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Stability of Centrality Measures in Social Network Analyses

*to Identify Long-Lasting Leaders from an
Indigenous Boarding School of Northern Mexico*

Joel Monárrez-Espino and José Ramiro Caballero Hoyos

Abstract

Aim: To assess the stability of centrality measures used in social network analyses aimed at identifying long-lasting leaders from an indigenous boarding school. **Methodology:** Data was collected from children aged 6-14 years interviewed in 2005 and 2006. Children were asked to mention five peers to whom they communicated more. Analyses included computation of centrality scores and attribute-related density by sex and school grade with UCINET. Stability was assessed using kappa and correlation coefficients; leaders with scores in the fourth quartile were selected. **Results:** There were differences in density values by sex and grade in both years ($p < 0.01$). Kappa coefficients were very low, but highest for closeness (0.15) and eigenvector (0.18); correlations ranged from 0.15 (betweenness) to 0.51 (closeness). The proportion of matching children with centrality scores in the fourth quartile between 2005 and 2006 was $< 12\%$ in all centrality measures. **Conclusion:** Using centrality measures to identify stable leaders proved difficult in this indigenous school scenario; unless this approach is used on annual basis, the leaders selected in one year might not be the same in the next potentially limiting the impact of health promotion interventions based on this strategy.

Key words: Centrality Measures; Leaders; Reliability; Schoolchildren; Social Networks, Tarahumara

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Resumen

Título: Estabilidad de medidas de centralidad en redes sociales para identificar niños líderes en una escuela-albergue indigenista del norte de México. **Objetivo:** Evaluar la estabilidad de las medidas de centralidad usadas en el análisis de redes sociales para seleccionar líderes duraderos en una escuela-albergue indigenista. **Metodología:** Se recolectó información en dos años consecutivos mediante entrevista a escolares de 6 a 14 años. Se pidió a los niños mencionar a los cinco compañeros con quienes más conversaban y se documentó la frecuencia de dicha comunicación. El análisis incluyó el cálculo de la densidad de la red por sexo y grado escolar, así como los puntajes de centralidad (grado, cercanía, intermediación, eigenvector) mediante el programa UCINET. La estabilidad fue evaluada mediante coeficientes de kappa y correlación. Se seleccionaron líderes con puntajes en el cuarto cuartil. **Resultados:** Hubo diferencias en la densidad por sexo y grado escolar en ambos años estudiados ($p < 0.01$). Los coeficientes de kappa fueron muy bajos, pero mayores para cercanía (0.15) y eigenvector (0.18). La correlación fluctuó entre 0.15 (intermediación) y 0.51 (cercanía). La proporción de niños con puntajes en el cuarto cuartil en los años comparados fue $< 12\%$ para todas las medidas de centralidad estudiadas. **Conclusión:** El uso de medidas de centralidad para identificar líderes estables resultó difícil en este escenario indígena; a menos de que este abordaje se implemente anualmente, la selección de líderes en un año determinado podría no ser similar el año siguiente reduciendo potencialmente el impacto de los programas de promoción a la salud basados en esta estrategia.

Palabras clave: Medidas centrales, Líderes, Confiabilidad, Escolares, Redes sociales, Tarahumara

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The innovation diffusion theory suggests that after an individual takes notice of an innovation from a new source, the person gains consciousness and learns from it developing a positive or negative attitude that will ultimately determine the acceptance or rejection of such innovation; the basic premise is that new ideas disseminate through interpersonal contact communication (Valente, 1995; Rogers, 2003).

The social network analyses comprehend a pool of methods, some that allow researchers identify individuals that are central in their community, thus possibly more influential within their group or community. As a result, a diffusion network model can take advantage of these opinion leaders to initiate and speed up the diffusion of a new idea or practice becoming the core of peer educational programs aimed at transforming or introducing social norms (Valente and Davis, 1999; Valente, 2007).

