Structure, change over time, and outcomes of research collaboration networks: The case of GRAND

by

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Abstract

In this dissertation, I study the interplay between the structure of a collaborative research network and the research outcomes produced by its members. To achieve this goal, I examine GRAND (an acronym for Graphics, Animation and New Media), a Canadian network with over 200 researchers funded by the Canadian government. I use the social network analysis (SNA) framework in order to aid in understanding the structure of the GRAND collaborative research network as well as how it changes over time. I look at the changes of the network’s structural characteristics over time and how they interplay with the researchers’ outcomes. Thereafter, I explain this interplay by discussing the changes of the structural network’s characteristics as conditions that can potentially affect a researcher’s social capital and that can, in turn, affect the researcher’s outcomes.

Using data collected through two online surveys, and research outcomes paper-based survey, I was able to capture the research networks (structure and changes over time) of GRAND researchers while also being able to obtain the perceptions of these individuals about their research outcomes. These networks captured four types of interaction among GRAND researchers: co-authorship of scholarly publications, communication activity, advice exchange, and interpersonal acquaintanceship. My sample consisted of 101
GRAND researchers, a subset of these researchers (N=50) were subsequently interviewed.

My findings lend support to the argument that social capital and social networks, when combined, yield richer theory and better predictions than when used individually. The social networks analysis conducted in this research offer precise measures of the social structure and documents the changes in the GRAND research network. The social capital-driven findings help move beyond the relations themselves to understand how personal relationships or social structures can either facilitate or hinder the achievement of different research outcomes. These results offer to substantiate previous work, while drawing attention to the importance of analyzing interpersonal networks when studying factors effecting research outcomes. This direction for future study is especially relevant, as research collaboration continues to increase both in scope and in importance.
Acknowledgement

Finishing a dissertation is a rewarding conclusion to a very challenging process. One of the things I found missing in this process was a formal outlet for my sincere gratitude for all the people that helped me along the way. As this dissertation is about research networks and their changes over time, I would like to take this opportunity to acknowledge the members of my own research network, which has evolved throughout my doctoral studies.

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<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2.3 Different Research Outcomes and Different Predictors</td>
<td>152</td>
</tr>
<tr>
<td>6.2.4 Complementary versus Integrative Research Collaboration</td>
<td>154</td>
</tr>
<tr>
<td>CHAPTER 7: CONCLUSION</td>
<td>156</td>
</tr>
<tr>
<td>7.1 LIMITATIONS</td>
<td>156</td>
</tr>
<tr>
<td>7.1.1 Data Sources</td>
<td>156</td>
</tr>
<tr>
<td>7.1.2 Participatory Researcher</td>
<td>157</td>
</tr>
<tr>
<td>7.1.3 The Boundary Problem</td>
<td>158</td>
</tr>
<tr>
<td>7.2 FUTURE WORK</td>
<td>158</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>161</td>
</tr>
<tr>
<td>APPENDIX A: ONLINE SURVEY</td>
<td>178</td>
</tr>
<tr>
<td>APPENDIX B: SURVEYS/INTERVIEW INVITATIONS AND CONSENT FORMS</td>
<td>186</td>
</tr>
<tr>
<td>APPENDIX C: OUTCOME SURVEY</td>
<td>188</td>
</tr>
<tr>
<td>APPENDIX D: INTERVIEW PROTOCOL</td>
<td>191</td>
</tr>
</tbody>
</table>
List of Tables:
Table 1.1: Network measures that were proposed as constructive for fostering social capital (adapt from Borgatti et al., 1998) ................................................................. 14
Table 1.2: Project outcomes (adapted from Cummings and Kiesler, 2005) .................. 15
Table 2.1: Different levels of research collaboration (Katz & Martin, 1997, p. 10) .......... 23
Table 2.2: Stages of research collaboration (Sonnenwald, 2007) ............................... 24
Table 2.3: Seven types of collaboratories (Bos et al., 2007) ....................................... 28
Table 2.4: Research outcomes (adapt from Cummings and Kiesler, 2005) .................. 36
Table 2.5: Ego level network measures used in this dissertation ............................... 41
Table 2.6: Framework for studying the interplay between network features, and social capital .......................... 50
Table 3.1: GRAND members by province .............................................................. 57
Table 3.2: Variables examined in this study, and the data source used to measure them ...... 66
Table 3.3: Equations for the calculation of network measures .................................. 69
Table 3.4: Interview data analysis process ............................................................... 74
Table 4.1: Average density of GRAND researcher’s ego-networks ............................ 81
Table 4.2: Average centrality of GRAND researcher’s ego-networks ....................... 85
Table 4.3: Average heterogeneity of GRAND researcher’s ego-networks .................. 86
Table 4.4: Average effective Size of GRAND researcher’s ego-networks .................. 87
Table 4.5: Average measures of all GRAND researcher’s ego-networks .................... 88
Table 4.6: A comparison of network density measures at 2010 and 2012 .................... 90
Table 4.7: A comparison of network centrality measures at 2010 and 2012 ................. 91
Table 4.8: A comparison of network heterogeneity measures at 2010 and 2012 .......... 94
Table 4.9: A comparison of network effective size measures at 2010 and 2012 .......... 95
Table 4.10: Regression analyses testing the interplay between the network change measures, and research outcomes ......................................................................................... 101
Table 6.1: Regression analyses testing the interplay between changes in network measures, and research outcomes ........................................................................................................ 145
Table 6.2: Proposed themes for the study of the interplay between network structures and researchers social capital ........................................................................................................ 147
List of Figures:

Figure 1.1: A nominal (conceptual) representation of the research questions ...................... 10
Figure 2.1: Example of dense network .................................................................................. 47
Figure 2.2: Theoretical framework ......................................................................................... 54
Figure 3.1: GRAND researchers' disciplinary backgrounds (n=208) ....................................... 57
Figure 3.2: Provinces from which the respondents are coming ............................................. 61
Figure 3.3: Disciplinary background of respondents .............................................................. 62
Figure 3.4: NVivo – primary themes ...................................................................................... 70
Figure 3.5: NVivo example node structure ........................................................................... 72
Figure 4.1: Partial non-response in a network studied at two time points (T1, T2) identifying four subsets of actors (A1– A4) (Huisman & Steglich, 2008). .......................................................... 78
Figure 4.2: Who Knows Whom in GRAND ........................................................................... 82
Figure 4.3: Who Co-Coauthored Publications with Whom in GRAND ................................. 83
Figure 4.4: All communication by media ................................................................................ 84
Figure 4.5: Changes in network density measures at 2010 and 2012 .................................... 91
Figure 4.6: Changes in acquaintance, advice and co-authorship networks centrality measures 2010-2012 .................................................................................................................. 93
Figure 4.7: Changes in email and face-to-face networks centrality measures 2010-2012 ....... 93
Figure 4.8: Changes in network heterogeneity measures at 2010 and 2012 ......................... 95
Figure 4.9: Changes in network effective size measures at 2010 and 2012 ......................... 96
Figure 5.1: NVivo – dimensions of social capital ................................................................. 105
Chapter 1: Introduction

