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Combining Conceptual Frameworks on Maternal Health in Indigenous Communities—Fuzzy Cognitive Mapping Using Participant and Operator-independent Weighting

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Abstract

A recurring issue in intercultural research is whose knowledge informs conceptualization and design of projects or interventions. Fuzzy cognitive mapping uses arrows and weights to represent stakeholder knowledge on

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causal relationships and can generate composite theories to inform research and action. Cognitive mapping is accessible across different cultures, but participant weighting is not always straightforward. We describe a procedure to combine and condense maps from different stakeholders and an alternative operator-independent weighting procedure adapted from Harris's discourse analysis.

Introduction

Grounded knowledge synthesis incorporates information from experience and local realities or cultural contexts (Andersson 2018). Combining stakeholder perspectives with formal literature is often an effective basis for local decision-making and action (Davidoff et al. 2015). A recurring issue in intercultural research is whose knowledge should inform project conceptualization and design. A related concern is how to contrast or to combine different theories or knowledge, ranging from standard literature reviews to informal knowledge.

Fuzzy cognitive mapping (FCM) has been used to combine different perspectives into composite theories that inform research and action (Andersson and Silver 2019; Giles et al. 2008). Cognitive maps are directed graphs (Harary et al. 1965) composed of three elements: factors (causes or outcomes), relationships between factors, and weights of relationships. The maps depict causal factors as nodes linked by arrows to describe how changes can happen. The maps are graphic forms sharable across different cultures and literacy levels. They collate complex knowledge as multiple sets of relatively simple components of cause, link, and outcome. As long as each component cause and outcome can be identified or translated into the same language or symbols, the language or culture of authors of each individual map does not affect interpretation. A common communication format for different cultural backgrounds facilitates intercultural dialog and the synthesis of evidence from multiple sources.

Fuzzy cognitive mapping recognizes uncertainty and accepts that multiple answers exist for the same question (Kosko 1994). Instead of using a binary indicator such as an arrow or no arrow to define certainty of relationships in the map, fuzzy maps allow a range of weights allocated to the relationship (arrow). Since causal knowledge is often uncertain and different from the viewpoints of different stakeholders—for each of whom it might feel certain—FCM allows modeling of "hazy degrees of causality between hazy causal concepts" (Kosko 1986a:65). The technique provides a visual representation of different knowledges (Andersson and Silver 2019) using well-established analytical tools (Felix et al. 2019). These maps can represent cyclic dynamics (Gray et al. 2014; Osoba and Kosko 2019) when a factor is

both a cause and an effect of another or when a self-pointing arrow indicates reinforcing internal dynamic (Osoba and Kosko 2019).

Intercultural researchers have used fuzzy cognitive mapping to explore indigenous perspectives on maternal health (Sarmiento et al. 2020a) and to examine how stakeholder perspectives vary from and expand on published literature in diabetes and maternal health (Dion et al. 2019; Giles et al. 2008). The weight of evidence method uses FCM to contextualize literature-based evidence according to the knowledge of relevant stakeholders (Dion et al. 2021). Previous FCM analysis with multiple stakeholder groups in Canada (Tratt et al. 2020), Mexico (Sarmiento et al. 2020a), Nigeria (Sarmiento et al. 2021), Uganda (Belaid et al. 2021), and Botswana combined multiple maps within each stakeholder group. Matching and reducing concepts juxtapose concepts across maps before consolidating individual maps into a single collective combined one (Papageorgiou and Kontogianni 2012). Combined maps are easier to communicate as there is less to visualize, but the process of combining maps can be easily influenced by the researchers, raising concerns about whose views are ultimately reflected in the maps (Andersson and Silver 2019).

An additional concern is that weighting the strength of relationships on the maps increases the length of the mapping sessions considerably, which risks reducing participant engagement. This challenge is more significant when multiple participants build the maps. In some concepts of causality, an outcome is the result of all interactions across the whole system. Although the elements can be identified, their working together defies weighting the influence of any one component against another. FCM is relatively simple to do and easy to understand by participants from different backgrounds (Gray et al. 2012), but weighting of relationships can be challenging for stakeholders who do not, as part of their culture, parse elements of causality (Tratt et al. 2020). In these views of causality, establishing a hierarchy of factors that contribute to an outcome may be incompatible with their overall understanding of an issue.

