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ORIGINAL PAPER

Understanding Interdisciplinary Collaborations as Social Networks

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Abstract The dynamics of interdisciplinary collaboration invite further investigation if we are to make this endeavour more rewarding and productive. We are using social network analysis to track the development of a new interdisciplinary collaboration on complex interventions to improve population health. It involves nineteen scholars across four countries. We report the Baseline network of formal relationships among the scholars, along with the impact of the collaboration on these relationships in the first 18 months. We observed statistically significant increases in the density of six types of relationship networks: citing publications by other members of the collaboration, email contact, meeting with each other (outside of the formal annual meeting), visiting one another's institution, submitting research grants together and working on research projects together. The initial strategic role in the network of key 'gate keepers' has not altered substantially (betweenness centralization of the networks), but reciprocity has increased, that is, people are more likely to cite those who have cited them and work together. Increased collaboration is also reflected in the rise in number of subgroups over time and the increase in the average number of subgroup memberships. Use of social network analysis to understand the dynamics of interdisciplinary collaborations is a relatively new field. It invites reflection about what the optimal network structures for interdisciplinary collaborations would look like.

Keywords Interdisciplinary collaboration · Interdisciplinary science · Social network analysis

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Introduction

The need for, and benefit from, collaboration in science is well accepted. Benefits include enhanced enquiry, improved problem solving and the possibility of enhanced productivity (Aboelela et al. 2007). Hackett (2005) suggests that the rising tide of interdisciplinary collaboration is part of a new landscape in science whereby the extent, intensity, substance, heterogeneity, and formality of scientific collaboration are all changing. It has been argued that these changes in the intellectual content and cultural reach of collaboration are driven in part by science policy that is focused on practical ends.

In community health, interdisciplinary research is increasingly being mandated by research agencies as a condition for funding. This mandate has prompted the search for factors that enhance collaboration. Collaboration is broadly understood to cover multidisciplinarity, where people from different disciplines retain their own perspective and work independently or sequentially on the problem at hand; interdisciplinarity, where people from different disciplines work jointly, again retaining their distinctive perspectives; and transdisciplinarity, where the

viewpoints come together and ideas transform (Rosenfield 1992). New technological tools for collaboration have arisen and new forms of social organization (beyond place-based teams) have emerged that were uncommon even a decade ago (Hackett 2005). New forms of social organization were featured in a previous special issue of the *American Journal of Community Psychology* on community-based interdisciplinary research in 2006. Papers in that issue highlighted the need to take seriously not just the processes by which collaborators work together but also the *structures* that emerge from these interactional processes (Maton et al. 2006a; b; Schensul et al. 2006).

The word "network" is widely used in the literature on interdisciplinary collaborations. The notion of network captures the essential elements of any collaboration: a set of actors (people and/or organizations) linked by relationships that constitute a social structure. Most of the collaboration literature does not go beyond using network metaphors to focus attention on relationships among actors rather than attributes of actors. Exploiting fully this focus on relationships, however, demands the use of social network analysis, which provides concepts, study designs, data collection methods, and data analytic techniques that have been developed for relational data (Wasserman and Faust 1994).

Recent social network research in the health literature has focused on social networks of health care professionals in clinical settings (West et al. 1999), collaborative inter-organizational partnerships (Provan et al. 2005) and community coalitions (Tanjasiri et al. 2007; Valente et al. 2007). These studies have used data from field studies to describe the structural properties of these social networks (West et al. 1999) and, less commonly, to investigate the links between these structural properties and the performance of the social networks (Aboelela et al. 2007; Valente et al. 2007). Scholars in the literature on academic collaborations have applied network analytic techniques to bibliographic data bases to explore these questions and to investigate how these networks of co-authorship change over time (Wagner 2005).

In this paper we provide an illustration of how network analytic methods can be used to study interdisciplinary collaborations by analyzing relational data within one scientific collaboration, the International Collaboration on Complex Interventions (ICCI), which was brought together to advance thinking and practice in complex population-based interventions. We describe these methods and the results of our use of network methods to measure and track changes in the structure of this collaboration. In our discussion we describe how tracking these changes has challenged us to consider what optimal network structures for interdisciplinary collaborations in health might be, taking this field a step further beyond its foundations.

The Illustration: ICCI as a Social Network

ICCI was created in 2004 to promote interdisciplinary theorizing and research, with a goal of strengthening complex interventions to improve population health. It was funded as part of a strategic investment by the Canadian Institutes of Health Research to develop research capacity in social and physical environments and health. ICCI has been designed to develop new thinking in four domains—the theory, ethics, economics and methods of complex interventions. It was prompted by concern that effect sizes in community-based interventions are small or minimal (Susser 1995). It was also based on the belief that untapped resources for improving the effect and sustainability of community interventions lie in working not only with communities themselves, but with disciplines currently not harnessed. The nineteen ICCI investigators are from nine academic disciplines: community psychology, economics, epidemiology, philosophy of science, mathematical psychology, sociology, medicine, education, and statistics; four countries (Canada, UK, US, and Australia); and ten institutions. Two of the authors (blind copy, initials to be inserted in final proof) are scholars within ICCI and hence are acting as participant researchers.

