Exploring Aboriginal Views of Health Using Fuzzy Cognitive Maps and Transitive Closure

A Case Study of the Determinants of Diabetes

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ABSTRACT

Objectives: To demonstrate how fuzzy cognitive maps may be used to extract, present and compare Aboriginal perspectives, using the determinants of diabetes as a case study.

Methods: Participants from the Mohawk Community of Akwesasne and the Miawpukek First Nation in Conne River created fuzzy cognitive maps (FCMs) (N=3) detailing their views of “the causes of diabetes in their community”, through a facilitated, group mapping session. For each FCM, the net causal effect of every determinant (direct or indirect) on diabetes was calculated from its transitive closure. The net causal effects were then compared across the set of FCMs to identify strong, weak and controversial determinants.

Results: Comparison of FCMs revealed significant heterogeneity in the perspectives of diabetes. The Akwesasne participants focused heavily on social, traditional and spiritual factors, while Conne River participants placed more importance on direct personal and lifestyle factors. There was, however, a core of strong, validated determinants related primarily to healthy diet and physical activity.

Conclusions: This work demonstrates how FCM may be used to extract and represent different perspectives of complex issues allowing for comparisons among stakeholders or knowledge groups. Comparison of multiple FCM employing the transitive closure may then be used to identify areas of agreement and controversy.

Key words: Knowledge; Native American; NIDDM; social medicine

La traduction du résumé se trouve à la fin de l'article.

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Aboriginal communities in Canada suffer poorer health than comparable non-Aboriginal communities,¹⁻³ especially with respect to chronic diseases such as diabetes.⁴⁻⁶ Although some important risk factors associated with poorer health of Aboriginal communities – lower socio-economic status, obesity, smoking, poor diet – have been described, for many Aboriginals the root cause is a life out of balance arising from the loss of traditional lifestyles, culture and spirituality.⁷⁻¹⁰ Accordingly, public health policies are increasingly seeking to incorporate Aboriginal perspectives of health.¹¹⁻¹³

Understanding the Aboriginal perspective on health is of considerable pragmatic importance. First, because the conventional set of health determinants are proscribed by a largely (western) scientific model of human health, this set may be expanded by considering factors derived from other knowledge systems. Second, community participation and incorporation of local cultural beliefs are invariably cited as important factors in program success.¹⁴⁻¹⁶ Interventions that target determinants viewed as of lesser (or no) importance by Aboriginal communities, irrespective of the empirical validity of this perception, are more likely to be unsuccessful.^{7,17-20} Third, any assessment of the effectiveness of health interventions requires indicators of disease incidence or prevalence and of the causal factor(s) the interventions are designed to mitigate. For national programs, this leads naturally to the question of the extent to which indicators are universal, applying to all (or most) communities.

Recently, we proposed a method for representing and comparing different perspectives of an issue^{21,22} or system using fuzzy cognitive maps (FCMs).²³ Here we show how the transitive closure of an FCM can be used to compare inferred causal structures, using an illustrative case study of the causal determinants of diabetes as reported by members of two Aboriginal communities. This work is part of an ongoing collaborative initiative by the Institute of the Environment (IE) at the University of Ottawa, the Assembly of First Nations and their Aboriginal community partners across Canada on the integration of conventional scientific and traditional knowledge.

METHODS

Fuzzy cognitive maps

Fuzzy cognitive maps (FCM) are graphical representations of the relationships between elements of a system (or issue), as perceived by “experts”.²³ Fuzzy cognitive maps comprise *concepts* (C), representing causal factors, joined by *connections* representing causal relationships between concepts. Each connection is assigned a weight $a_{ij} \in [-1, 1]$ which quantifies the strength of the causal relationship between factors C_i and C_j . A positive weight $a_{ij} > 0$ indicates an excitatory relationship (i.e., as C_i increases, C_j increases), while a negative weight $a_{ij} < 0$ indicates an inhibitory relationship (i.e., as C_i increases, C_j decreases). Causal weights denote the knowledge holder’s opinion about the magnitude and nature of the corresponding causal relationship. As such, the method – as applied here – is not concerned with whether this assessment accurately reflects the true causal structure of the system under consideration.

Transitive closure and net causal effect

Fuzzy cognitive maps are directed graphs whose properties may be investigated using well-developed graph-theoretic tools and techniques.²⁴ For any directed graph, one can compute its *transitive closure* which comprises all of the connections between pairs of concepts, as well as all the implied connections between two concepts as a result of their being part of the same indirect pathway. For example, the transitive closure of the simple FCM in Figure 1 includes all direct connections between concepts A, B and C as well as the direct connection between A and C implied from the causal connections between A and B and between B and C (Figure 1a). If there are no causal pathways linking A and C (i.e., C cannot be reached from A), then there is no $A \rightarrow C$ connection included in the transitive closure (Figure 1b). For example, if A, B and C represent Access to Healthy Food, Healthy Diet and Diabetes respectively, then there is an implied connection between Access to Healthy Food and Diabetes (through the Healthy Diet) even if the two concepts were not directly linked.