The strategy to identify opinion leaders to promote social change constitutes part of the development communication field. Its implementation requires the dissemination of information by prominent intermediaries capable to persuade others to rationally adopt new ideas and practices (Morris, 2005). It is a structural approach grounded in social influence models to pursue the modification of individual beliefs and practices through the interaction with expert and prestigious peers in a social network (Friedkin, 1998).

The use of opinion leaders to promote behavior change can be found in several health promotion models. In public health, efforts have been directed at identifying peer leaders to use them as agents of change to effectively implement health promotion programs (Lomas *et al.*, 1991; Latkin 1998; Sikkema *et al.*, 2000; Schuster *et al.*, 2006).

Social influence network analysts have used the structural centrality concept to identify key persons that could take leadership roles from a network structure according to positional attributes describing actors' positions relative to others and in relation to the complete network (Freeman, 1978/1979). Individuals obtaining high centrality scores derived from sociometric interviews are usually identified as potential opinion leaders. Such standardized protocol has been thought as a valid and reliable tool to identify opinion leaders (Valente, 2006).

In spite of its limits, as it misses other dimensions to attain a full understanding of the leadership dynamics, the use of centrality measures to identify potential leaders could be instrumental to foster health promotion

programs for indigenous children living at boarding schools located in remote areas with a strong traditional culture such as the Tarahumara of northern Mexico. However, for this approach to become operational and feasible within this indigenous context, one would need to be able to select long-lasting child leaders who can promote healthy behaviors among their peers, and to remain as such for at least two or three consecutive years given the financial and logistic constraints that hamper the possibility to administer sociometric interviews and run the corresponding analyses every year to thousands of children attending the 105 indigenous boarding schools located in the region.

Some studies have looked at factors affecting the reliability of centrality measures finding variability. For instance, a Swedish study reported irregular reliability in women, and lower at younger ages, assessed by kappa coefficients (Hanson *et al.*, 1997), and a study with Slovenian high school students found a higher reliability with a denser network using correlation coefficients (Zemljic and Hlebec, 2005). In fact, a study conducted to determine how sampling affects the stability of centrality measures showed that some are more stable than others, and that this is also a function of network and study properties (Costenbader and Valente, 2003).

The current study aimed at documenting the stability of centrality measures in two consecutive years in their empirical performance to identify leaders from an indigenous research scenario of northern Mexico. This project was part of a larger investigation to assess the effectiveness of a comprehensive strategy to prevent intestinal parasite infections among Tarahumara indigenous schoolchildren, which included an educational component based on leaders that acted as promoters of healthy behaviors.

The original proposal was reviewed and approved by the National Council for Science and Technology (project FOMIX CONACyT-Chihuahua grant No. 23223). All participant children in this study provided verbal informed consent.