ICCI was put together much like any other research grant, by a principal investigator pitching an idea and inviting others to take part. She invited people she was already working with in the field of complex interventions, as well as people she had not met personally but knew by reputation. These people had different levels of involvement in intervention research, from none to extensive. Most were very senior in their field, but others were just starting out. Some, such as the philosophers of science, had no experience working with empirical researchers of any kind. The 6 year infrastructure funding for ICCI was put together to foster interaction and capacity building through such mechanisms as face-to-face meetings (for site visits among the scholars), small grants for pilot projects, post-doctoral fellowships, an annual 3 day meeting of investigators, a website, and funds for the support of scholarly works (special issues of journals and/or a text book). Our broad objective is to capture the changes ICCI makes to scholarly inter-relationships. We examine measures that tap changes in network structure.

Methods

In this paper we present network data on the structure of ICCI from our Baseline survey and our first 18 months of interaction.

We use a sociometric (or whole or complete or global) network design to study ICCI. Sociometric designs are

appropriate where all of the members of a network (actors) can be identified before the data collection begins. Data collection involves asking each actor about his/her relationships (connections) to all other actors in the network. Asking actors about multiple relationships to every other actor in the network permits researchers to examine the extent to which the structure of the network varies across different types of relationships. Asking people about relationships to network members at multiple points in time permits researchers to track changes in these network structures.

Actors and Relationships

In our study the actors are the nineteen members of ICCI. The thirteen types of relationships we investigate range from very basic ones such as whether or not actors had ever heard of each other or met each other professionally (excluding the annual ICCI meeting itself), through to whether they had previously worked together on a book, paper or research project. Other relationships we are following across time are visiting at each other's institution, co-teaching courses or co-presenting in conference sessions, co-organizing a workshop, submitting a grant together, citing work by an ICCI member, emailing, assisting each other's student or trainee, and accepting a visiting appointment at another ICCI member's institution. We examined each of the thirteen relationships separately as single networks (e.g., the network of meeting professionally, the network of working together on a research project).

Key Structural Concepts Examined

Density is the number of ties among network members expressed as a percentage of all possible ties. A higher density indicates that more of the actors in a network are interacting with others than in a network with lower density. Density in a network supports the creation and reframing of meaning that is essential to the spread of ideas and information within a collaboration. In the case of ICCI, a potential downside of high density—too few connections to external information and resources (Valente et al. 2007)—is mitigated by the maximally cosmopolitan (Rogers 1995) nature of ICCI. Here every investigator has ties outside the collaboration and is able to play boundary spanning roles that link ICCI to the outside world.

Increases in the density of a network reflect the formation of new ties. Therefore, we also consider the extent to which members form *new ties over time*. Because these new ties are formed within ICCI, they pull into the collaboration members who had few connections to co-members at Baseline. We thus also look at the change in the *number of isolates* (people with no ties) in the networks over time. By reducing the number of isolates in ICCI, new ties increase interaction among members of the collaboration; this interaction leads to higher levels of shared knowledge (Carley 1991; Smith-Lovin 1999) which, in turn, enhances the spread of ideas and information within ICCI.

Reciprocity (expressed as a percentage) in a network tells us the extent to which ties are returned (Wasserman and Faust 1994). We would expect reciprocity to increase over time as members of the network get to know one another or cite one another. It has been argued that reciprocated relationships are important for interdisciplinary and transdisciplinary collaborations where exchange of information across diverse actors is crucial. It requires a period of learning and trust development where people assess the benefits, risks and likelihood of reciprocation (Aviv et al. 2008).

Betweenness centrality examines the number of times one person lies on the shortest path between two others (Freeman 1979) Betweenness centrality is thought of as a measure of control or strategic gate keeping in terms of whom a person has to link with or get through to get to someone else. Occupying a highly central position in the network allows a person to influence the spread of ideas and information (Wasserman and Faust 1994). The corollary across the whole network is betweenness centralization. The higher the centralization of a network, the greater the likelihood that that there is one person or small set of people to whom all the others are connected (Aboelela et al. 2007). Given the way ICCI was established by a single actor who deliberately set the network up to connect people largely unknown to each other (but known to her), we would expect betweenness centralization to be high in the beginning and to decrease over time as other people in the network form ties independent of her. Betweenness centralization and betweenness centrality are expressed as scores (not as percentages).

Subgroups illustrate the presence of cohesion in a network through the opportunity they provide for shared reasoning and perspective (Burt 2000). A subgroup, or clique, is a part of the network where all the people are directly connected to one another and no additional person in the network is also connected to all the members of the subgroup (Wasserman and Faust 1994). In other words, within a clique, all possible links are present. It has been argued that cliques help to drive collaborative processes by constructing knowledge and taking advantage of their strong inter-relations (Aviv et al. 2008).

Survey Implementation

We conducted the first on-line survey in May–July 2006. The response rate for this survey was 100%. The first part

of this survey collected retrospective data on connections among ICCI members that existed *before* the first official face-to-face meeting of ICCI (i.e. prior to 30 April 2004). In the analysis that follows, we refer to these data and the time period they represent as "Baseline". We used the second part of this survey to ask about connections during the time period between the first official ICCI meeting (April 2004) and December 2005. We refer to the time up to the end of this first full calendar year of ICCI's existence as "Time 1". All relationships listed at Baseline are also counted in our Time 1 analyses; in other words, the Time 1 networks consist of the Baseline networks plus all additional ties made during the first year of ICCI.