Research Context and Objectives

This project is part of the Safe Birth in Cultural Safety project in Mexico, which aimed to improve maternal health outcomes in indigenous groups without undermining their culture or identity. This approach recognized equal value of indigenous and Western knowledge and aimed to bridge them through an intercultural dialog in the search for solutions. The project used FCM to contrast and to combine three knowledge sources about factors that affect maternal health in indigenous communities. The first two sources were traditional midwives in the south of Guerrero State (Sarmiento et al. 2020a) and a literature review of published and unpublished evidence (Sarmiento et al. 2020b). This article describes the third source, researchers with

experience in indigenous health promotion. We introduce a procedure to combine and condense maps made by different stakeholders. We also describe and test an alternative procedure to calculate the weights of relationships within the maps, as an alternative to obtaining the weights directly from mapping participants and compare the results obtained from the two weighting approaches.

Methods

We invited eight international researchers with extensive experience in culturally safe health promotion to participate in online sessions to map their understanding of factors affecting maternal health in indigenous communities in 2019. All the researchers had contributed to our work in Mexico (Sarmiento et al. 2018). Supplemental Material 1 shows characteristics of the participants.

Drawing Maps and Initial Rationalization

Fuzzy cognitive mapping participants (mappers) can create maps individually or in groups to describe their knowledge of complex systems one relationship at a time. They begin with the factors (nodes), then show how they are related to one another (arrows), and then weight the strength of the relationships.

Individual FCM sessions followed a standardized protocol (Andersson and Silver 2019). We opted for individual sessions to accommodate the busy schedules of researchers and, given the different backgrounds of the researchers, to reflect as much variation in perspectives as possible. The lead author (IS) provided each researcher with a guide about the process before facilitating individual mapping sessions. After informed consent, IS drew the maps using yEd (yWorks 2017) following the mapper's directions and recorded each session to document discussions behind each decision. The mappers indicated the factors, relationships, and weights. They then rationalized their maps by identifying duplicated concepts and unnecessary distinctions between similar factors to reduce their number. Mappers weighted the causal influence of each relationship using a scale from one for the weakest to five for the strongest. To facilitate weighting, the lead author asked two "if-then" questions for each relationship in the map (Stylios et al. 1999). First, if (the origin factor) increases, then would (the resulting factor) increase or decrease? Weights were positive for the former and negative for the latter. Second, if (the origin factor) increases, then would (the resulting factor) rarely change (weight of 1) or very often change (weight of 5)? After each session, each mapper received an electronic version of the individual map to confirm the content.

Combination

We calculated the fuzzy transitive closure (Niesink et al. 2013) for each map and combined the results into a single average map. Transitive closure is an algorithm that identifies all the possible paths between factors and calculates the total influence that one factor might have on another when all the possible paths between those factors are considered. Fuzzy transitive closure implies that indirect relationships between factors are only as strong as the weakest weight within the paths between them. It is the algorithm of choice when the number of factors and relationships differ across maps (Niesink et al. 2013).

We used a pattern correspondence table (Supplemental Material 2), in which each column reflects one map with factors in the map arranged by rows to line up with the factors of the other maps that share meanings. We used the row label as the standard name for factors mentioned in several maps. Sometimes the map authors described the same factor but as opposites in name and weight. For example, one map included violence with a negative effect on maternal health, while another included no violence with a positive effect on maternal health. Before combining the maps, we adjusted these differences. If one factor in a causal chain had to change from a positive to a negative relationship, the sign of the relationship would change. If both factor and outcome changed, the sign of the relationship remained the same.

Once all factors on the maps received a standard name, we calculated the average weight for each relationship. The resulting value was the sum of all the weights for that relationship across the maps divided by the total number of maps in the set (Kosko 1986b). The average is a simple way to combine stakeholder maps with equivalent perspectives and relevance. Weighted averages or Bayesian updating can help adjust for differences in expertise, relevance, or uncertainty around the weights (Dion et al. 2021). Group discussion among mappers can also be a way to define summary values for the relationships in a combined map.

Condensation

Condensation reduces the number of nodes and relationships by grouping them. Condensation helps avoid semantic differences that might hide similar meanings of concepts and facilitates combining multiple maps (Papageorgiou and Kontogianni 2012). It is particularly useful when a large number of factors hinder interpretation. A qualitative step identifies categories, and a quantitative step condenses factors and calculates the influence of each category (Gray et al. 2012; Özesmi and Özesmi 2004). We followed principles of coding and categorization (Saldaña 2016) for the former and principles of directed graphs theory (Harary et al. 1965) for the latter.