1.1 Research Background

Collective knowledge production and diffusion processes among researchers have captured the attention of many sociology of knowledge scholars (Kuhn, 1970; Mannheim, 1985; Merton, 1968; Scheler & Stikkers, 1980); however, the recent availability of a large amount of digital information has made it possible to more readily conduct analysis of large-scale research patterns. This data availability has allowed recent observers to suggest there is a weakened link between location and research work (Sonnenwald, 2007). As such, it has been deduced that the advances in information and communication technologies (ICTs), and the Internet in particular, have the potential to remove the barriers of distance, broadening access to geographically distant collaborators (Rainie & Wellman, 2012). However, while of great benefit, these advances also have potential implications for the location, research quality, and social stratification of research work (Knorr-Cetina, 1999; Latour, 1987).

Recently, we have been exposed to evidence indicating that research collaboration has increased both in frequency and importance (Sonnenwald, 2007). Although many studies discuss the benefits associated with research collaboration, the ability to generalize these findings remains unclear (Cummings & Kiesler, 2007). Collaborative research teams face significant challenges and are not always successful. For example, collaboration can be hindered by competition for funding or efforts to guard intellectual property (Olson et al., 2008b), and coordinating research activities across large organizations such as universities or government organizations can be difficult and slow (Cummings & Kiesler, 2005). Thus, although there is a weakened link between location and research work, there are still significant barriers to the success of any collaborative undertaking.

The social, cognitive, and technical processes that drive knowledge production and dissemination among researchers have been the focus of intense study (Pepe, 2011). While current studies of research collaboration are largely focused on how modern technologies can be used to establish the resource base and infrastructure to conduct collaborative work (Olson, Zimmerman, & Bos, 2008a), issues relating to how these new
arrangements interplay with the social and cognitive challenges facing research collaboration has not been adequately addressed in current literature. In an attempt to fill this gap, this dissertation looks at research collaboration embedded within the social and epistemic practices of the constituent researchers.

An examination of these social and epistemic dimensions requires a platform of investigation in which individuals are studied within the knowledge domains and discourse communities to which they belong (Hjorland & Albrechtsen, 1995). To that end, I offer a theoretical framework to analyze specific social activities (as evinced by researchers’ social ties and communication patterns) and epistemic activities (indicated by the production of research outputs around the same research topics). Then, I examine how these social and epistemic dimensions can be used to study the structure, changes, and outcomes of a given collaborative research project.

My examination of the social and epistemic dimensions of collaborative research, and their interaction, is structured around three objectives:

1) **Provide a structural analysis of researchers’ social and epistemic ties.**
   Essentially, this analysis offers structures that group individuals according to specific relationship and interaction patterns.

2) **Provide an analysis of the changes in researchers’ social and epistemic ties.** Research collaborations are not static structures; they are all time-dependent. Thus, I extend my analysis to look at the changes of the above discussed structural analysis over a period of four years; and

3) **Examine the relationship between research outcome and the changes in the structural characteristics of researcher’s epistemic and social networks.** Both the structural features of researchers’ social networks, and changes in these features, can significantly affect the research outcome of the researcher.

As noted, the focal point of my study is the GRAND, Network Centre of Excellence. GRAND, an acronym for Graphics, Animation and New Media, is a network of Canadian researchers—computer scientists, social scientists, and humanists—that stretches from Dalhousie University, in Halifax, on the Atlantic Coast, to the University of British Columbia and Simon Fraser University, in Vancouver, on the Pacific Coast. As part of
the terms of their participation and research funding, each of the more than 200 GRAND researchers is encouraged to work on three or more research projects, and each research project is required to include faculty researchers from at least three universities. GRAND comprises an array of distributed physical and virtual environments; physically, the GRAND headquarters are located in Vancouver, British Columbia and faculty offices are scattered across the country at member institutions, and virtually, mailing lists, online forums, and other computer-supported communication platforms connect these individuals.

GRAND offers an appealing research network case study, particularly due partly to its size. Many research collaboration studies are based on large, domain-centric, bibliographic repositories. As a result, these studies rely on a wealth of bibliographic data but examine only a single manifestation of collaboration. In contrast, the manageable size of the GRAND research network makes it possible to collect a wealth of information through asking the involved researchers some explicit questions. The relatively limited size of the constructed network also allows for more nuanced interpretations of results, as compared to those obtained in large-scale analyses.

1.2 Statement of Problem

I define “research collaboration” as sets of individual researchers who interact with each other to share meaning, develop understanding, and perform tasks to achieve a mutually shared superordinate goal that generally produces knowledge (Sonnenwald, 2007). It seems clear that the realization, and further implications of any benefits that arise from this collaborative process, depends on the willingness of the researchers to cooperate with one another. Thus, the researchers are expected to share useful information, especially critical information that others might not possess (Bonacich & Schneider, 1992); to exercise responsible restraint when using valuable, but frequently limited, resources (Turner, 2001); and to devote a fair amount of time and attention toward the achievement of the collective goals (Turner, 2001).

As previously noted, I study the interplay between the structure of a collaborative research network (as revealed through researchers’ social and epistemic ties) and the researchers’ research outcomes which is. My work is built on the two theoretical pillars of social network analysis (SNA) and social capital. In my study, I use the SNA
framework to aid in understanding the structure of a collaborative research network and how it changes over time before examining the changes in structural networks’ characteristics and their interplay with the researchers’ outcomes. Together, social network analysis and social capital can yield better insights on the operation and potential success of a collaborative research network (Baker & Faulkner, 2009). Throughout this undertaking, I enrich my analysis with insights from burgeoning research in the field of social capital; in order to do so, I discuss how the social capital literature can help interpret and understand the interplay between the changes in the structural networks’ characteristics and the researchers’ outcomes.