The ICCI network study was approved by the University of Calgary Conjoint Faculties Research Ethics Board. The idea was part of the original grant commitment of ICCI to the funding body and ICCI members were invited to take part in the survey via email by ICCI's principal investigator. Respondents were first directed to an informed consent form, and then to the survey. They were guaranteed that details of individual responses about specific relationships would not be presented to the ICCI and that all identifying material would be removed in publications. For this reason we have not indicated which actors (the nodes in the diagram) belong to which discipline, country, or institution.

Network Data Analytic Techniques

We used the network statistical software package UCINET 6.0 (Borgatti et al. 2002) to conduct two analyses of our network data: (1) network visualization of all thirteen networks (Baseline and Time 1) and (2) analyses of properties of all thirteen networks and actors' positions in these networks (Baseline and Time 1) that, taken together, permit us to examine changes in the networks over the two time points.

Network visualization presents information on network structure in graphic form. This way of analyzing network data is an important part of social network analysis because graphic representations can reveal information that may not be statistically obvious (Luke and Harris 2007). To produce the Baseline graphic representations of our networks, the layout uses the spring embedded procedure in Netdraw 2.24 which graphs the nodes (the ICCI members, who are numbered) according to their geodesic (shortest distance) proximities. For the Time 1 graphic representations, the layout is the same as the corresponding Baseline layouts. Nodes (circles) are people. Lines indicate the presence of a relationship.

We report density as the percentage of possible ties in a network that are present. We measure new ties by the number and percentage of ties in Time 1 that are new since the Baseline survey. We also measure the number of isolates in each network at Baseline and Time 1 as ICCI members with no ties to other ICCI members. For relationships that are not inherently reciprocal (e.g., citation is not by definition reciprocal, but co-teaching is) we measure reciprocity as the percentage of ties that are returned. Betweenness centralization is assessed for each network and betweenness centrality for each actor in that network. We counted the number of cliques of three people or more in each of the 13 networks at Baseline and Time 1 and also the change in the number of cliques of which each person was a member.

UCINET 6.0 tests for statistical significance using a bootstrap technique to compare the densities of networks with the same actors, allowing two different time points to be compared. The bootstrap technique, in a nutshell, takes the existing nodes and ties from the network as the population and generates a large number (at least 1,000) of sample networks of the same size as the original by re-sampling *with replacement* from the original. Then the statistic of interest is constructed from each of these "artificial" networks. This method yields estimates of standard errors for the estimate in question (density in our case). With these, the usual paired t-test can be approximated or one can infer the significance by looking at the actual percentage of samples that yielded a difference as extreme (or more) as the one observed (Snijders and Borgatti 1999). We are advised that the procedures for testing the statistical significance of changes in our other network properties are not yet sufficiently advanced.

An introductory glossary for social network analysis given by Hawe et al. (2004) may provide further assistance to the reader.

Results

Analysis of Network Properties

Table 1 presents the densities of each of the thirteen networks at Baseline and Time 1, the number of new ties formed and the percentage of Time 1 ties they constitute, and the number of isolates at Baseline and Time 1.

A density of 100% indicates that every actor is connected to every other actor. If only half of the possible ties are present, then the density is 50%. The networks with the highest densities both at Baseline and at Time 1 are the "emailed" and "met professionally" networks. Approximately one quarter of the actors are tied to others through these relationships. The "cited" and "visited professionally" networks have higher densities than the remaining, more intense networks. The least dense networks at Baseline are "co-taught a course", "co-organized a workshop",

Table 1 A comparison of network density measures at Baseline and Time 1; ties at Time 1 that are new, and the number of isolates at Baseline and Time 1

Relationship	Baseline density %	Time 1 density %	New ties number and (%)	Baseline isolates	Time 1 isolates
Emailed*	24	36	42 (34)	0	0
Cited*	16	24	28 (35)	2	1
Met professionally*	24	30	18 (18)	0	0
Visited professionally*	17	23	18 (23)	2	1
Visiting appointment	7	8	3 (11)	5	5
Co-taught a course	2	2	1 (14)	12	11
Co-organized a workshop	2	5	8 (50)	9	6
Assisted student/trainee	2	3	3 (27)	11	8
Co-presented	5	8	12 (44)	6	4
Submitted a grant*	5	9	13 (42)	4	4
Worked on a paper	5	8	9 (33)	6	5
Worked on a chapter	3	3	1 (9)	8	8
Worked on research*	9	13	16 (35)	2	1

Baseline networks refer to all connections among ICCI members that existed before the first official face-to-face meeting of ICCI. At Time 1 the relationships referred to all past activity PLUS the time period since the inaugural ICCI meeting

* Statistically significant difference between Baseline and Time 1 densities ($P < .05$)

and "assisted a member's student/trainee". At Time 1 the least dense networks are "co-taught a course", "assisted a member's student/trainee", and "worked on a chapter together".

