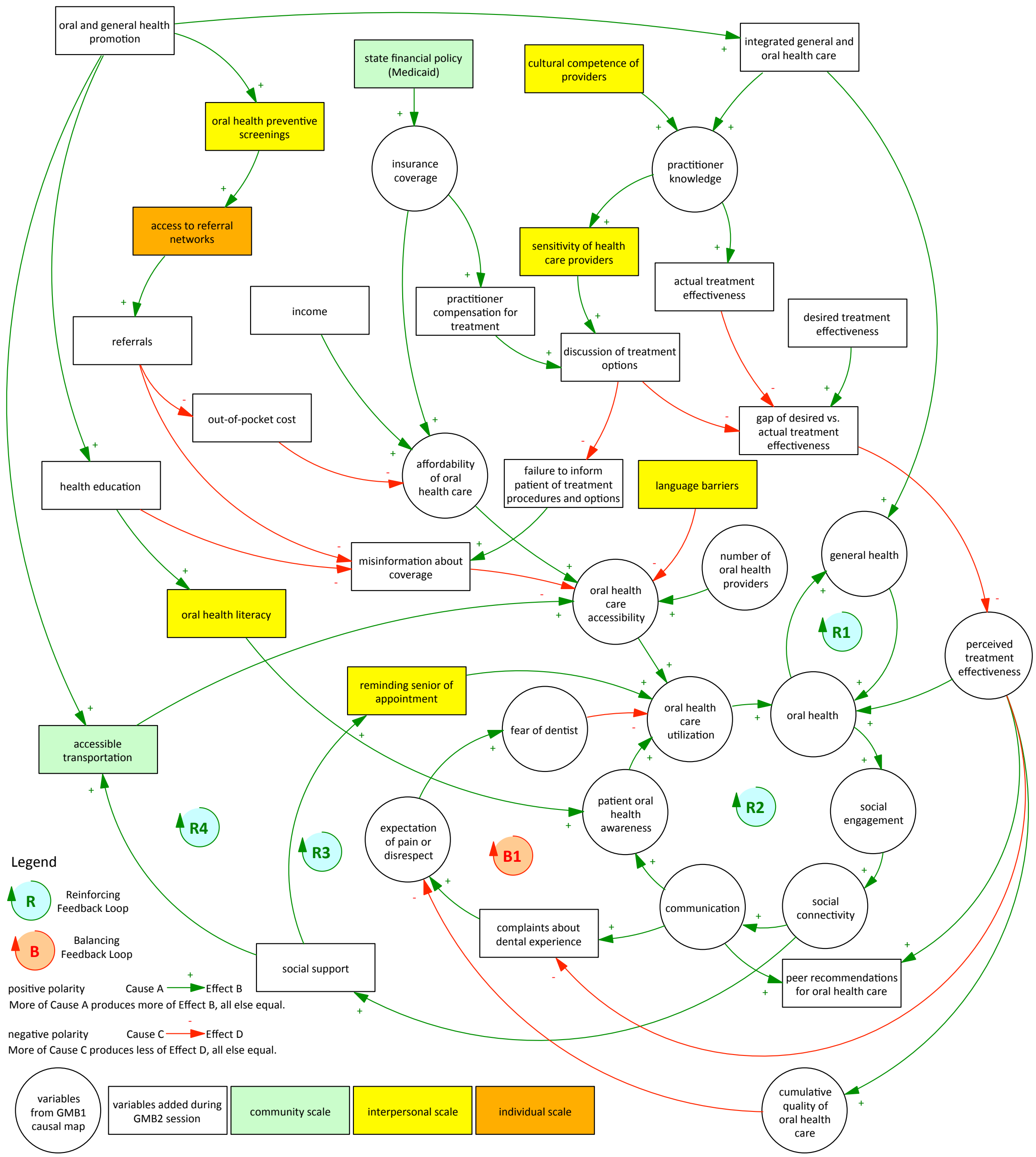

Figure 8. Causal map from GMB2

The causal map in Figure 8 emerged from the physical boundary object used to facilitate the hands-on modeling activity during the second group model building workshop. Starting at the top left of the causal map, oral and general health promotion are shown to have positive effects on health education, participation in oral health preventive screenings, efforts towards integrated general and oral health care, and provision of accessible transportation for treatment. More health education would lead to greater patient oral health awareness, since a person gains more oral health literacy. Increased participation in oral health preventive screenings, such as those offered by the ElderSmile program, can lead to more referrals to treatment when oral health problems are still manageable, which in turn reduces out-of-pocket costs for dental treatment. Reducing out-of-pocket costs, augmenting incomes, and extending insurance coverage by means of, e.g., an expansion in Medicaid can increase the affordability of oral health care. Expansion of insurance coverage can lead to more practitioner compensation for treatment. In turn, practitioners may be more inclined to offer more discussion of treatment options, reducing the likelihood of failure to inform patients about treatment options. Gains in practitioner knowledge through more experiences with integrated general and oral health care and enhanced cultural competence of providers can increase actual treatment effectiveness as well as lead to greater sensitivity to patients on the part of oral health providers. Greater sensitivity of oral health providers can contribute to more discussion of treatment options. More health education and referrals for patients can reduce misinformation about coverage for treatment. Reducing misinformation about coverage, increasing the affordability of oral health care, providing more accessible transportation options, reducing language barriers, and increasing the number of oral health providers can all contribute to greater oral health care accessibility. Oral health care utilization is likely to increase as oral health care accessibility increases.