For each new implied connection (e.g., $A \rightarrow C$ in Figure 1a), one can calculate a

Figure 1. Transitivity in directed graphs

In a) the indirect connection between concepts A and C, through concept B, implies a causal relationship and a connection in the transitive closure (dotted line) between concepts A and C, while in b) there is no indirect relationship between concepts A and C and therefore no connection in the transitive closure. In c) there are two pathways from concept A to concept C (through B and D respectively) and therefore two possible implied connections.

causal weight (e.g., a_{AC}) based on the set of causal weights for each direct connection in the corresponding causal pathway (e.g., a_{AB} and a_{BC} in Figure 1a). This may be viewed as the strength of the causal relationship between A and C, which is mediated through B, for example, calculating the relative impact that Access to Healthy Food has on Diabetes, through its direct impact on Healthy Diet.

Clearly there may be multiple pathways (direct and indirect) between any two concepts (Figure 1c), resulting in multiple implied connections whose causal weights may have different strengths, and may even be of different sign (i.e., positive or negative causal effects). Calculating a **net causal effect** (e_{ij}), taking into account all the

direct and implied causal weights between concepts i and j , therefore, requires a method to a) calculate the causal weight for all implied connections from the causal weights in the corresponding causal pathway on which they are based and b) combine the weights of all direct and implied connections to yield a single value.

Here we adopt a probabilistic interpretation of connection weights in FCMs²⁵ whereby the weight a_{ij} is regarded as the probability that a change in C_i will result in a change in C_j . Thus a large positive (negative) connection weight a_{ij} is interpreted as a high probability that an increase in the level of causal factor C_i will result in an increase (decrease) in the level of factor C_j . The net causal effect of C_i on

Figure 2. Simplified, recoded fuzzy cognitive map of the determinants of diabetes created by Mohawk Council of Akwesasne health professionals (MCA-HP)

Figure 3. Simplified, recoded fuzzy cognitive map of the determinants of diabetes created by Conne River health professionals (CR-HP)

C_j is calculated by taking all causal paths from C_i to C_j and calculating the probability that there will be at least one pathway between the two concepts. The net causal effect, therefore, decreases with pathway length (i.e., the length of the causal chain of factors connecting the two), but increases with the number of pathways (the number of different sets of causal factors by which two concepts are joined) connecting them.

The sign of the net causal effect is calculated as the product of the signs of the direct connections along the corresponding pathway. It is possible to have implied connections between the same two concepts with conflicting causal effects, i.e., both positive and negative pathways, indicating that C_i both promotes and inhibits C_j . The weights of positive and negative causal effects are thus calculated separately so these situations may be identified. Transitive closures were calculated using the algorithms described by Šajna.²⁵

Comparing FCMs

If separate FCMs are constructed by different knowledge holders, then differences among FCM in the enumerated concepts (vertices) and causal relationships (connections) reflect differences in perceived causal structure. Differences in the weights accorded a connection reflect differing opinions on the strength of this causal relationship. Although there are many different ways to compare FCMs, here we focus on a method concerned with estimating the net causal effect (e_j) of each concept in the FCM on an outcome of interest. The greater the $|e_j|$, the greater the likelihood that changes in concept i will result in changes in the outcome of interest (j). This allows identification of the key promoters ($e_i > 0$) or inhibitors ($e_i < 0$) of j as represented in a given FCM. Given a set of FCMs, for a given concept i we can then calculate a) **Consensus**, the number of FCMs with $e_i \neq 0$; b) **Causal importance**, the mean e_i across all FCM including those for which $e_i = 0$; and c) **Heterogeneity** as the coefficient of variation (CV) in mean e_i . These three metrics are then used to identify:

1. *Strong determinants* – those with both high causal importance and high consensus;
2. *Weak determinants* – those with low causal importance and high consensus;

TABLE I

The Net Causal Effect (e_{ij}) on Diabetes for Each Determinant for Each Individual FCM, the Number of FCM which Included the Concept (N), the Average Net Causal Effect ($\bar{e}$) and Co-efficient of Variation (CV_e) over All FCMs in the Sample