The densities of the "co-taught a course" and "worked on a chapter together" networks did not change between Baseline and Time 1. The densities of all of the other networks increased significantly between Baseline and Time 1. This pattern of results makes sense given that one goal of the first ICCI meeting was to facilitate interactions among ICCI members, both formally by having each investigator describe his or her own work and its links to the goals of ICCI and informally by offering a wide array of opportunities to interact with other members of ICCI. The findings for density suggest that ICCI is becoming more cohesive as an increasing proportion of its members become connected.

The highest increases in new ties are found in the "co-presented" (44% new ties), "submitted a grant" (42% new ties), and "co-organized a workshop" (50% new ties) networks. Partly, these differences simply reflect the relative size of the different networks. But they also indicate that new ties are being formed across different types of relationships. By the end of Time 1, ICCI members are working together on multiple fronts with people they have not worked with before. There is increased complexity in the ways in which members of ICCI interact and work together.

Table 1 also reveals a decline in the number of isolates across almost all types of ties. The only networks where the number of isolates did not decline were "accepted a visiting appointment", "submitted a grant", and "worked on a chapter". This suggests that people are being brought into the network in multiple ways. A decline in isolates indicates that the network is becoming more cohesive.

Table 2 illustrates reciprocity on those relationships that are not automatically reciprocal. For most relationships, reciprocity increases. Although reciprocity for helping with another's student declines, it is based on a very small number of ties.

Table 3 illustrates the changes in betweenness centralization across the two time points. Betweenness centralization is the extent to which certain people are more central than others in the network. Our analyses show that over time there has not been much change in the betweenness measures as yet, although in the two most highly centralized networks (emailed and met professionally), betweenness centralization did decline. An investigation of each person's betweenness centrality score on each of the 13 networks (results not shown here for space reasons but available upon request) illustrated that one

Table 2 Reciprocity over time in six relationships

Relationship	Baseline reciprocity (%)	Time 1 reciprocity(%)
Emailed	53	62
Cited	36	48
Met professionally	63	63
Visited professionally	51	60
Visiting appointment	26	35
Assisted student/trainee	60	38

Table 3 Betweenness centralization over time

Relationship	Baseline	Time 1
Emailed	0.5630	0.4321
Cited	0.2188	0.2431
Met professionally	0.5163	0.4671
Visited professionally	0.3453	0..4022
Visiting scholar	0.0963	0.0093
Co-taught	0.0065	0.0093
Co-organized	0.0065	0.0349
Worked with student/trainee	0.0031	0.0093
Co-presented	0.0325	0.0657
Submitted a grant	0.0044	0.0438
Worked on a paper	0.0060	0.0584
Worked on a chapter	0.0029	0.0062
Worked on a research project	0.0864	0.1055

Table 4 Number of subgroups of 3 people or more

Relationship	Baseline	Time 1
Emailed	18	27
Cited	10	11
Met professionally	14	14
Visited professionally	9	9
Visiting scholar	4	4
Co-taught	0	0
Co-organized	0	1
Worked with a student/trainee	0	0
Co-presented	1	3
Submitted a grant	3	5
Worked on a paper	1	3
Worked on a chapter	0	0
Worked on a research project	5	7

particular actor at Baseline had the highest betweenness centrality score on many of the relationships but that this declined over time as other people in the network started to form ties with each other independent of this person.

The subgroup investigation appears in Table 4. It shows that over time the number of cliques, or subgroups (of three people or more), increased in the following networks: emailing, citing an ICCI member's work, submitting a grant, co-organizing a workshop, working on a paper and working on a research project. Correspondingly, the average number of subgroups to which a person was member increased from 1.02 at Baseline to 1.43 at Time 1 (results not shown but available upon request).

Network Visualizations

Figures 1, 2, 3, 4, 5, 6 capture the differences between the Baseline and Time 1 networks visually. We have chosen relationships that illustrate the diversity of the structural differences and changes across the 13 relationship networks.

Discussion

We showed statistically significant increases in the density of six types of relationship networks: citing publications by other members of the collaboration, email contact, meeting with each other (outside of the formal annual meeting), visiting one another's institution, submitting research grants together and working on research projects together. Reciprocity increased or stayed the same (with one exception, assisting a student or trainee, which declined). Betweenness centralization declined in the two networks that were originally the most centralized (emailing and met professionally), increased slightly in relation to citation and visiting professionally but was otherwise unchanged. The number of subgroups increased among the relationships that might be considered the most directly research related—emailing, citing, submitting grants, working on a paper and working on a research project—as well as in co-organizing a workshop. These findings are consistent with ICCI meeting its objective of becoming more collaborative.

Field studies of the structural properties of interdisciplinary collaborations using social network analytic techniques are rare. Aboelela et al. (2007)have conducted work closest to our own, but theirs was on a single interdisciplinary research network with fewer people, fewer relationships and the analysis of differences over time did not include testing for statistical significance. At the other extreme, Stokols et al. (2003) have outlined a massive program of work investigating the functioning of interdisciplinary tobacco control research centres equating with an $86 m investment of effort. They are setting out to develop a grounded theory of interdisciplinary scientific collaboration using participant observation, self completed surveys and interviews. It has involved the design of such instruments as a Principal Investigator's Perspectives scale, to assess the extent to which the ethic of transdisciplinarity is embraced, a Research Outcomes Check list, to enumerate papers and other products, an Emergent Themes Survey, to track new ideas, and a semantic differential scale, to assess changes in affective experiences (Stokols et al. 2003). Their work also includes a Collaborative Relations Survey to identify which centre members work together most, although it is unclear if this is a formal network analysis.