Greater oral health care utilization is expected to lead to better oral health. In turn, increased levels of practitioner knowledge are expected to lead to better actual treatment effectiveness. There may, however, be a gap in desired versus actual treatment effectiveness. More discussion of treatment options may reduce this gap. Moreover, if the gap is reduced, the patient's perceived treatment effectiveness may be higher. Higher perceived treatment effectiveness can lead to more peer recommendations for oral health care, fewer complaints about dental experiences, and greater overall or cumulative quality of oral health care. Greater cumulative quality of oral health care and fewer complaints about dental care experiences can decrease expectations of pain or disrespect, decrease fears of the dentist, and thereby increase oral health care utilization.

There are five feedback loops in the GMB2 causal map shown in Figure 6. Four of these are reinforcing (R) and one is a balancing (B) feedback loop. R1 indicates the reinforcing relationship between oral health and general health, which is abstracted as a two-way relationship, although there are more particular pathways that could be traced between oral health and chronic diseases, such as diabetes and hypertension. In R2, better oral health is likely to result in more social engagement, greater social connectivity, and more communication, thus enhancing patient oral health awareness and leading to more oral health care utilization that contributes to better oral health. In B1, more communication can instead lead to greater exposure to complaints about dental experiences, amplifying the expectation of pain or disrespect, intensifying the fear of the dentist, thereby leading to lower utilization of oral health care that contributes to worse oral health. In R3, greater social connectivity can lead to more social support, such as more instances of reminding older adults of dental appointments, which can lead to more oral health care utilization that contributes to better oral health. Similarly, in R4, greater social connectivity can lead to more social support, such as more accessible transportation options that improve oral health care accessibility, leading to more oral health care utilization that contributes to better oral health.

Discussion

The research team identified novel forms of boundary objects, including the interactive TimeMap and a physical causal map construction using index cards and pipe cleaners. The advantage of using the latter materials to build a causal map lies in the flexibility by which the causal map can be extended and adjusted using team input. Although the form was designed to be modifiable by all team members, the modeling team facilitated these adjustments. The potential for facilitator bias was therefore present, but was expected to be less than it would be with a single facilitator drawing a causal map on a whiteboard (as was the case in GMB1, as depicted in Figure 2). The group model building processes undertaken in this study built upon earlier research (Hovmand 2014, Richardson and Andersen 1995). Simulation models using both agent-based and system dynamics frameworks comprise the team's portfolio (Metcalf et al 2013), providing a range of examples that can be demonstrated to motivate the value and limitations of different kinds of model constructions.

As anticipated, the research team encountered several difficulties in bounding the problem and effectively linking our dynamic hypothesis to oral health equity, in particular. Nonetheless, we found that because of its complexity, the causal mapping process was an excellent vehicle for stimulating team discussions. These discussions continue as the team uses the GMB2 causal map in Figure 6 as a boundary object. In addition to our annual GMB workshops, various members of the research team meet regularly on key aspects of the project. We continue to develop our causal map and also revisited the reference modes in the GMB3 workshop emphasizing formulation of model structure. During GMB3, group activities were designed to help participants appreciate the function of stocks and flows in a system, as well as the operation of agents in a spatially explicit agent-based model. The modeling team developed a complementary game as a group exercise, playing out the sequence of events encoded in the simulation model. Boundary objects of the game included wooden pegs representing the older adult agents who attend senior centers and receive oral healthcare from oral healthcare provider agents. This experiment helped all members of the research team to appreciate both the possibilities and limitations of an agent-based model. Under the workshop theme of integration to inform model structure, other group model building activities that were developed for the workshop involved exploration of worst-case scenarios for oral health equity, identification of inflows and outflows for stocks of health, elicitation of reference modes, and illustration of causal maps for different dimensions of oral healthcare accessibility.

When asked to reflect upon the first two group model building workshops, one participating team member explained:

> "I found the activities very helpful in providing a better understanding to what modeling entails. Prior to the sessions I had little to no experience in modeling, but the activities presented insightful ways to define modeling and its process. For instance, from the first modeling session, I was able to visually follow the development of models through the collaborative effort made by each of the team members when we created the reference modes. The activity allowed me to initially draw my ideas on a graph and then see how my perspectives matched or differed from the others when the team shared their individual ideas.

> "For the second group modeling session, the activities were very engaging and I was able to picture the process of modeling through different means. For example, the use of pipe cleaners and index cards to create a causal map provided an opportunity for me to utilize the knowledge I received in modeling to physically create the casual map. This allowed me to decipher and question the connections made with each variable in a more concrete way. However, coming to a consensus on certain ideas or connections was challenging at times because of the diverse amount of wisdom and background of the team. But by having a facilitator who led the discussions, the activities were able to move forward with a more focused goal that summarized what the team was trying to convey. Overall, I believe the first two modeling sessions were very effective in creating a collective effort to instill knowledge of model building for the team."

Summary

This paper describes the collaborative construction of boundary objects for group model building in ways that elicit diverse disciplinary perspectives and domain expertise. In both digital and physical forms, the boundary objects developed in this study helped to facilitate knowledge flow and group consensus building. These boundary objects include the ElderSmile TimeMap as a spatially-explicit reference mode that contextualizes trends and the physical representation of a modifiable causal map. This participatory systems science approach to group model building holds promise for other interdisciplinary teams that seek to leverage the knowledge of all team members to address a complex problem.

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