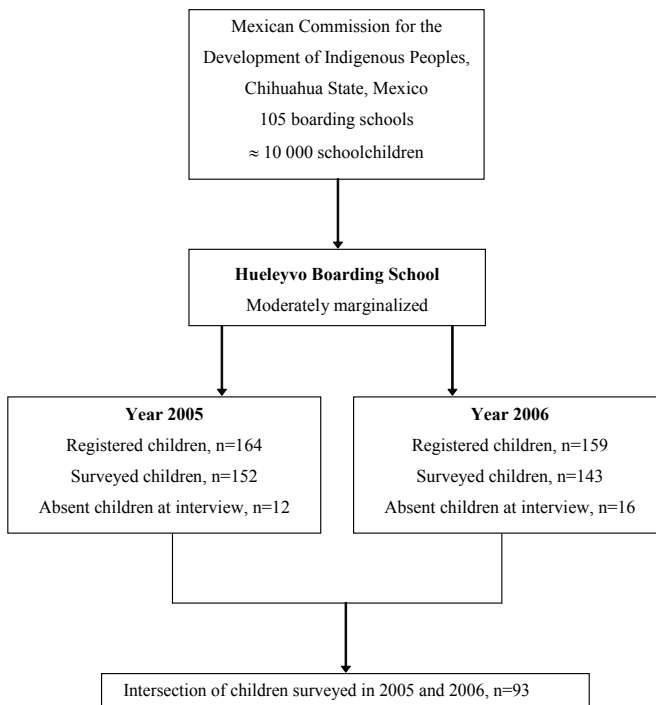
Methodology

Study design

Two cross-sectional sociometric surveys were conducted in 2005 and 2006 with indigenous children from a boarding school to compute centrality measures to assess the stability of the scores obtained.

Children present at the moment of data collection in the selected boarding school, conceived as a closed network, were interviewed in November 2005 ($n=152$) and 2006 ($n=143$), three months after the beginning of the academic year. A total of 93 children were present in both interviews as shown in Figure 1. The reasons for not intersecting were: 1. Graduated from primary school ($n=28$) in June 2006; 2. Started primary school ($n=31$) in August 2006; and 3. Present in one but not both interviews ($n=18$).

Figure 1
Diagram Depicting the Selection of Schoolchildren for the Stability Analyses,
Hueleyvo Boarding School, Chihuahua State, Mexico, 2005-2006



Study population

The Tarahumara or Rarámuri, the largest ethnic minority of northern Mexico with nearly 100 000 members that represent nearly 1% of the country's indigenous population, live in a mountainous region in small and scattered settlements (INEGI, 2001). Their health and educational conditions are precarious (Monárrez-Espino, 2004) in part due to the geographical isolation and logistical problems faced to deliver public services. Children receive scholarships to attend indigenous boarding schools that provide free housing and food; they usually come to the school on Mondays and return home on Fridays walking alone (CDI, 2004).

An archetypal boarding school from the Municipality of Guachochi hosting approximately 150 children (Hueleyvo) was selected from those run by the National Indigenous Commission in Chihuahua State; it was a poor and moderately marginalized school.

Sociometric data collection

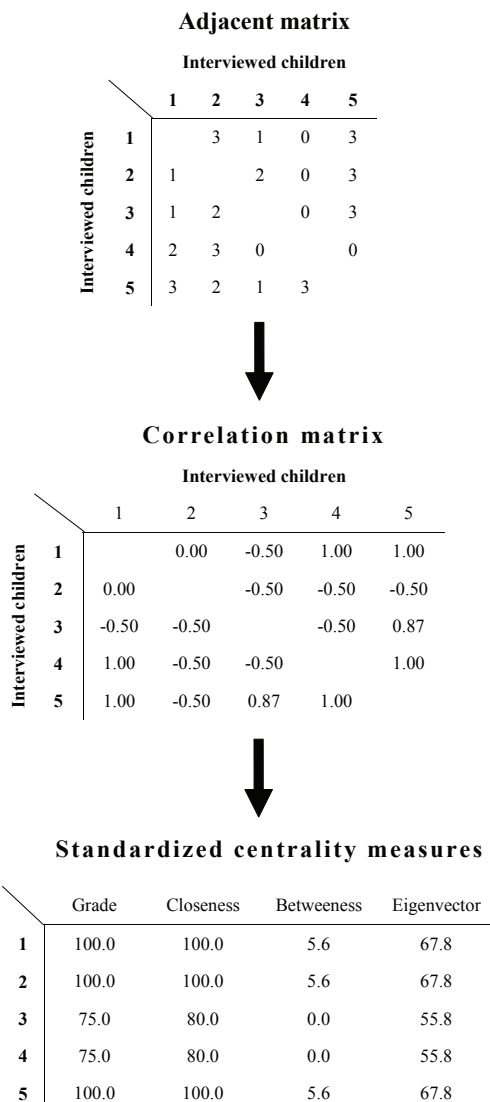
Sociometric data was collected to describe the structure of the social network (Valente, 1997) and to identify leaders (Valente *et al.*, 2003). At each studied year schoolchildren were asked to mention in order the name of the five children to whom they communicated more (Who is the child of this school with which you talk more about important issues? who else? then?) and the frequency of such relation (i.e. every day, almost every day, sometimes, seldom). These questions were extracted from a standard data collection format for complete communities used in social network research (Marsden, 2005), in this case the interaction of all boarding schoolchildren, which enabled a procedure of matrix algebra to detect leaders based on their position within the connectivity structure.