The contribution of our own modest work is to illustrate the concrete added value of taking a structural approach. We have shown how social network analysis permits researchers to quantify and map properties of complete

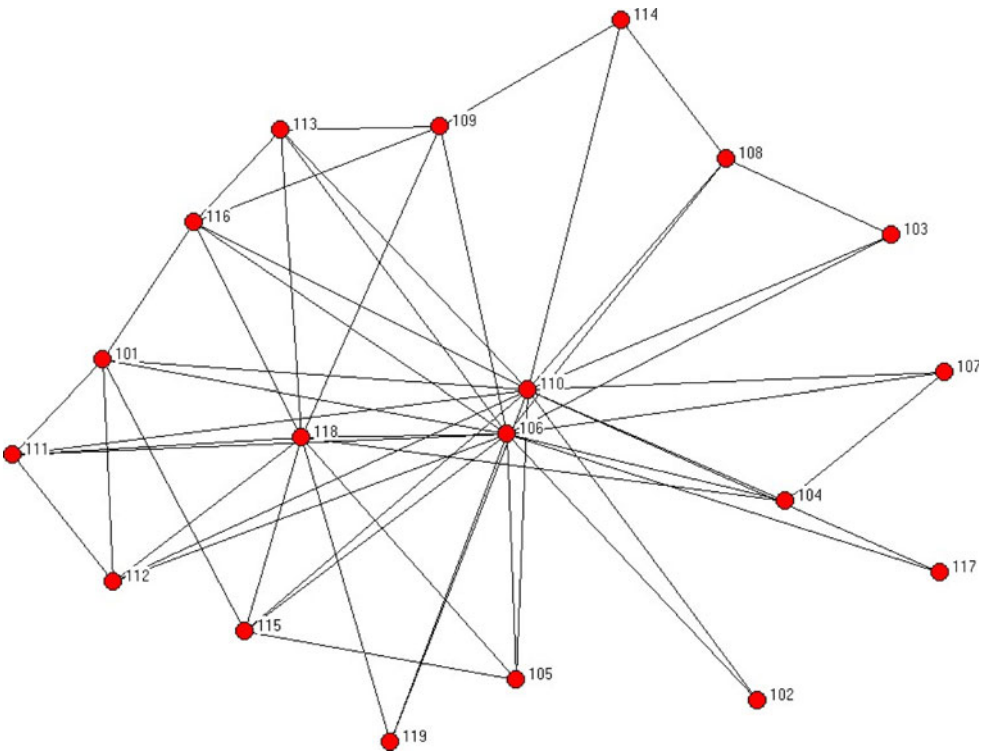

Fig. 1 Network of email contact at Basline

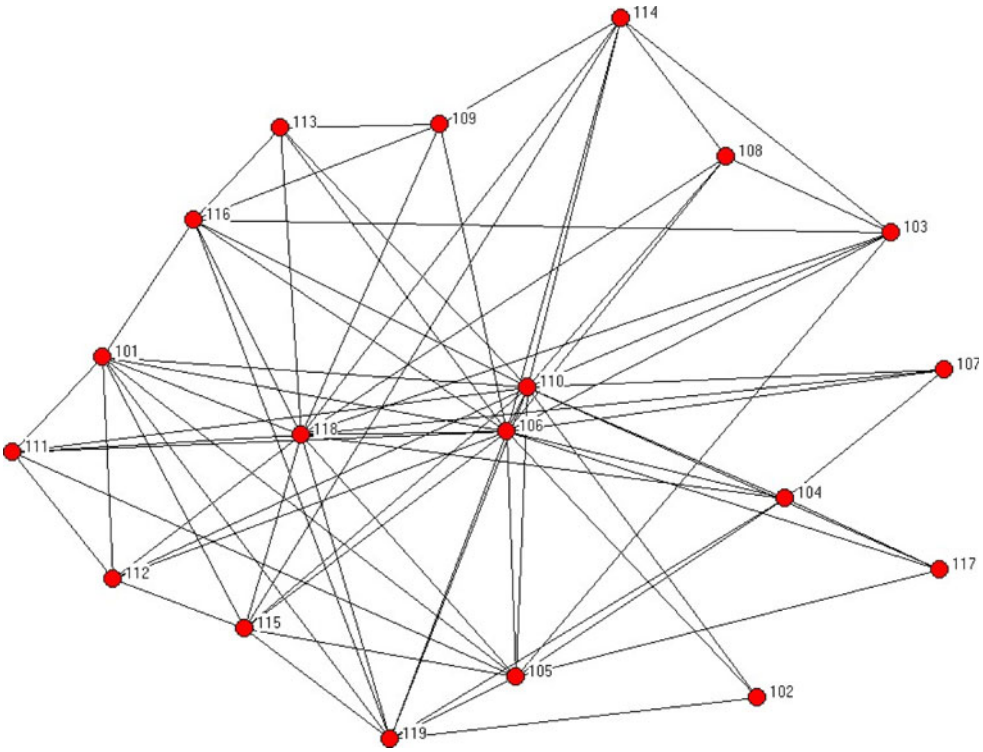

Fig. 2 Network of email contact at Time 1

networks, identify key players within a network (e.g., gate keepers (actors with high betweenness centrality) who link otherwise unconnected parts of the network together) and track changes in both. We have also shown that these network properties differ across different networks.