There is no firm, commonly agreed-upon definition of “social capital” and the particular definition adopted by any given study is dependent on the discipline and level of investigation. In its simplest form, “social capital” can be defined as the social networks or connections through which one gains access to resources (Bourdieu, 1986). Coleman defines “social capital” as a function of social structure producing advantage (1988), and Pierre Bourdieu further defines “social capital” as “the aggregate of the actual or potential resources that are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance and recognition” (Bourdieu, 1986, p. 248). Building on Bourdieu’s definition, Nahapiet and Ghoshal (1998) explained social capital in terms of three dimensions: network structures (i.e., existence of social connections), relationship quality (i.e., trust developed across these connections), and cognitive dimension (i.e., shared understanding among members). These dimensions emphasize the need for social infrastructure and for shared norms and values for achieving high social capital. Thus, social capital does not reside within the individual; rather, it resides in the relationships that an individual or group has with others. For the purpose of this study, social capital theory is defined as the sum of the actual and potential resources embedded within, available through, and derived from the network of relationships possessed by an individual. It comprises both the network and the assets that may be mobilized through this network (Nahapiet & Ghoshal, 1998). Therefore, “social capital” is an individual’s advantage or accrued value arising from the structure of his/her network and the assets mobilized through it. Such value or advantage can influence and
facilitate the flow of information (Lin, 2001), which, in turn, can help generate different research outcomes.

The structural dimensions of research networks, and whether they are constructive in fostering social capital, is also a source of lively debate in research collaboration literature (Hayat & Lyons, 2010). This debate has been addressed in recent studies that have highlighted the need to examine both the processes by which collaborators work together and the structures that emerge from these interactional processes (Maton et al., 2006; Schensul et al., 2006). These types of studies consider the nature of the social networks brought about through collaboration, including the social networks of researchers and, more specifically, the collaborative network of specific collaborative groups (i.e., within a given discipline or collaborative research project). Work on the nature and structure of research networks is part of a growing body of literature that examines the nature and structure of complex adaptive systems in which network structures play a fundamental role. In the majority of these studies, network theory is used.

Generally, network theory is concerned with networks of nodes and links. Social network analysis (SNA), which can be considered a specialization of network theory, focuses on nodes as social objects. SNA focuses on the structure of relationships among units—whether individuals, groups, or organizations—and on the way these relationships affect processes in a network (Wellman, 1988). The links in social networks depict various kinds of relationships, including: collaboration, kinship, shared ideologies, economic exchange, or communication. Thus, aspects of boundaries and hierarchy can be addressed in these networks by adding different attributes to the discussed nodes and incorporating them into an analysis.

Social network analysis can be particularly useful in analyzing the typically informal network that characterizes collaborative research networks such as GRAND, and as previous studies indicate (e.g. Hayat & Lyons, 2010), SNA can offer a compelling framework for addressing these challenges when studying research collaboration because: 1) No formal organizational chart of such a diverse network, characterized by the absence of any formal hierarchy, could ever be meaningfully constructed; and 2) These networks
are characterized by the lack of clear boundaries (geographical, institutional, disciplinary, etc.).

The SNA framework is often used to look at the structure of research networks (Fenner, Levene, Loizou, & Roussos, 2007), and an example of this approach can be seen in a large-scale study of the collaboration patterns in the biomedical and computer science research communities. In this particular study, Newman (2001) found that research communities constitute “small world” networks where the average distance between collaborating scientists is small but varies logarithmically with community size. Only five or six steps are necessary to get from one member of a community to another in most instances. This “smallness” is thought to be critical to social capital and collaborative development (Barabási, 2002) and has been acknowledged by other authors in studies of research networks of various sizes (e.g. Morlacchi, Wilkinson, & Young, 2005). These studies also support the idea that certain network structures can potentially foster social capital. More broadly, these studies also highlight the potential benefit in combining social network analysis with the social capital field.

Numerous ways to study research collaboration exist, and these can be divided broadly into two types: one focuses on the social dimension of the interaction (e.g., communication and acquaintanceship), and the other on the epistemic one (e.g., co-authorship) (Pepe, 2011). It is important to note that the social and epistemic dimensions of research collaboration are tightly coupled and are difficult to be set apart; for instance, although co-authorship is commonly looked at as a proxy for epistemic ties, some scholars also looks at it as a proxy for social ties (most notably Newman, 2004). Despite this difficulty, a number of ad-hoc indicators to study the nature of research collaboration have emerged in specialized literature, and will be utilized in this dissertation.

In this dissertation, I have been guided by studies looking at the social and epistemic dimensions while studying the interactive patterns emerging within the GRAND research network. I examine co-authorship, acquaintanceship, advice exchange, and communication ties among the GRAND researchers. These interactions have been identified as the most relevant for the formation and management of the social and epistemic dimensions of collaborative research projects (Olson et al., 2008b). While the
literature covers many aspects of co-authorship, acquaintanceship, advice exchange, and communication in the context of research communities, rarely has the relationship among them been examined in detail. This is because collecting data about communication practices as well as acquaintanceship and advice exchange is a time-consuming and elaborate procedure, especially for large research networks.

I address this gap by studying research collaboration among GRAND researchers via manifestations of co-authorship, acquaintanceship, advice exchange, and communication, while controlling for key relevant variables that have been identified in the research collaboration literature (see Chapter 2). Furthermore, I have used data gathered through interviews with GRAND researchers which has allowed me to capture the nuances of GRAND members’ relationships that extend beyond the mere identification of the ties discussed above. These interviews also enable me to understand more about the meaning and context behind the relationships that exist among GRAND researchers, thus highlighting the social capital of GRANDs’ members and its interplay with their research outcomes.

The first part of this dissertation provides an analysis of the network structure of individual GRAND researchers. The networks of co-authorship, acquaintanceship, advice exchange, and communication are essentially large structures that group individuals according to specific patterns of relationships. I study the patterns of activity of each individual in these networks (i.e., ego level analysis), and via network analysis methods, I can quantify and explore the structure of these networks. As discussed above, I am mainly interested in looking at network structures that have been proposed as constructive for fostering social capital for individuals (these measures will be discussed in section 1.3: Research approach).

With these considerations in mind, my first research question is as follows:

RQ #1. Which types of structures can be detected in the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers?
The second part of this dissertation provides an analysis of changes in the network over a four-year period through examining the research collaboration dynamics that take place among GRAND researchers. The networks of collaboration studied here—co-authorship, communication, acquaintanceship, and advice exchange—are not static structures; they are all time-dependent. For example, the network of co-authorship represents the collaborative act of writing an article. Co-authoring events take place during a fixed point in time, “time-stamped” by the date of publication. Similarly, co-authorship, acquaintanceship, advice exchange, and communication change with time. With these notions in mind, I look at patterns of changes in the aforementioned networks using a comparative approach, and this analysis provides an understanding of the ways in which the structures examined for my first research question changes over this four-year period (2010–2013).

My second research question is as follows:

RQ #2. What collaboration changes can be evinced from the co-authorship, acquaintanceship, advice exchange, and communication networks of GRAND researchers?