Defining Categories

Categorization allows organization and grouping of factors based on shared characteristics (Saldaña 2016) relevant for the research question that represent some level of patterned response or meaning within the data set (Braun and Clarke 2006). Using inductive analysis, the lead author initially arranged the factors in the maps into categories, aided by the records from the mapping sessions. In a member-checking exercise (Birt et al. 2016), each of the eight mappers examined the categories and suggested any necessary adjustments. After two iterations, the participating researchers agreed on a final set of categories. The correspondence table (Supplemental Material 2) shows the final classification.

Condensation of Factors and Category Weights

Harary et al. (1965) initially described condensation in the analysis of unweighted directed graphs as the process of reducing parts of the map (nodes and arrows) into single nodes and arrows. Several authors have described procedures for condensation (Balakrishnan 1995; Iwasaki and Simon 1994; Louati et al. 2011; Sterling 2004) based on the weights of nodes, arrows, or both. Here, we used only the arrow weights because mapping sessions focused on weighting the relationships between factors, rather than the factors themselves. Condensation of factors followed a qualitative procedure.

We renamed the factors (nodes) in the combined map described above (under subheading Combination) with the agreed-on categories. We then listed all the relationships in the map to indicate one cause and one outcome linked by an arrow. Condensation is equivalent to aggregating multiple sub-maps (sub-graphs), each corresponding to a relationship (cause-arrow-outcome). We then added the weights of all the relationships with the same category names (Kosko 1988). The resulting list had the relationships of the map condensed at the category level. In this map, the weights of each arrow indicated the strength of the influence of one category on another, and we normalized these weights into a range between 0 (no relationship) and 1 (the maximum category weight) to facilitate comparability. If an initial and landing factor belonged to the same category, condensation will result in a self-pointing loop indicating reinforcing dynamics within the category. Loops are common results of operations with maps (Osoba and Kosko 2019). Supplemental Material 3 has a step-by-step graphical description of the condensation process.

Following the same procedure, we then generated a condensed map for each of the eight individual maps. The comparison of these eight condensed maps identified: (a) validated connections (all maps share the non-zero connection with the same sign), (b) non-validated connections (the connection

is not mentioned in all the maps), and (c) conflicting connections (the connection is positive in some maps and negative in others). As described elsewhere (Sarmiento et al. 2020a), we used a similar process with traditional midwives to identify shared and conflicting views to develop intervention strategies grounded in community understanding of maternal health.

Harris's Discourse Analysis and Comparison with Participant Weights

Zellig Harris proposed the earliest formal discourse analysis in the 1950s to explore meaning based on the frequency of occurrence of discourse elements (Harris 1952). The approach identified the role of morphemes (part of a word, a word, or several words with an irreducible meaning) exclusively from their relative frequency in the text without assuming any prior meaning for them. The comparison of frequencies between texts allowed Harris to identify similar structural meanings of morphemes. Harris's analysis thus collated the patterns of relationships between words (internal structure) to understand how interactions between words held meaning. Because it was based on frequency of occurrence, among other criteria (partial order, redundancies, and dependencies), it did not depend on the researcher assumptions of meaning. This operator/researcher independence is a major advantage in the intercultural context.

We applied the concept of morpheme frequency across different maps to establish weights of causal relationships between two factors. A factor that caused an outcome across multiple maps would have stronger influence than a factor that causes the same outcome only on one or two maps. In the eight original individual maps of the independent researchers, we ignored the participant weights. We kept only the indication of whether a mapper said a causal relationship and whether it was positive or negative. We used a weight of 1 if the relationship was on the map and 0 if it was not. For the relationships with weight 1, we maintained the sign (positive or negative) as indicated by the mappers. The analysis started by calculating the transitive closure of each map to identify direct and indirect relationships, revealing the internal structure of the map (Niesink et al. 2013). We then calculated the number of times each relationship repeated across all the individual transitive closure maps and established their relative frequency by dividing each occurrence by the highest frequency across the eight maps. Thus, we obtained a value between 0 for the relationships that did not exist and 1 for the relationship that was most frequently mentioned. We then used the same procedure described before to create a condensed map.