As shown in Figure 2, the interaction responses were processed using an adjacent matrix containing the relations and frequencies of the interactions between schoolchildren (i.e. rows and columns by interviewed children); thereafter, the interactions' correlations were calculated to ultimately estimate the standardized centrality measures.

Sociodemographic data was also obtained in 2005 and 2006 to describe the study population basic characteristics.

Interviewers were trained and standardized in the interview technique, but were not the same in the first (n=2) and second interviews (n=3) to prevent interview and response biases. The interview lasted 10 minutes on average. Two trained translators were used to conduct interviews with children who did not speak Spanish.

Figure 2
Matricial Procedure to Calculate Centrality Measures



Data analyses

Data analyses to describe the structure of the social network included the computation of density and centrality values. Density, defined as the proportion of connections between the children divided by the total number of possible connections, was computed, and statistical differences were calculated using chi-square permutation tests. Attribute-related density, defined as the proportion of connections among actors that share some common trait, was assessed by sex and school grade; this measure allowed detecting homophilic connections (i.e. the tendency of children to relate to each other based on certain attribute such as sex or grade) to recognize the need to identify male and female leaders of different classrooms. School grades were categorized into two-year categories (1-2, 3-4, and 5-6 grades) following the multiclass model of the boarding school.

Centrality describes the position of an individual within the organizational structure of the group; it was assessed using following four measures (Freeman 1978/1979; Bonacich, 2007):

Grade: The number of direct connections of each person with other members of the network. Those with high scores are believed to have a higher potential to disseminate information compare to those with lower scores who appear rather peripheral or isolated in the network.

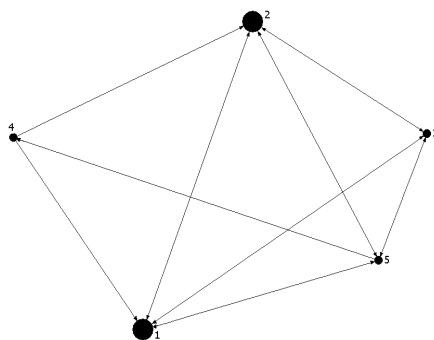
Betweeness: The linking role of a person with other members of the network, namely, the frequency a node lies on the shorter path between other nodes in the network. This measure is thought as an indicator of the potentiality of actors to coordinate the communication in the group.

Closeness: The efficiency of the individual's role as facilitator of the integration of other members of the network. It measures how many steps it takes on average for an individual to reach everyone else in the network. Those with high scores can most efficiently make contact with others in the network facilitating an efficient control and coordination of the group independently of the influence of actors with more *grade* (capacity to inform) or *betweeness* (capacity to coordinate). They can disseminate information faster, cheaper and with fewer intermediaries.

Bonacich's eigenvector: The popularity role of a person based on his/her connection with other members with higher centrality in the network. It measures the extent nodes are connected to other central nodes. A few connections to prominent people can provide access to valuable resources saving energy and time, gaining access to social capital through intermediaries.

Density and centrality measures were computed using the software UCINET version 6.143 (Borgatti, 2006a). The software Key Players metrics version 1.45 (Borgatti, 2003) was used to identify leaders for years 2005 and 2006 using the *closeness* centrality measure; this method finds a set of nodes maximally connected to all other nodes via direct links or short paths (Borgatti, 2006b), as shown in the example of Figure 3.