The third part of this dissertation offers an analysis of the structure and change of the co-authorship, acquaintanceship, advice exchange, and communication of GRAND researchers as well as of the research outcomes the researchers produce. Both the structural features and their change over time can potentially affect the researchers’ research outcomes (Baker & Faulkner, 2009). Thus, I explore the interactions between these dimensions. Many scholars have studied how the structure of researchers’ networks interplay with the nature of research work and its outcome (e.g. Palla, Barabasi, & Vicsek, 2007), but these studies have mainly looked at one type of interaction among researchers (e.g., co-authorship) and usually ignore the importance of the diversity of ties a researcher might have with his/her peers. By looking at the structural patterns of co-authorship, acquaintanceship, advice exchange, and communication and their change over time I learn how they interplay with researchers’ research outcomes. Thus, my third research question is:
RQ #3. How do the structural features of the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers, and the change of these features over time interplay with the researchers’ research outcomes?

The fourth part of this dissertation offers a more nuanced analysis of the interplay examined by RQ3. As discussed above, although social network analysis researchers generally agree that network structure is an important aspect that affects work outcomes, they differ on which aspects of social networks are important. One of the reasons for this uncertainty is that social networks analysis often focuses on networks and network structure as content free (i.e., focuses on whether a connection exists, rather than looking at connections as being of a particular type such as friendship, social support, or enmity (Bonacich, 1987). Thus, I seek to combine the structure of networks with the content of social capital, in order to better understand the interplay examined in RQ3.

This analysis will be guided by Bourdieu’s (1986) work which conceptualized the content of social capital as rising from ‘lasting’ and ‘durable’ social relations, which require the expenditure of significant ‘time and energy’. Nahapiet & Ghoshal (1998) proposed three main dimensions for the study of these social relations: structural (i.e., overall patterns of ties among the researchers), relational (i.e., the kind of personal relationships researchers have developed with each other through a history of interactions), and cognitive (i.e., resources which are providing shared representations, interpretations, and systems of meaning among researchers). This widely used conceptualization has been adopted for the study of social capital within research networks (Trier & Mølka-Danielsen, 2013).

Thus, I will use these three dimensions in order to frame my usage of the social capital theory when examining the interplay between the structure of the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers, and their change over time, and of research outcomes. This fourth research question, depicted in Figure 1.1, is as follows:
RQ #4 How can the social capital literature be used to interpret the interplay between research outcomes and the structural features of the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers, as well as the changes of these features over time?

Figure 1.1: A nominal (conceptual) representation of the research questions

As discussed above the interplay between the structure and change of research networks, and research outcomes has not been clearly defined as yet. Thus, the work conducted in this thesis is exploratory in nature. This approach enables researchers to begin to identify effective research designs, data collection and analysis methods(Kothari, 2004). Due to the exploratory nature of this work no hypothesis are proposed here.

I presented my problem statement and a nominal definition of the concepts I address in my research questions. In the following section, I present my research approach as well
as the operational definitions used in my dissertation. These specify how the discussed concepts (as depicted in Figure 1.1) have been measured.

### 1.3 Research Approach

During the writing of my dissertation, I had the privilege of being involved in NAVEL (Network Assessment and Validation for Effective Leadership). NAVEL is one of GRAND’s 34 projects. The goal of NAVEL is to analyze GRAND itself. The data that I use in my dissertation was collected by the NAVEL team (Appendices A, B, C, and D provide full descriptions of the data collection tools used by the NAVEL team). In particular, I have co-authored (jointly with other NAVEL team members) a study of collaboration and productivity in network organizations (Hayat, Dimitrova, Gruzd, Mo, & Wellman, 2011), and another on the evolutionary interplay between epistemic networks (i.e., linking researchers who have utilized identical or related concepts, key phrases, and knowledge constructs in their research work) with social networks (i.e., linking researchers based on their social ties) (Hayat, Dimitrova, Gruzd, Mo, & Wellman, 2012).

Having a personal affiliation with NAVEL allowed me to gain in-depth knowledge about the minutiae of research collaboration at GRAND and to familiarize myself with the narratives behind certain collaboration practices. However, this familiarity also requires me to consider how my affiliation with NAVEL can potentially impact my research. Rather than trying to eliminate these biases, it is important to identify them and to monitor how they shape the collection and interpretation of data (Merriam, 2002); I will also try to be reflective about my assumptions because they may shape the way I interacted with my study participants. Thus, in section 3.4: Qualitative Data Analysis, I will reflect on my own suppositions (and practices) by subjecting my own assumptions to critical review (Alvesson & Sköldberg, 2009). Overall, I believe that this knowledge of the human infrastructure of GRAND has been essential to the interpretation of my research results, regardless of potential biases.

In this dissertation, to study the GRAND research network, I employ a network approach with both quantitative and qualitative components. By representing interactions in a networked fashion, one can rely on a platform of well-established tools and network analysis methods to depict and study various different interactions in detail. In a

Social networks represent patterns of social interactions among people and friendship, acquaintanceship, kinship, business relationships, and sexual relationships are examples of interactions that can be represented by a social network.

Information networks depict information and knowledge exchange. An example of an information network is a scholarly citation network that represents referencing patterns between academic papers. Similarly, the World Wide Web is an information network in that it represents linking patterns between web pages.

Technological networks are human-made networks developed for the distribution of a commodity or resource. The electrical, road, railway, and postal networks are examples of technological infrastructure networks devised for the distribution of electricity, vehicles, trains, and mail. Biological networks represent interactions within or between living organisms. Widely studied biological networks include food networks, which depict preying patterns in an ecosystem, and neural networks, which depict the structure of the brain.

This dissertation focuses solely on social networks that depict interactions between people; particularly, as noted, depict co-authorship, acquaintanceship, advice exchange, and communication. Using a network approach, these interactions can be described using the same underlying scheme: Individuals are represented as nodes in the network; nodes are connected to one another by an edge, if a relationship between them exists. Social network analysis is becoming increasingly common in the study of research collaboration, as it can benefit both policymakers and practitioners. Policymakers often prefer general findings that have a statistical background while practitioners may benefit more from the context and history that case studies provide (Sammons, 2010).

The first part of my dissertation studies the structure of the GRAND researchers’ social networks and their change over time. In order to achieve this, I have conducted an ego-network analysis of GRAND researchers’ co-authorship, communication, acquaintanceship, and advice exchange networks. Ego-network analysis deals with the relationships that exist from the perspective of a particular node, which is referred to as
an “ego” (Wasserman & Faust, 1994)—in my case, this is from the point of view of a specific GRAND researcher. Each of the other nodes in the ego-network are referred to as “alters.”