To compare participant-weighting and Harris's discourse analysis at the factor level, we calculated outdegree centrality on the combined maps

(described above) as the sum of the absolute values of the weights for each factor's outgoing edges (Papageorgiou and Kontogianni 2012). This measure indicates the total strength of the factor in terms of its outgoing relationships (Gray et al. 2012). Higher outdegree centrality suggests a higher level of influence of one node in the map and signals actionable factors, that could be of interest to promote change. The free software yEd (yWorks 2017) generated this and a graphical output scaling the size and position of the factors in a relative order from the highest to the lowest for each map. To measure the overall agreement of category weights between participant-generated and operator-independent weights, we calculated the average of the absolute value of the difference in weights. A small average difference indicates similarity of the weighting approaches and higher values indicate less agreement.

Results

For the eight researchers, maternal health was a broad concept that included all aspects of woman's well-being during pregnancy, childbirth, and postpartum periods, including, for example, the spiritual dimension, the physical condition, and positive mental condition. The eight individual maps each identified between 10 and 24 causal factors for maternal health, and between 32 and 99 relationships between those factors—between 1.9 and 4.3 relationships per factor. The eight maps together identified 106 unique factors, which we grouped into 12 categories, linked by 886 relationships identified after transitive closure.

The values of all the relationships in the condensed maps are available as Supplemental Material 4. We describe below the three categories with the highest influence on maternal health based on 330 relationships between 67 factors identified after transitive closure. Figure 1 presents a sub-map of the relationship at the category level and the factors involved in the strongest internal dynamics of each category.

Cultural continuity included maintaining indigenous identity and support of traditional midwifery as the two most influential factors (higher outdegree). This category also included spiritual practices, access to traditional midwifery, following traditional self-care practices (diets, purge, menstruation care, etc.), and respectful behavior in the family. A self-pointing loop described the reinforcing dynamics of maintaining identity in higher engagement with self-care practices, including traditional diets, and less use of alcohol and drugs. The reinforcing role of traditional midwifery was reflected through a range of paths, including, more self-care practices, more support from traditional midwives for women during pregnancy and delivery, more positive partner attitudes, and less alcohol consumption. This category was validated across all the maps.

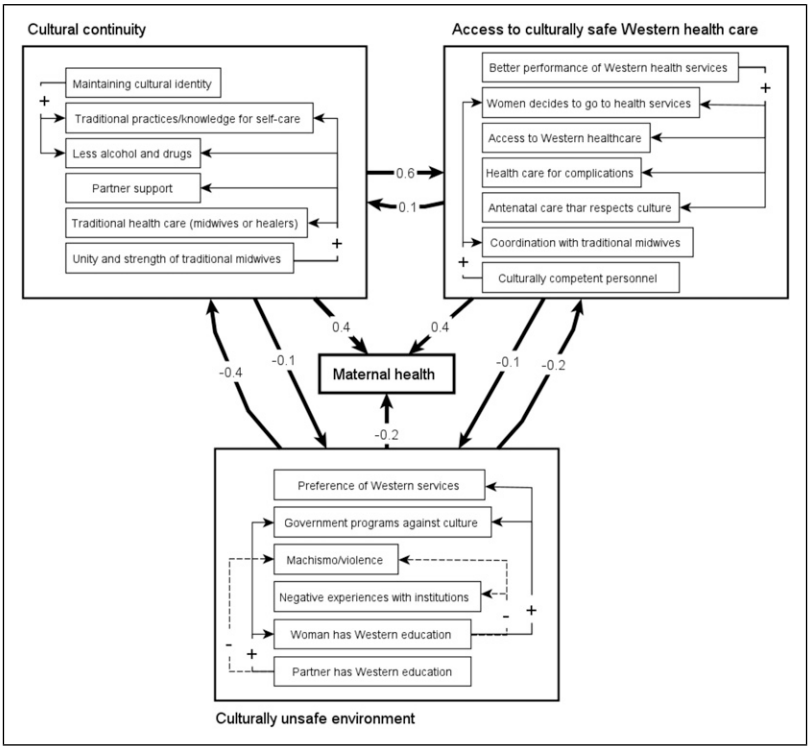

Figure 1. Map of the three strongest categories and their internal dynamics. Legend: Each box corresponds to a category and the thick arrows to category-level relationships. Within the categories some factors had positive and negative interactions, thus indicating internal dynamics.

Access to culturally safe Western health care included quality and accessibility of health care services, especially for complications, as the most influential factors (higher outdegree centrality). Other factors in this category referred to respectful health care and antenatal care within an intercultural framework, coordination with traditional midwives, and cultural competence of health personnel. A prominent self-pointing loop depended on a better performance of health services that contribute to women's decision to seek care and increasing access to health services and the impact of culturally competent personnel on increasing coordination with traditional midwives and reducing women's delay in deciding to visit health services.