Studying interdisciplinary collaborations as social networks allowed us to measure and track changes in the structure of ICCI. However, we entered into this young field aware that we were unable to specify what constitutes "optimal" network structures for interdisciplinary

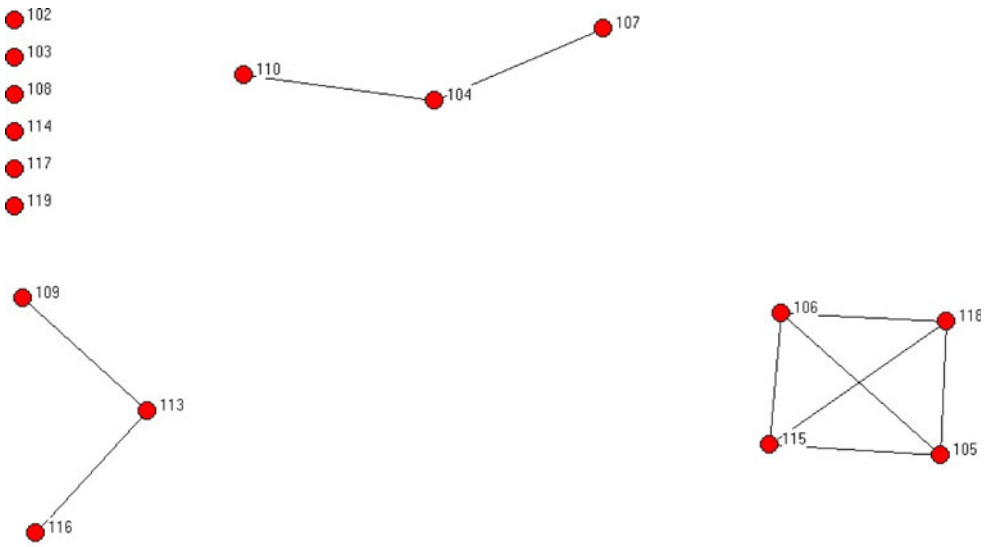

Fig. 3 Network of working on a paper together at Baseline

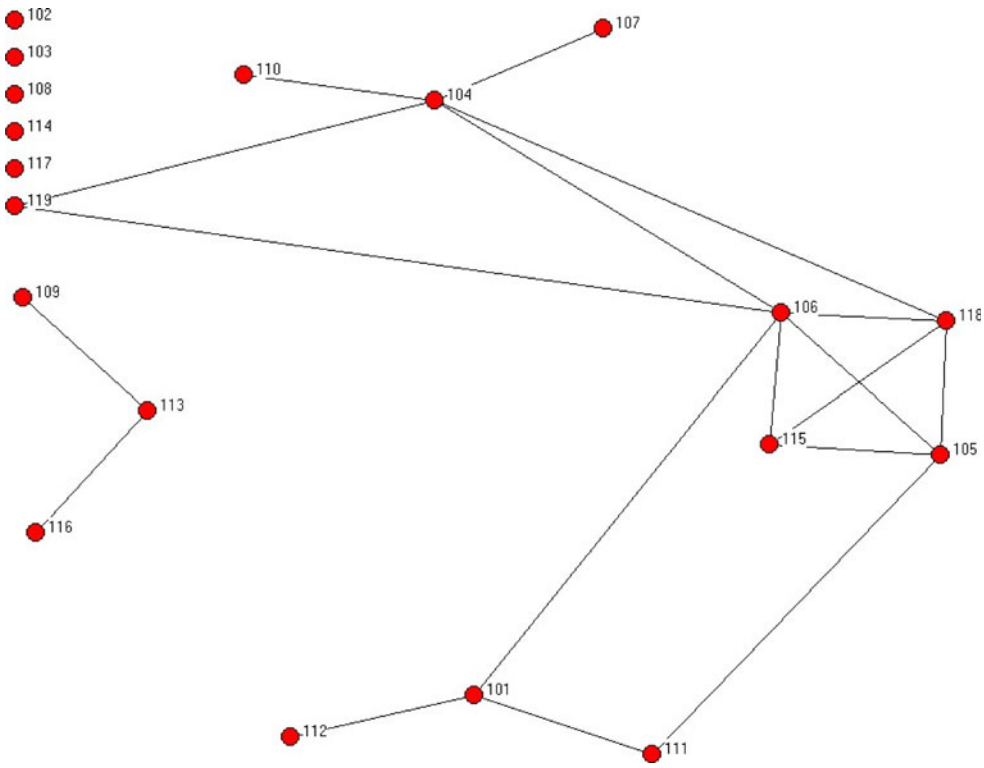

Fig. 4 Network of working on a paper together at Time 1

collaborations in population health. While one answer to this question seems obvious—it would be undesirable in a funded research network for some members to never meet or interact—it is not clear, for example, *how much* interaction is enough. Because the study of interdisciplinary collaborations as social networks is still in its infancy, we do not know how much citation, or research collaboration or co-publication is necessary or sufficient for