I am specifically interested in looking at network measures that are proposed as constructive for fostering social capital for individuals. Table 1.1 summarize the six ego-level network measures proposed by Lin (1999), and Borgatti, Jones, and Everett (1998) which I examine in my study. The first column in this table describes the characteristics measured. The second column describes how the measure relates to social capital, while specifically stating the potential social capital–associated benefits that have been found to be correlated with the measure (i.e., access to information or political resources and mutual trust). The third column presents the network measure name and cites the article(s) in which the measure's relationship to social capital was first introduced.

These measures are calculated based on data collected via an online survey circulated among GRAND members by the NAVEL team. The first round of the survey was conducted between September and November 2010, and the second round of the survey was conducted between September 2012 and March 2013 (full descriptions of the survey tool and how it was used for collecting the desired data is presented in Chapter 3 of this dissertation). As I wanted to capture the baseline ego-networks among GRAND researchers, the structural network measures are based on the results of the first survey.

It is also important to reiterate that I am studying the structure of four different ego-networks for each GRAND member (i.e., co-authorship, communication, acquaintanceship, and advice exchange). Thus, each of the variables presented in Table 1.1 is calculated for the four examined networks. Therefore, I have 24 network measures (four different networks times six measures for each of the networks) that are used for studying the network structure of GRAND researchers. Furthermore, as I am also interested in the changes of the network over time, I look at the changes in these measures over time (i.e., the network measures calculated based on the results of the first survey as compared to the network measures calculated based on the results of the second survey). Thus, I also have 24 network measures representing the change of the examined network measures.
Table 1.1: Network measures that were proposed as constructive for fostering social capital (adapt from Borgatti et al., 1998)

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Relation to Social Capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size / degree</td>
<td>The number of alters that an ego is directly connected to, weighted by strength of tie.</td>
<td>The higher the number of researchers with whom a researcher has relationships, the greater the chance that one of these peers has the resource the researcher needs.</td>
</tr>
<tr>
<td>(Burt, 1983)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Betweenness</td>
<td>The number of times that ego falls along the shortest path between two other alters in the network.</td>
<td>Researcher with high betweenness link researchers that are otherwise unconnected, thus creating opportunities for exploitation of information and other resources that he/she channels.</td>
</tr>
<tr>
<td>(Freeman, 1977)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eigenvector</td>
<td>A measure of the importance of a node in a network. It assigns relative scores to all nodes in the network based on the principle that connections to high-scoring nodes contribute more to the score of an ego than equal connections to low-scoring nodes. In essence, it measures the extent to which an ego is connected to alters that are themselves high in eigenvector centrality.</td>
<td>Connections with well-connected peers is considered a valuable resource for political and information resources.</td>
</tr>
<tr>
<td>(Bonacich, 1972)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heterogeneity</td>
<td>The variety of alters with respect to relevant dimensions (e.g., sex, age, occupation).</td>
<td>Connection to a more diverse group of researchers can lead to having access to more diverse spectrum of resources.</td>
</tr>
<tr>
<td>(Burt, 1983)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effective Size</td>
<td>The number of alters—weighted by strength of tie—to which an ego is connected, minus a &quot;redundancy&quot; factor.</td>
<td>Being connected to more different network regions can help expose a researcher to a greater spectrum of resources.</td>
</tr>
<tr>
<td>(Burt, 1992b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>The proportion of pairs of nodes that are connected.</td>
<td>A network of tightly connected researchers can facilitate sanctions that make it less risky for people in the network to trust one another.</td>
</tr>
<tr>
<td>(Coleman, 1988)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
It is also important to note that although the data regarding the communication, acquaintanceship, and advice exchange networks of GRAND researchers comes from the surveys discussed above, the co-authorship network data is based on the analysis of the GRAND online forum. Among other things, the GRAND online forum contains the publications produced by each GRAND researcher during his/her involvement in GRAND. These data was used to construct the ego co-authorship networks of GRAND members, and it enabled me to calculate the aforementioned network measures.

Table 1.2: Project outcomes (adapted from Cummings and Kiesler, 2005)

<table>
<thead>
<tr>
<th>Research Outcomes</th>
<th>Items Used for Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge Outcomes</td>
<td>Started new field or area of research; developed new model or approach in field; came up with new grant or spin-off project; submitted patent application; presented at conference or workshop; published article(s), book(s), or proceeding(s); was recognized with award(s) for contribution to field(s).</td>
</tr>
<tr>
<td>Training Outcomes</td>
<td>Grad student finished thesis or dissertation; grad student/post-doc got academic job; grad student/post-doc got industry job; undergrad/grad student(s) received training; undergrad(s) went to grad school.</td>
</tr>
<tr>
<td>Outreach Outcomes</td>
<td>Formed partnership with industry; formed community relationship through research; formed collaboration with researchers; established collaboration with high school or elementary school students; established collaboration with museum or community institution; established collaboration with healthcare institution.</td>
</tr>
<tr>
<td>Collaboration Outcomes</td>
<td>Started with people in your project team collaborations that will continue beyond that scope. Started collaborating with people who are not members of my project, and this collaboration will continue in the future. Shared data with other research projects.</td>
</tr>
</tbody>
</table>
The data regarding the research outcomes of GRAND researchers were gathered through a paper-based outcome survey that was distributed during the 2013 GRAND annual conference (in this conference GRAND researcher meet in official project meetings, showcasing posters and demos based on their research. Furthermore, each project presents a summary of the work conducted by its members in the preceding year). An invitation to participate in the survey was also sent via e-mail to the GRAND members who did not attend the annual meeting. The survey was based on the Cummings and Kiesler (2005) framework which looks at: (1) knowledge outcome, (2) training outcome, (3) outreach outcome, and (4) collaboration outcomes.

This framework is appealing because it relies on self-reported outcomes rather than on observed outcomes (e.g., citation counts); relying on self-reported outcomes fits nicely with the analysis of the self reported outcome survey. Table 1.2 presents the composites proposed by Cummings and Kiesler (2005). For instance, in their work, Cummings and Kiesler (2005) measure knowledge outcomes by listing seven possible specific outcomes related to gains in new knowledge (starting a new field or area of research; developing a new model or approach in field; coming up with new grant or spin-off project; submitting a patent application; presenting at conference or workshop; publishing article(s), book(s), or proceeding(s); being recognized with award(s) for contribution to field(s)). In my analysis, I evaluate each of the four research outcome dimensions presented in Table 1.2 for each of the GRAND researchers that completed the outcome survey. The result is four research outcome indices for each researcher; a detailed discussion of the evaluation process is presented in Chapter 3.