Figure 3
Example of a Network Structure to Identify Opinion Leaders Using *Closeness*



Stability analyses

Various strategies were used to assess the stability of centrality scores in the intersecting children from years 2005 and 2006:

Pearson product-moment correlation coefficients (r) were computed for the scores obtained between years 2005 and 2006.

Intersecting children were ranked according to the scores obtained for each centrality measure and year; children were then divided up into quartiles and Cohen's Kappa agreement coefficients (K) computed.

The proportion of total agreement was presented, namely, the percentage of children with centrality scores within the same quartile, and in the fourth quartile, for years 2005 and 2006.

As *closeness* showed the highest statistically significant test-retest agreement, it was used to identify opinion leaders using the Key Player software and to subsequently assess the two year concordance through Cohen's Kappa coefficient.

Statistical significance was set at $p < 0.05$. Data were analyzed using the SPSS computer software, version 16.0 (SPSS Inc., 2007).

Results

Table I presents the schoolchildren's sociodemographic characteristics as reported in 2005 (n=152) and 2006 (n=143). The percentage of boys and girls was 58.3% and 41.7% in 2005, and 54.5% and 45.5% in 2006, respectively. Age and grade distribution was similar in 2005 and 2006, with slightly more children aged 6-8 years (~35%), but slightly more in the 5th-6th grades (~36%). Roughly one out of three children did not speak Spanish (2005=39.2%; 2006=32.2%), and the majority lived in small localities with ≤10 households (2005=65.8%; 2006=55.2%).

Table I
Sociodemographic Characteristics of the Schoolchildren for Years 2005 (n=152)
and 2006 (n=143), Hueleyvo Boarding School, Chihuahua State, Mexico

Sociodemographic characteristics	Percentage	
	2005	2006
Sex		
Boys	58.3	54.5
Girls	41.7	45.5
Age Group in Years		
6-8	35.8	35.0
9-11	32.5	32.1
12-14	31.7	32.9
School Grade		
1-2	33.3	32.9
3-4	30.0	31.5
5-6	36.7	35.7
Language		
Only Rarámuri	39.2	32.2
Rarámuri and Spanish	60.8	67.8
Size of the Locality of Residence		
≤10 households	65.8	55.2
>10 households	34.2	44.8

Table II compares density measures for the whole sample for years 2005-2006 stratifying by sex and school grades. Overall density was 0.07 and 0.08 for years 2005 and 2006, respectively. There were statistical differences in density values between boys and girls in 2005 (0.14 vs. 0.11; $p=0.001$) and 2006 (0.14 vs. 0.19; $p=0.001$). Density values were also significantly different by grades with ascending values for higher grades in both years analyzed ($p=0.001$).

Table II
Density Measurements by Sex and School Grade for Years 2005 and 2006 to Assess Homophilic Patterns, Hueleyvo Boarding School, Chihuahua State, Mexico

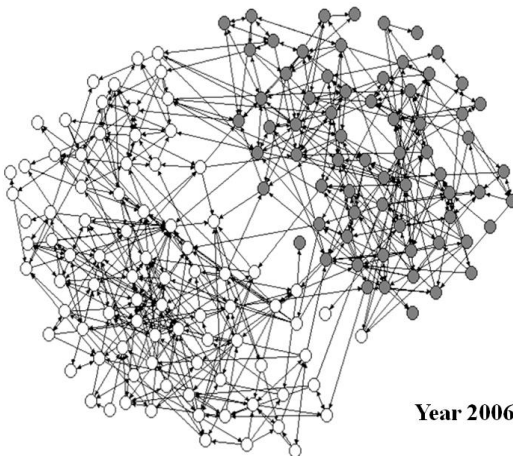
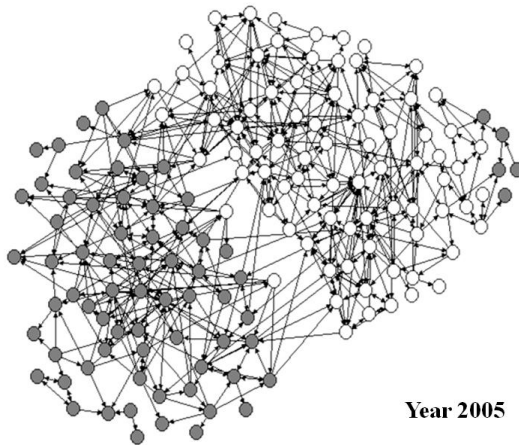
Variables	Year 2005 (n=152)		Year 2006 (n=143)	
	Density	p*	Density	p*
Sex				
Boys	0.14	0.001	0.14	0.001
Girls	0.11		0.19	
School grades				
1-2	0.12	0.001	0.09	0.001
3-4	0.17		0.17	
5-6	0.23		0.19	
Complete school	0.07	—	0.08	—