A *culturally unsafe environment* had a negative impact on maternal health, decreased access to Western medicine, and impaired cultural continuity. This category included institutions and programs that do not value indigenous

culture, religious missionaries, or Western education that replaced cultural values, structural or personal racism, loss of territories, negative experiences of indigenous people in their interaction with Western institutions, a culture of violence, and inadequate communication strategies. The most influential factors according to their outdegree centrality were Western education of the woman and her partner guided by Western values with ambiguous positive and negative effects via direct or indirect displacement or de-valuing of traditional approaches to maternity care. Another category with negative, although weaker, influence on maternal health was *woman's comorbidities*, particularly diabetes.

Comparison of Participant and Harris's Discourse Analysis Weights

All but one of the 10 factors with the highest outdegree centrality in the participant-weighted consolidated map coincided with the top 10 in the Harris's discourse analysis consolidated map (Supplemental Material 5 shows the outdegree centrality of each factor). The order of importance as cause across the system varied for these factors (Table 1). When we considered only the influence on maternal health, the strongest factors were *previous poor*

Table 1. Factors with Higher Outdegree Centrality.

Centrality (and order) in Participant-based weights			Centrality (and order) in Harris's discourse analysis
Support from partner or family	1.00	1.00	Support from partner or family
Woman has caring and working husband	0.99	1.00	Support from the community
Western health services are available	0.90	1.00	Western health services are available
Maintain the cultural identity	0.88	0.97	Woman has Western education
Woman has Western education	0.87	0.90	Traditional practices (food, purge, others)
Woman's economic stability	0.86	0.90	Woman has caring and working husband
Strength and unity of traditional midwives	0.85	0.83	Strength and unity of traditional midwives
Support from the community	0.80	0.79	Woman's economic stability
Traditional practices (food, purge other)	0.76	0.69	Maintain the cultural identity
Western education against culture (community)[a]	0.74	0.62	Traditional midwives in the community

[a]These factors did not appear among the most important factors identified by the other weighting procedure.

health conditions of the woman in the discourse analysis map and *maintaining cultural practices* and *support from a traditional midwife* in the participant-weighted map.

Figure 2 shows the condensed maps with each node scaled according to its outdegree centrality. The condensed maps showed an almost identical internal structure, whether based on participant- or discourse-analysis weighting. Both similarly identified those categories with stronger influence in the system. The average difference of relationships between the two weighting procedures was 0.01, and the largest difference was 0.1, for the effect of *culturally unsafe environment* on *cultural continuity*. *Cultural continuity* had the highest outdegree centrality or the strongest influence on the system for both weighting procedures. Similarly, in the second order of importance of both condensed maps was *access to culturally safe Western health care*. *Cultural continuity* and *access to culturally safe Western health care* also had the most prominent positive influence on *maternal health* (Figure 2).

Discussion

The combined map is a soft model (Strickland 2011) of the views of eight knowledge sources (independent researchers) about influences on maternal health in indigenous communities. The researchers shared several characteristics, including positive attitudes toward participatory approaches and respect for indigenous traditions. The purposive sampling explains the prominence of indigenous cultural continuity and cultural safety as strong positive influences. Recognition of these influences is growing

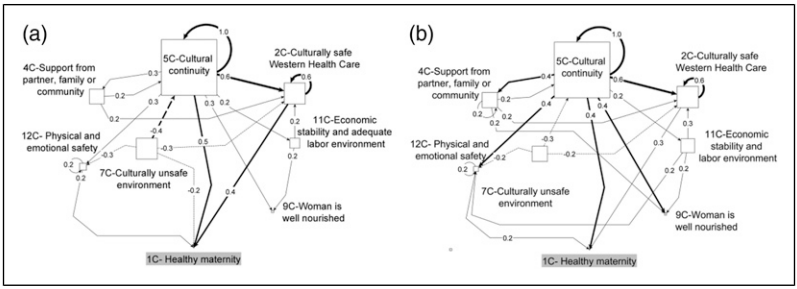

Figure 2. Map of categories affecting maternal health in indigenous communities. Legend: The figure compares the condensed maps obtained from participant-based (panel a) and discourse analysis weighting (panel b). To simplify the graph, we only included the relationships with the five strongest levels of influence. Appendix B contains all the relationships on the map. Solid lines represent positive relationships and dashed lines negative ones. The numbers on the edges represent the cumulative net influence of one category on another, where 1 is the highest influence in the map.