Thus, I was able to operationalize the notion of network structure through constructing 24 items representing the network structure of each of the GRAND researchers; I was also able to operationalize the notion of network change by constructing 24 items representing the researcher’s network change over time. By doing so, I was able to address research questions 1 and 2. By statistically examining the interplay between these structural and change items with the four research outcome indices, I was able to address research question 3. A full discussion of the statistical procedure used for this analysis is presented in Chapter 3.
The qualitative portion of my research is intended to further explain the interplay between the structural and change items and the four research outcome indexes. In order to do so, I use data from the NAVEL team’s semi-structured interviews with 50 GRAND researchers (details will be presented in Chapter 5). Unlike the quantitative social network data collection, the purpose of interviewing is not to evaluate or to examine a phenomenon. Instead, interviewing provides a means by which to understand people’s experiences and the meaning they give to their own behaviour (Seidman, 2006). Using the interviews, I investigated whether the structure and change of the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers interplay with the benefits associated with greater social capital. To achieve this, I ensured that the interview questions addressed the network structure and its interplay with the collaboration among the researcher and his/her collaborators (i.e., alters). The second part of the interview is geared toward addressing how the benefits associated with greater social capital interplay with GRAND researchers’ research outcomes which enables me to address research question 4. A full description of the interview structure and procedure is discussed in Chapter 3.

1.4 Significance of the Study

The intellectual contribution of this dissertation falls within several categories. First, a great deal of studies dealing with research collaboration have been performed on large networks, constructed from large bibliographic datasets and harvested from domain-based and institutional document repositories. These studies document the organization and growth of large-scale collaborations, such as astronomical surveys, international high-energy physics experiments, and similar “big science” endeavours. This dissertation demonstrates that the opposite is also true: network analysis is a convenient platform for documenting and examining research collaborations on smaller scales. Moreover, I have demonstrated that working with smaller-scale networks presents many benefits. For example, studies of research collaboration based on networks of manageable size (such as GRAND) can be easily complemented and elucidated by qualitative methods. The relatively small size of the GRAND research network allowed for interviews to be conducted with approximately 25% of the researchers involved in GRAND; the use of
similar methods would not be feasible for “big science” collaborations that involve tens of thousands of researchers.

This dissertation also lends support to the argument that social capital and social networks, when combined, yield richer theory and better predictions (Baker & Faulkner, 2009). Social network analysis can offer precise measures of social structure as well as the change of research networks. Social capital driven findings can help to move beyond the relations themselves to understand how investment in personal relationships or social structure can either facilitate or hinder the achievement of different research outcomes.

Although the findings of this dissertation do not offer a clear generalizable lesson, they suggest ways of looking at network structures and social capital properties that are useful for the study of research networks. Furthermore, I show that the efficacy of SNA in the study of research networks should be driven by an understanding of what the networks are aimed at facilitating and fostering. Specifically, I show that: (1) Knowledge outcomes are positively correlated with the density of the co-authorship ego network, and with the betweenness centrality, heterogeneity and effective size of the advice ego network; knowledge outcomes are also negatively correlated with the size of the co-authorship ego network; (2) Training outcomes are positively correlated with the size and density of the advice ego network, and with the density of the communication ego network, training outcomes are also negatively correlated with the effective size of the co-authorship ego network; (3) Outreach outcomes are positively correlated with the effective size of both the acquaintanceship and advice ego networks, as well as with the size and eigenvector centrality of the co-authorship ego network; (4) Collaboration outcomes are positively correlated with the size of the advice ego network as well as with the size and density of the co-authorship network.

Lastly, this dissertation highlights the importance of studying the different networks that connects researchers. The findings discussed highlight the notion that exploring a single manifestation of connection among researchers would fail to reveal the rich web of interactions in which researchers engage, and thus will prevent us from fully capturing how network structures can interplay with research outcomes. My dissertation findings stress the need to examine the different types of ties that exist among researchers as different ties have different patterns of correlations with different research outcomes.
1.5 Structure of the Dissertation

In the next chapter, I outline the theoretical concepts used to frame this research and provide a background of past and present related research. This chapter also introduces the concepts of research collaboration, social network analysis and social capital. The blending of these particular theoretical frameworks helps to guide the methodology of this research.

In Chapter 3, I present, in detail, the subject of study of this dissertation: the GRAND Networks of Centres of Excellence (NCE). Prior to presenting a general overview of the research methods and data sources employed throughout this dissertation. I then move to discuss how I will analyze both the qualitative and quantitative data used in this research and conclude this chapter by discussing the limitations of my methodology.

In Chapters 4, I present the quantitative results of the GRAND network structure and change analysis of the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers as well as my results regarding the research outcomes. In Chapter 5, I describe the use of qualitative analysis in order to explain the interplay between the structure, and its change over time, of the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers and of research outcomes. Chapter 6 discusses the results and the interpretation of the findings in terms of how they address the research questions and fit with the theories presented in the literature review chapter. I also discuss the significance of this dissertation. Chapter 7 concludes by acknowledging the limitations and assets of this research and delineating possible directions for future work.
Chapter 2: Literature Review

2.1 Literature on Research Collaboration

This chapter outlines the theoretical concepts used to frame the dissertation and provides a background of past and present research. The conceptual framework will give a brief perspective on the sociological foundations of the study and how it can be applied to examine the structure, change, and outcomes of research networks. This section also introduces the concepts of research collaboration, social network analysis, and social capital. As will be discussed below, blending these particular theoretical frameworks helps to guide the methodological approach of this dissertation.

2.1.1 Defining Research Collaboration

The literature examining the characteristics and determinants of research collaboration is rather abundant; because different disciplines have brought forward different perspectives, theories, and methods. Studies of research collaboration grounded in sociology, for example, analyze the processes of research activity in the social, cultural and political context in which research takes place (Hess, 1997) whereas cognitive scientists focus on the study of the researchers’ mind and the mental processes underlying their reasoning (Dunbar, 2005). Information Studies contributes to this body of knowledge by studying research practices and the artifacts generated in the process of research collaboration; Information Scientists employ digital collections of scholarly papers and bibliographic repositories in order to model and analyze networks of research collaboration (Sonnenwald, 2007). Although theoretically grounded in their own domains, these and other approaches to the study of research collaboration, do not exist in isolation; rather, they have often borrowed principles and concepts from each other.

This process of cross fertilization helped establish a theoretical framework for the study of research collaboration. This framework has been reformulated in terms of the collective dimension in which research work takes place. Studies of research and its knowledge production mechanisms focusing on the individual have been progressively complemented by studies that account for the collective. For these latter investigations, research work is not only an individual endeavour, it is also a collective, distributed process, involving close interaction among a number of social, cultural, technological,
economical, and political dimensions. The distributed and collective components of research work are at the heart of this dissertation.