* Permutational chi-square test was used to calculate statistical significance by sex and school grade

Figure 4 (on next page) portrays the homophilic patterns by sex for years 2005 and 2006. The image shows graphically the tendency of children to relate with those of the same sex, namely, the preference of boys (in white circles) to communicate with other boys, and of girls (in dark circles) with other girls.

The stability of centrality measures from the intersected sample of 93 children and the identification of leaders for years 2005 and 2006 is presented in Table III. Pearson correlation coefficients were low ranging from 0.15 for betweenness to 0.51 for closeness. Kappa agreement coefficients were very low, but higher for closeness (0.15) and eigenvector (0.18). The proportion of matching children with centrality scores within the same quartile in years 2005 and 2006 was highest for closeness (36.6%) and eigenvector (38.7%), and less than 12% for those in the 4th quartile in all four centrality measures. Key Player used closeness to select 10 leaders in

Figure 4
Homophilic Patterns by Sex (Boys: White Circles, Girls: Black Circles)
among Indigenous Schoolchildren for Years 2005 and 2006
at Hueleyvo Boarding School, Chihuahua State, Mexico



the complete database in each year; 6 leaders were selected in 2005 and 7 in 2006 in the 93 intersecting children, but only one was selected in both years ($1/13=7.7\%$).

Table III
Stability of Centrality Measures and Selection of Matched Leaders Between Years 2005 and 2006 at Hueleyvo Boarding school, Chihuahua State, Mexico

Reproducibility indicators	Centrality measures			
	Grade	Closeness	Betweenness	Eigenvector
Pearson correlation coefficient (p-value)	0.34 (0.00)	0.51 (0.00)	0.15 (0.16)	0.43 (0.00)
Kappa agreement coefficient (p-value)	0.11 (0.04)	0.15 (0.01)	-0.03 (0.57)	0.18 (0.00)
Proportion of total agreement (%)¹	33.5	36.6	22.6	38.7
Proportion of leaders matched in 4th quartile (%)²	10.8	7.5	6.5	11.8
Matched leaders using the Key Player software (%)³	—	7.7	—	—

1 Proportion of children within the same quartile in years 2005 and 2006

2 Proportion of children within the fourth quartile in years 2005 and 2006

3 Key Player used closeness to select 10 leaders in the whole database for each year: 6 were selected in 2005 and 7 in 2006 in the 93 intersecting children, but only 1/13 was selected in both years

Discussion

The application of centrality measures to select leaders among indigenous Tarahumara schoolchildren as agents of change was thought to be a novel approach to implement health promotion programs. However, the stability of these measures over time remained a major question, as this can affect its feasibility considerably since it would not be viable to conduct interviews with thousands of children from more than hundred schools on a yearly basis; this constitutes the practical implication of this study.

The results presented here show a very low stability of centrality scores between the two consecutive years studied, which lead to the identification

of different leaders. As Wasserman and Faust noted (1994: 55-59) this could be the product of methodological shortcomings or be the consequence of a dynamic social network structure, or both.