(Curtis et al. 2019), particularly in the Americas, where indigenous groups are increasingly vocal about the value of their worldview and knowledge (Dietz 2018; Walsh 2008). At best, however, the soft model generated by these experienced intercultural researchers would only be generalizable to a certain type of intercultural researcher, not all researchers.

Fuzzy cognitive mapping offers a sharable language to collate knowledges from multiple sources. Combining maps offers a partial answer to uncertainty about the "correct" knowledge of causes of a particular outcome (Kosko 1986b). Peirce proposed a pragmatic response to uncertainty of beliefs as "the final opinion," the one that is fated to be ultimately agreed to by all who investigate it. (The Peirce Edition Project 1998). Although new inquiry may modify what is known about something, the aggregation of knowledge contributed by an indefinite community of inquiry reduces uncertainty (Kosko 1994).

In conventional research, researchers trained in Western scientific methods have conventionally held a monopoly of inquiry. FCM extends the boundaries of what could be included in research synthesis (Dion et al. 2019). This expansion of what is perceived as valid knowledge is particularly relevant for indigenous groups who have developed complex bodies of knowledge, know-how, and practices over many generations (International Council for Science 2002), and whose knowledge has been systematically ignored for centuries (Santos 2009). Increased collaboration across cultural differences opens space for intercultural dialog (Dietz 2018; Pérez Ruíz and Argueta 2011), a communication process in which different parties contribute their knowledge to identify solutions for a shared concern (Council of Europe 2008).

Participant weighting of influence and Harris's discourse analysis of the frequency of relationships showed very similar outdegree centrality for the 10 most important individual factors and almost identical broader categories. Harris's discourse analysis uses binary indicators of the presence or absence of a relationship *across multiple texts* or, in this case, across multiple maps. This analysis cannot work for a single map. Our application of discourse analysis considered each cause-outcome set as we would consider a similar causal concept in an interview/discussion. Our intention was not to eliminate participant weighting of influence, but to adapt FCM to stakeholder settings where participants declined or could not generate the weights.

Limitations and Challenges

The causal relationships in the maps constitute a soft model of participant knowledge and, as such, are bound to be partial. One makes the models not so much for prediction as for learning about how different stakeholders see possible paths that would lead to an outcome (Mingers 2006). In this application, FCM allowed us to present perspectives of a small number of

participants with similar viewpoints about maternal health. The smaller the number of maps, the less amenable this would be to Harris's discourse analysis and the generalizability of results.

Condensation of factors into categories carries the risk of any summary of complex information from multiple sources (Louati et al. 2011). Categories are an abstraction to deal with different framing of factors across individual perspectives (Felix et al. 2019). In our case, we included map authors in the categorization process, an option that might not always be available.

Analysis at this higher level of abstraction (categories) often addresses structural issues, like behaviors shared by groups or maintained for a long time, often overriding important details within the categories. We should thus not infer factor-level conclusions from category-level results. A relationship between two categories does not imply that all factors in one category will have the same summary influence on all factors in the outcome category (Harary et al. 1965). Once categories help clarify the general picture, it may be appropriate to revert to factor-specific measures identified by outdegree centrality as the most influential.

Conclusions

The most influential factors in maternal health identified in the combined maps were consistent with the mappers' experience with indigenous traditions. These eight researchers believe culturally safe approaches and adequate intercultural interactions can make positive contributions to indigenous maternal health. The procedure to combine and condense maps allowed us to present the perspectives of this group in a concise yet meaningful format. Increasing the level of abstraction using categories made the combined map more accessible. The condensed maps explored structural issues and offered suggestions for future research. Exploring internal dynamics of condensed maps indicated relevant factors that could contribute to promote change.

Harris's discourse analysis to generate operator-independent weights of influence makes FCM relevant in communities where participant-weighting is not feasible. It could thus increase participation of stakeholders with causal philosophies that do not include parsing causes and their relative importance. This should complement, not replace, a commitment to intercultural dialogue.

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Ethics

The research project received approval of the Ethics Committee of the *Centro de Investigación de Enfermedades Tropicales* of the *Universidad Autónoma de Guerrero*, Mexico, and of the McGill University's Faculty of Medicine and Health Sciences Institutional Review Board.

Availability of Data and Materials

The data that support the findings of this study are available in the supplementary material of this article.

Supplemental Material

Supplemental material for this article is available online.

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