The above discussed pragmatic shift is also accompanied by a challenging attempt to offer a definition of the notion of research collaboration. Katz and Martin (1997) define research collaboration as researchers working together to achieve the common goal of producing new scientific knowledge. A variety of ‘collaborative activities’ have been identified as falling under this broad concept and as Bordons and Gomez (2000) claim, these include the expression of opinions, the exchange of ideas and data, working together during the course of a project, working separately on different parts of a project with the purpose of integrating the results at the end, sharing equipment, and exchanging personnel.

However, Katz and Martin (1997) acknowledge that both the concept of ‘working together’ and the assumption of a ‘common goal’ as a distinctive characteristic of a collaborative activity are rather conceptually and empirically problematic since: a) it is not clear how closely researchers have to work together in order to constitute a collaboration and b) either no two researchers ever have precisely the same goals, or, conversely, every single researcher in the world is in fact a member of a greater collaboration called the ‘scientific community’ for they all work to advance scientific knowledge and are all somewhat interrelated: they all exchange ideas on which experiments to do next, which hypothesis to test, which new instrumentation to build, how to relate their latest experimental results to theoretical models, and so on.

Bordons and Gomez (2000) further argue that if we take a narrow definition and agree that collaboration is defined as two or more researchers working together on a joint research project, sharing intellectual, economic and/or physical resources, a wide range of situations can still be included, and a wider range of contributions will in fact be excluded under such definition. It seems therefore that, as the authors acknowledge, research collaboration has a very “fuzzy” or ill-defined border, and exactly where that border is drawn is a matter of social convention and open to negotiation. Furthermore, perceptions regarding the precise location of the ‘boundary’ of the collaboration may vary considerably across institutions, fields, sectors, countries, actors, and purposes over time.
The fact is that, as with any other social process, research collaboration is governed mainly by complex human interactions that we still do not understand completely.

Despite these challenges, I offer the following definition for research collaboration: research collaboration is a social process, taking place in a social context, in which researchers interact to share meaning, develop understanding, and perform tasks to achieve a mutually-shared superordinate goal, which generally produces knowledge (Sonnenwald, 2007). This definition highlights the conception of collaboration as a process of participation in epistemic communities, which has been well documented in numerous empirical works in science and technology studies (e.g., Latour, 1987). Peter Haas (1992) defines epistemic communities as a transnational network of professionals that shares sets of causal and principled beliefs, as well as consensual knowledge base.

The literature dealing with epistemic communities have brought forward a detailed discussion about the different types of research collaboration. These different types can help better frame and understand the quandary relating to the notions of working together within a given collaborative research project such as GRAND. Furthermore, as research collaboration is an intangible concept, the epistemic communities’ literature helps highlight the different types of collective activities that fall under the broad notion of “research collaboration.”

2.1.2 Types of Research Collaboration

Research collaboration can be characterized in terms of the disciplines involved, the geographical setting, and the organizational and community focus (Sonnenwald, 2007). Collaboration can involve participants at different levels, from the micro-level of individuals (e.g., dyads, triads), to the meso-level of department/institutions, and to the macro-level of countries (Sonnenwald, 2007). Table 2.1 summarizes the definitions of each form of collaboration in terms of its scope.

Some researchers argue for a need to make an analytical distinction between the different levels of collaboration according to the purpose of a study (Katz & Martin, 1997). For instance, a study that assesses research outcomes can be conducted at the level of an individual researcher, or an academic department, or a university. However, in this dissertation, I chose not to make the distinction between the different levels, because they are dependent. Creating a dualism between two or more levels runs the risk of
configuring groups or departments as structures with a capacity to collaborate on their own. Instead, it is important to establish a link connecting the different levels, to make visible the individual in the group or department, and vice versa. Collaboration is not a process engaging individuals disembodied from their group, or group devoid of individuals. Instead, a collaborator always operates in a set of organizational and material circumstances that contribute to shaping the process and its outcome.

Table 2.1: Different levels of research collaboration (Katz & Martin, 1997, p. 10)

<table>
<thead>
<tr>
<th>Proposed Level of Analysis</th>
<th>Type of Internal Ties</th>
<th>Type of External Ties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual</td>
<td>--</td>
<td>Between individuals</td>
</tr>
<tr>
<td>Group</td>
<td>Between individuals in the same work group</td>
<td>Between groups (e.g., in the same department)</td>
</tr>
<tr>
<td>Department</td>
<td>Between individuals or groups in the same department</td>
<td>Between departments (e.g., in the same organization)</td>
</tr>
<tr>
<td>Institution</td>
<td>Between individuals or departments in the same organization</td>
<td>Between organizations</td>
</tr>
<tr>
<td>Sector</td>
<td>Between organizations in the same sector</td>
<td>Between organizations in different sectors</td>
</tr>
<tr>
<td>Nation</td>
<td>Between organizations in the same country</td>
<td>Between organizations in different countries</td>
</tr>
</tbody>
</table>

While these forms of collaboration encompass the full continuum of relationships – from informal, one-to-one interactions to formal, complex and structured arrangements – it can be difficult to determine when a less formal relation ends and a formal collaboration between researchers begins (Katz & Martin, 1997). These different forms of collaboration can range from collocated and organizationally embedded within the same institute, to geographically distributed across institutions and countries. In terms of disciplines involved, research collaboration can take different forms, depending on
whether participants work within the same discipline or use knowledge from different disciplines, with or without the intent of integrating such knowledge (Sonnenwald, 2007). The organizational focus also varies, as it ranges from collaboration within academia to variously arranged collaborations engaging companies, universities and non-profit organizations to share resources in pursuit of a common goal (Sonnenwald, 2007).

Within each of these different contexts, research collaboration is a complex process that requires intentional knowledge and information sharing and joint responsibility for accomplishing the outlined goals. Research collaboration often occurs within long-term relationships between participants and follows a developmental trajectory that evolves over time. Drawing on previous identification of stages of the scientific process, Sonnenwald (2007) described the different objectives and levels of organizational structure characterizing each stage (see Table 2.2):

Table 2.2: Stages of research collaboration (Sonnenwald, 2007)

<table>
<thead>
<tr>
<th>FOUNDATION STAGE</th>
<th>FORMULATION STAGE</th>
<th>SUSTAINMENT STAGE</th>
<th>CONCLUSION STAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examine aspects that are required to initiate a collaboration or that prohibit collaboration from being initiated.</td>
<td>Decide and plan collaboration. Articulate and share goals with the stakeholders.</td>
<td>Set up organizational structure and management practices.</td>
<td>Results may or may not emerge. Funding and other resources can come to an end.</td>
</tr>
</tbody>
</table>

The foundation stage focuses on factors that are required in order for collaboration to be considered and initiated, or factors that can inhibit the formation of collaboration. During the formulation stage, researchers initiate and plan collaborative research projects. As multiple researchers are involved in this process, some of whom may have different disciplinary backgrounds, work in different institutions, and not be collocated; sufficient time for (additional) planning is required for success. After collaboration has been formulated and work has begun, it needs to be sustained over a period of time if it is to achieve its end goals. Ideally, in the conclusion stage of research collaboration, successful
results emerge, although it can happen that funding and other resources simply expire without the hoped-for results having been produced (Sonnenwald, 2007).