As to potential methodological biases, we tried to prevent these by using a standardized methodology in 2005 and 2006, including interviewers, sociometric questionnaires, and data analyses. Nonetheless, bias might have arisen from differences in the 2005 and 2006 samples. We only compared the scores obtained by the 93 intersecting children, as computed with the whole sample for each year (2005=152; 2006=143), so that not intersecting leaders were left out affecting the observed results. However, apart from several children who were not present in the two interviews, the majority corresponded to children who left the school because they graduated and small children who had just entered primary school that could not be present at both interview times, namely, a limitation inherent of the longitudinal study design.

The results found could not be either explained by sociodemographic differences in the school configuration, as very little variation was seen between years 2005 and 2006.

As to the second consideration, our results point to a changing school network that resulted in differential identification of leaders between the two years under study. How this has occurred is to be yet explored. We are not aware of any published data on leadership roles for school-aged Tarahumara children, so very little is known, leaving much to speculation. For instance, it has been thought that leadership in Tarahumara adults is rather weak, with a relative lack of hierarchy and flexibility of sex roles contributing to the configuration of poor cohesive social units (Kennedy, 1978). What attributes are associated to leadership roles among these indigenous schoolchildren and how they gain social knowledge to establish more and better interactions with other children is yet to be established.

On the other hand, it is worth noting that the stability of centrality scores, as measured by correlation and kappa coefficients, was highest for closeness ($r=0.51$; $K=0.15$) and eigenvector ($r=0.43$; $K=0.18$), two very efficient centrality measures. This was also reflected in the highest proportions of total agreement (closeness=36.6%; eigenvector=38.6%). These results point to the importance of the quality rather than the quantity of the interactions seen here.

As to the selection of leaders, a very low proportion matched the selected in 2005 and 2006 for any centrality measure according to the strategies used: when the highest quartile was utilized, the proportion ranged from

6.5% (betweenness) to 11.8% (eigenvector); and when key player method was used, the proportion reached only 7.7%. We use these approaches to select leaders for its feasibility when implemented at large scale, as it would be necessary in this indigenous context.

The homophilic patterns reported by sex and school grade were expected indicating the need to select male and female leaders from different classrooms to increase the potential success of a health promotion program. The ascending density values by school grade were also expected, as older children tend to communicate more with each other than younger children (McPherson *et al.*, 2001).

Regarding the internal validity of the results, we asked teachers and boarding school personnel about their opinion regarding the leaders we identified, and most of the selected corresponded to children referred as very popular among their peers providing some face validity to our results.

From a theoretical stance, the sociometric approach utilized here has the constraint to identify opinion leaders only by their position in the structure of interrelations and their power of collective influence. Since it focuses on the description of leadership performance, it loses sight of other dimensions required to achieve a comprehensive understanding of the leadership dynamics, including the subjective perception and culture of leadership, and the leadership systems (Küpers and Weibler, 2008). Opening the scope, by integrating these elements in the analyses, could provide the context to explain the low proportion of statistical agreement seen between centrality measures in time among these indigenous schoolchildren. To accomplish this, it might be useful to combine quantitative and qualitative data collection strategies to generate mixed analyses and interpretations, so that leadership could be judged as a construction of social influence with elements of form (structure) and content (processes). For instance, the use of biographic methods would help explaining the subjective perception of leadership amongst social actors, the use of group dynamics improve the understanding of the intersubjective culture of leadership, and the combination of sociometric and qualitative data analyses could facilitate the inference of structural patterns and the notion of the constrictive effect of the social system on the leadership dynamics.

In summary, using centrality measures to identify leaders in this indigenous scenario proved more difficult than expected; unless this strategy is used under yearly basis, which seems impractical, the leaders selected in one year might not be the same in the next, potentially lessening the impact of the health programs in concern.

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