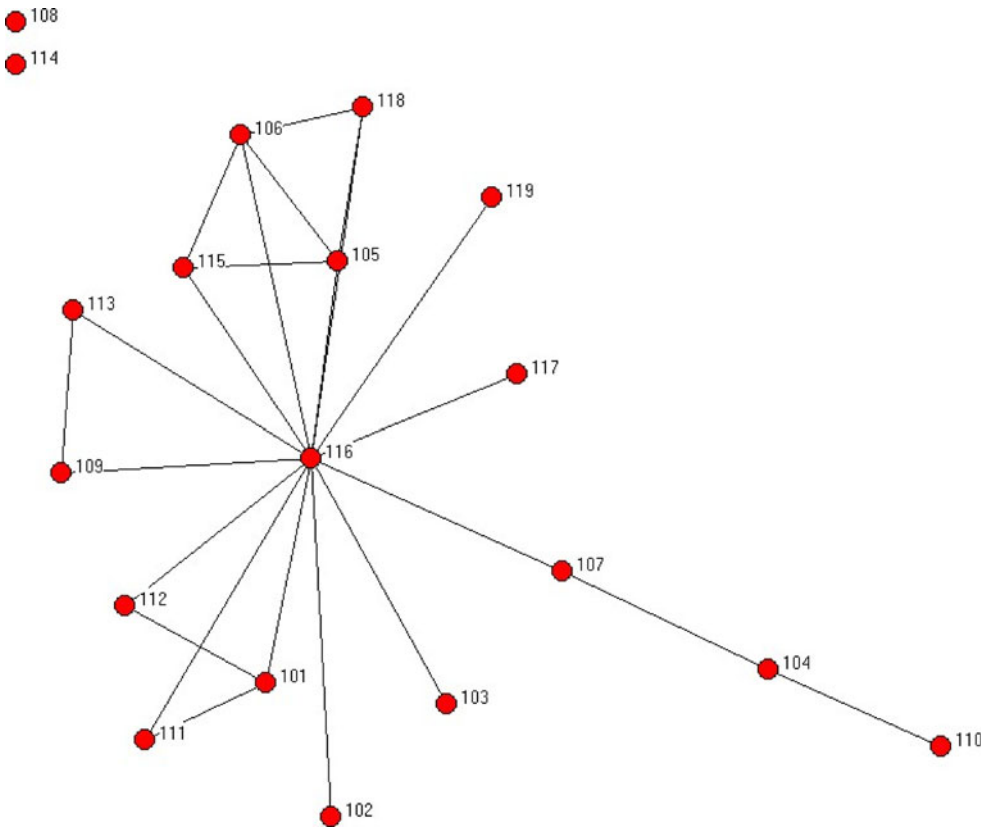

Fig. 5 Network of working on a research project together at Baseline

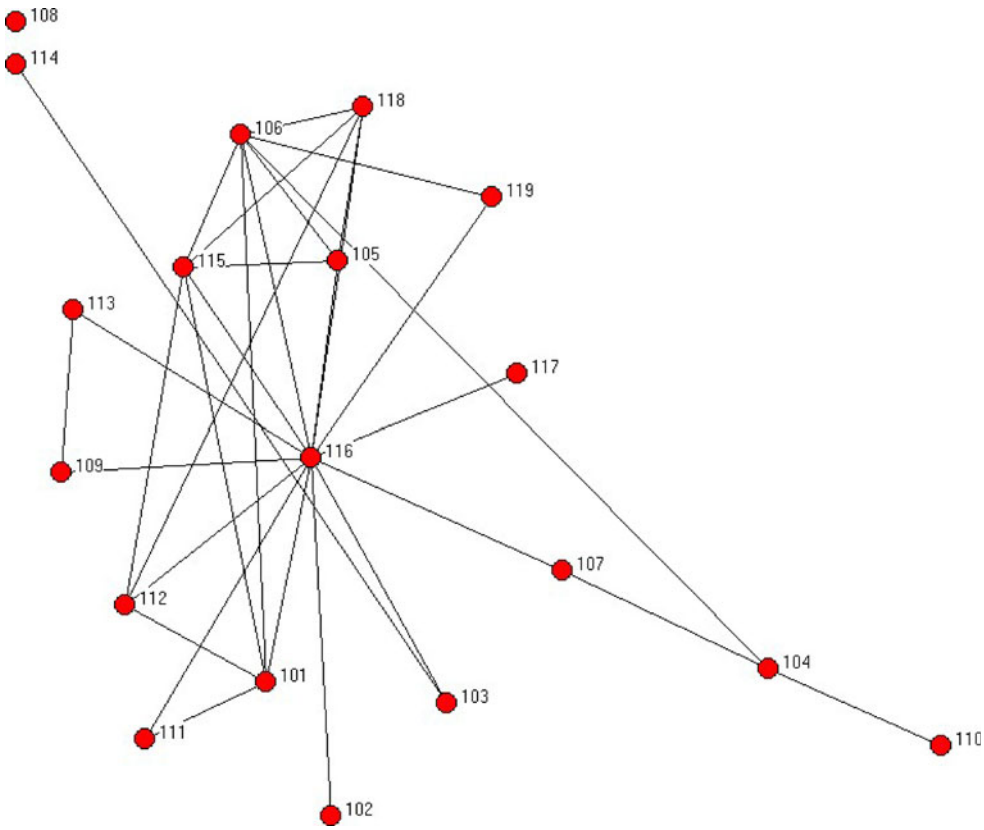

Fig. 6 Network of working on a research project together at Time 1

effective interdisciplinary collaboration. (Note also that while work like that of Stokols and his colleagues is still underway operational definitions of "effective" interdisciplinary collaboration are still being defined).

What we can start doing within our own program, however, is analyse how each network evolves over multiple time points by tracking key events (such as publications, workshops, and other research productivity outputs) and assessing how an actor's position in the network and covariates such as discipline and country influence these events. This could also incorporate self reports of the benefits of participating in the collaboration. We can also expand our analysis to explore the possibility of network contraction. This is relevant for relationships like emailing, visiting and co-authorship for which timing is discrete. We used the logic of "once a co-author always a co-author" and constructed Time 1 networks as Baseline networks plus all additional ties made during the first year of ICCI. We did not explore network contraction. Future analyses of the extent and nature of network expansion and contraction over multiple time points would offer a more complete picture of how networks change (e.g., by adding ties, removing ties, replacing ties).[1]

Researchers may have to look to other fields to get a sense of what types of network structures may best suit the purpose of particular types of interdisciplinary endeavor (e.g., when are dense ties better than loose ties; when is high centralization of the network around particular people better than low centralization?). Monge and Contractor's (2003) work on very large computer-based communication networks may be instructive in this regard. Their work is beginning to lay out theory regarding which network structures best suit different purposes—such as exploring for new information, exploiting existing resources, mobilizing action, swarming (acting together), or bonding among members. Taking their lead, one could argue that, in a general sense, scholarly networks might best fit what is known as "theories of self interest" (in this case, self interest is pursuing academic knowledge better) so network members need an interdisciplinary network structured in a form best for exploring and exposure to new information (loose networks). But when a number of ICCI members come together, say, to work on a paper sparked by a discussion at the annual ICCI meeting, then theories of "exchange" might best fit and hence the most useful structures might be smaller, tighter networks, with many reciprocated relationships. Our hope is that the long term investigation of ICCI might contribute to this literature. Having other investigators adopt the same methods as us will also enable cross site comparisons.

[1] We are grateful to an anonymous reviewer for this suggestion.