Determinant	CR-HP	CR-NHP	MCA-HP	N	$\bar{e}$	CV_e
Healthy Diet	-0.9	-0.9	-0.9	3	-0.90	0
Healthy Food Choice	-0.7	-0.9	-0.9	3	-0.83	14
Physical Activity	-0.7	-0.9	-0.9	3	-0.83	14
Healthy Lifestyle	-0.5	-0.9	-0.9	3	-0.77	30
Knowledge (Diabetes/Diet)	-0.9	-0.9	-0.5	3	-0.77	30
Education Programs	-0.7	-0.9	-0.5	3	-0.70	29
Healthy Food Access	-0.7	-0.5	-0.9	3	-0.70	29
Social Support	0	-0.9	-0.9	2	-0.60	87
Stress	0.9	0	0.9	2	0.60	87
Exercise Opportunities	-0.7	-0.1	-0.9	3	-0.57	73
Obesity	0.9	0.7	0	2	0.53	89
Heredity	0.9	0.5	0	2	0.47	97
Knowledge (Local Food Production)	-0.3	0	-0.9	2	-0.40	115
Local Food Production	-0.5	0	-0.7	2	-0.40	90
Time Available	-0.5	-0.7	0	2	-0.40	90
Traditional Family Operation	-0.7	0	-0.5	2	-0.40	90
Abuse	0	0	0.9	1	0.30	173
Balance and Harmony	0	0	-0.9	1	-0.30	173
Childhood Education by Parents	0	-0.9	0	1	-0.30	173
Community Involvement in Planning	0	0	-0.9	1	-0.30	173
Culture	0	0	-0.9	1	-0.30	173
Language	0	0	-0.9	1	-0.30	173
Men Leave to Work in Cities	0	0	0.9	1	0.30	173
Organ Cleansing	0	0	-0.9	1	-0.30	173
Political Support	-0.9	0	0	1	-0.30	173
Positive Attitude	0	-0.9	0	1	-0.30	173
Prejudice	0.9	0	0	1	0.30	173
Relationship to Land	0	0	-0.9	1	-0.30	173
Relationship to Others	0	0	-0.9	1	-0.30	173
Relationship to Sacred	0	0	-0.9	1	-0.30	173
Smoking	-0.9	0	0	1	-0.30	173
Support Programs	0	-0.9	0	1	-0.30	173
Tax Free Tobacco	-0.9	0	0	1	-0.30	173
Traditional Diet	-0.9	0	0	1	-0.30	173
Population Density	0	0	0.9	1	0.30	173
Access to Health Care	-0.7	0	0	1	-0.23	173
Alcohol Abuse	0.7	0	0	1	0.23	173
Clean Water Availability	0	0	-0.7	1	-0.23	173
Family Employment Tradition	0	0	0.7	1	0.23	173
Pollution	0	0	0.7	1	0.23	173
Preferred Employment	0	0	-0.7	1	-0.23	173
Rural v. Urban Living	0.7	0	0	1	0.23	173
Trained for Work	0	0	-0.7	1	-0.23	173
Trust in Food Quality	0	0	-0.7	1	-0.23	173
Trust in Local Medicine Quality	0	0	-0.7	1	-0.23	173
Use of Local Medicines	0	0	-0.7	1	-0.23	173
Ability to Preserve Local Food	0	0	-0.5	1	-0.17	173
Ability to Store Local Food	0	0	-0.5	1	-0.17	173
Activity in Home	-0.5	0	0	1	-0.17	173
Availability of Work in Community	0	0	-0.5	1	-0.17	173
Breastfeeding	-0.5	0	0	1	-0.17	173
Employment - Aboriginal Status Policy	0.5	0	0	1	0.17	173
Empowerment	0	0	-0.5	1	-0.17	173
Family Size	0	0	-0.5	1	-0.17	173
Good Weather	-0.5	0	0	1	-0.17	173
Inter-Marriage	0.5	0	0	1	0.17	173
Traditional Activities	-0.5	0	0	1	-0.17	173
Cultural Beliefs	0	0.3	0	1	0.10	173
Depression	0	0	0.3	1	0.10	173
Pregnancy (GDM)	0	0.3	0	1	0.10	173
Diabetes	0	0	0.3	1	0.10	173

This lack of consensus means these concepts had low overall importance, despite potentially having high causal effects in an individual FCM (Table I). The MCA-HP cited the largest number of novel determinants (26), followed by CR-HP (15) and CR-NHP (5). The larger number of novel determinants articulated by the MCA-HP correlated with increased size and complexity in the original FCM (Figure 2).

DISCUSSION

Aboriginal perspectives are neither static nor homogenous.^{7,8} Incorporating Aboriginal perspectives into public health policy, therefore, requires input from a large number of participants in order to accurately represent the full range of views. Fuzzy cognitive mapping is a simple procedure through which input from participants of diverse backgrounds may be struc-

tured and synthesized. Net causal effects calculated from the transitive closure of the FCM may then be used to identify key determinants within an individual perspective, and the degree of consensus, or controversy, among FCMs representing different perspectives.