The ICCI membership is enormously diverse, so one thing was immediately obvious: the notion of "network" fits ICCI much better than, say, that of "team" or "centre". We do not expect all ICCI members to have contact with all other members. Their day-to-day work commitments, interests, settings, and accountabilities are different. So are their views on our guiding topic (complex interventions in population health). Some design and evaluate community interventions as the main focus of their work. Others are more enmeshed with philosophy and literature from evolutionary biology. The intellectual spark that we have experienced in ICCI comes from these types of differences (Wagner 2005). Viewed this way, it may not be the number or structure of ties among members that capture fully the success of this interdisciplinary collaboration, but rather the opportunities it provides for further ties to be created. ICCI is designed to create opportunity and choice.

Put another way—the ICCI network provides the initial "social capital" and opportunity for investigators to "browse". But when an idea forms, small subgroups arise within the network, in relation to specific projects. These groups might form and reform over time (and act like teams). The fact that members know that these subgroups could be brought into action, helps to define the social organization, over and above the actual behavioural ties we have tracked here. The key to ICCI success might therefore be considered to be sufficient facilitation and coordination of the more superficial relationships so that members might maximize more in-depth opportunities subsequently (Cummings and Keisler 2005). This would suggest that a threshold level of density is more important than the common notion that "denser is better", an idea that has been challenged by Valente et al. (2007).

We caution that ours is a small collaboration and hence we are likely to be limited in what we can conclude from it about optimal structures for interdisciplinary collaborations. But the network method that we used to study it may prove useful to those studying larger collaborations from their formative to more mature stages. The survey took less than 10 min to complete and was relatively free of queries/help required from our respondents. We were careful to ask about the general state of the relationships as this is considered to gain more accurate information, than if we have investigated recall of frequency over specific time periods (Marsden 1990).

We have not reported on the experience of collaboration and/or the interpersonal process skills and resources that assist it. Nor have we reported the products of this collaboration or their quality. Further, we cannot say that outcomes we are beginning to observe from ICCI (papers, grants, conferences, traineeships) are causal, that is, the direct result of ICCI processes rather than the other merits and structures among ICCI scholars. But, even in the

absence of this, our study suggests that using network analytic techniques to measure and track changes in network structures formed by interactional processes among members may offer useful and unique insights into the study of interdisciplinary collaboration.

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