In the case study of diabetes, analysis revealed a core of strong, validated determinants related primarily to those direct determinants (e.g., healthy diet and physi-

cal activity) commonly cited by health professionals and researchers.^{4,5,26-28} Strong determinants would seemingly be appropriate targets for intervention in a national level program targeting diabetes in Aboriginal communities, as they were perceived as important causes (directly or indirectly) of diabetes across all communities and sectors within communities, at least in our limited study.

The FCM and net causal effects may also identify controversial determinants; those with either a) considerable variation in perceived causal importance, b) lack of consensus as to its presence or c) conflicting directions (signs) for its causal effect. Controversial determinants may be seen as having a lower "weight of evidence" compared to strong, or even weak, validated determinants. In policy planning, such determinants would benefit from investigation as to the sources of controversy, which may a) reveal and correct misunderstandings, b) introduce new ideas and increase awareness among stakeholders, or c) identify areas of uncertainty or conflict to be resolved through further study and/or dialogue. For example, the failure of CR-HP to attribute any role to social support would appear to be an oversight. The omission of obesity and heredity as determinants from the MCA-HP FCM, however, may be deliberate in light of the attention focused on these factors in the scientific literature,^{26,27,29-31} of which the MCA participants were well aware. Similarly, CR-NHP participants explicitly omitted local (traditional) food during workshop sessions, and in particular, expressed strong doubts that a return to traditional foods would substantially improve diet quality or that community members would be willing to return to traditional diets.

Variation among FCMs may reflect variation in the nature of the facilitation. Facilitation effects can be minimized by using the same facilitator for all groups, as was done here. Ideally, the facilitator will participate as little as possible in creating the FCM, but it is not possible for them to remain completely detached from the process. The facilitator must, for example, interpret participants' input in creating short descriptions to represent similar concepts as expressed by participants. It is important, therefore, that any input by the facilitator be presented to those creating

the FCM and that the final decision remain with them. Our experience suggests that FCM facilitation works best with few (e.g., 3-5) participants, which allows for greater participation and reduces the required time. With a small group, a complete FCM can be produced in about three hours.

The FCM is a generic tool for organizing and comparing knowledge about hypothesized causal (inter)relationships, which may be employed wherever there are potentially differing perspectives of a system or issue. Comparison of multiple FCM, representing multiple perspectives, may be used to identify areas of agreement and controversy, which in turn may then guide a) future research to resolve areas of uncertainty or controversy, b) policy interventions aimed at strongest, consensually identified determinants or c) identification of indicators along the proposed causal pathways for appropriate monitoring programs.²¹

FCMs provide a possible means of rendering input from a diverse group of participants into a common, easily interpreted representation which is nonetheless amenable to rigorous analysis using graph-theoretic tools. Participants in all three FCM sessions regarded the process as a simple, effective and efficient means of structuring discussion and debate, and were pleased with the resulting representations. Moreover, there exists considerable potential for the tool to be used in policy development, policy decision-making and management intervention³² by, for example, assessing the extent to which causal factors representing policy or management foci are indeed considered strong determinants.

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RÉSUMÉ

Objectifs : Montrer comment les cartes cognitives floues peuvent être utilisées pour extraire, présenter et comparer des perspectives autochtones. Ici, ces perspectives ont porté sur les déterminants du diabète.

Méthode : Lors d'une séance de cartographie de groupe facilitée par un animateur, des participants de la communauté mohawk d'Akwesasne et de la Première nation Miawpukek de Conne River ont créé des cartes cognitives floues (CCF) (N=3) décrivant selon leurs points de vue « les causes du diabète dans leur communauté ». À partir de la fermeture transitive de chaque CCF, nous avons calculé l'effet causal net de chaque déterminant (direct ou indirect) sur le diabète. Les effets causaux nets ont ensuite été comparés d'une CCF à l'autre pour repérer les déterminants forts, faibles et controversés.

Résultats : La comparaison des CCF a mis en évidence une grande hétérogénéité dans les perspectives du diabète. Les participants d'Akwesasne ont beaucoup insisté sur les facteurs sociaux, traditionnels et spirituels, tandis que ceux de Conne River ont accordé plus d'importance aux facteurs personnels directs et au mode de vie. Nous avons néanmoins extrait un solide noyau de déterminants validés, surtout liés à l'alimentation saine et à l'activité physique.

Conclusion : Ce travail montre comment on peut utiliser les CCF pour extraire et représenter des questions complexes selon différentes perspectives, et ainsi établir des comparaisons entre des intervenants ou des groupes détenant un savoir. La comparaison de multiples CCF par une opération de fermeture transitive peut ensuite servir à dégager des zones d'accord et de désaccord.

Mots clés : savoirs; Amérindiens; diabète de type II; médecine sociale

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