Issues relating to types and stages of research collaboration have been extensively addressed in previous studies. It is generally accepted that an inclusive longitudinal study of research collaboration should take account of the different research stages (Olson et al., 2008b). One of the most prominent examples for that can be seen in Laboratory Life, one of the earliest and most notable ethnographic studies of research work. In this work, sociologists Bruno Latour and Steve Woolgar explored the construction of research facts in a biological research laboratory (Latour & Woolgar, 1979). The aim of that investigation was to capture the latent minutiae of the different stages of research activity by in situ monitoring of the researchers, working in their most natural working environment.

In this dissertation, I join this line of work through my acknowledgement that research collaboration might take different forms in different research stages. For instance, according to Stokols, Harvey, Gress, Fuqua, and Phillips (2005), face-to-face interactions plays a more central role in the early stages of research collaboration (i.e., foundation) than in later stages (i.e., conclusion). Thus, by guiding my analysis of GRAND according to the stages of research collaboration proposed by Sonnenwald (2007) (see Table 2.2), I am better able to understand the change of the GRAND research network over time and its interplay with the research stages of the involved researchers.

The work of Latour and Woolgar (1979), and similar studies aiming at the anthropology of research, took place in the late seventies when the laboratory, in the traditional sense, was certainly the most obvious environment in which to study the production and dissemination of research work. Much collaboration in the traditional laboratory was driven by physical proximity and physical exchange of paper literature: books, journals, preprints, and articles. With the advent of digital collaborative platforms in the past two decades, research, as an undertaking, has changed considerably. Some modern researchers operate in a very distributed fashion by heavily relying on electronic communication and on distributed computing resources (Jones, Wuchty, & Uzzi, 2008). The laboratory, as a collaborative research environment, has extended beyond the traditional laboratory walls: the intellectual space in which research collaboration takes
place no longer corresponds to a single physical working environment. In turn, a
laboratory, in the traditional sense, ceases to pose a reliable framework for the study of
modern research activity, and the notion of collaborator was introduced.

2.1.3 Defining a Collaboratory

To mark the importance of computer-supported collaboration for research
collaboration, the term “collaboratory” was coined in the early 1990s from a blend of the
words “collaboration” and “laboratory.” The earliest definition of collaboratory described
it as:

\[ A \textit{center without walls in which the nation's researchers can perform their} \]
\[ \textit{research without regard to geographical location — interacting with colleagues,} \]
\[ \textit{accessing instrumentation, sharing data and computational resources, and} \]
\[ \textit{accessing information in digital libraries} \text{(Wulf, 1993, p. 854)}. \]

In favour of a novel organization of research activity, in this definition, the
requirement of physical and geographical proximity of the researchers ceases to exist.
The use of computer-based communication technologies relaxes the constraints of
distance and time imposed by traditional laboratory work. Nowadays, both large-scale
and smaller collaboratories represent a substantial portion of the ecology in which
scientific knowledge production takes place. Modern collaborative research extends
beyond national, institutional, and disciplinary boundaries to make up dedicated networks
of people, information, artifacts, technologies, and ideas dispersed around worldwide
locations and institutions. More recent definitions of the notion of collaboratory stress the
need to solve problems simultaneously and remotely, to access and distribute datasets,
and to provide flexible, informal interaction among colleagues (Bos et al., 2007).

Being founded upon the notions of multi-disciplinary research, and modern multi-
sited collaboration, collaboratories have attracted investments from major funding bodies
both at the national (Canadian) and international level (Landry, Traore, & Godin, 1996).
The function of collaboratories has received particular attention from sociologists of
science and scholars interested in computer-supported cooperative work. Much of this
research is especially concerned with the social, human, and organizational arrangements
of these working environments. Most importantly, the pioneering work of Star and
Ruhleder (1994) has paved the way in this direction. Using the notion of "infrastructural inversion," initially introduced by Bowker (1994), they propose to study infrastructural complexity with a focus on relations rather than things. Recent research in this field, has built around this and similar notions.

Like laboratories, collaboratories are social organizations that provide for the diffusion and preservation of knowledge created from collaboration (Finholt & Olson, 1997). In addition, they can support networking and collegiality that may have a socially levelling effect and lower the barriers to dialogue. According to Lunsford and Bruce (2001), a collaboratory differs from other socio-technical systems because of the characteristics of: (1) Shared inquiry. Not only do participants share common goals but also a set of problems that they all consider to be significant and worth the effort to work on. (2) Intentionality. Participants feel involved in a mutual project. There is a tipping point that brings about the critical mass awareness that is necessary to turn the joint work into a collaboratory. (3) Active participation and contribution. Participants actively contribute to joint activities and engage in constant negotiation regarding the objects of their projects. (4) Access to shared resources. Participants can use tools, documents, and information provided by the collaboratory. (5) Technologies. Technologies used in collaboratories vary depending on the research field, nature of tasks, purposes, and goals. They range from enormous shared databases used in space physics to ordinary technologies including electronic mail, file transfer software, online community websites, video conferencing, transcription software, and database software. (6) Boundary crossings. Collaboratories always cross some kind of boundaries, which can be geographical, time-based, institutional and disciplinary. Building on these elements, a collaboratory can become a generative space, which is perceived by its members as a source of epistemic and social gain (Pepe, 2011).

Collaboratories can take different forms depending on their main type of resource (instrument, data, or knowledge) and activity (aggregating resources across distance or co-creating knowledge across distance). As presented in Table 2.3, Bos et al. (2007) grouped collaboratories into seven categories, based on their main function.
Table 2.3: Seven types of collaboratories (Bos et al., 2007)

<table>
<thead>
<tr>
<th>Type</th>
<th>Main Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shared Instrument</td>
<td>Increased access to equipment (e.g., large telescopes)</td>
</tr>
<tr>
<td>Community Data System</td>
<td>Information resource created and maintained by a distributed community</td>
</tr>
<tr>
<td>Open Community Contribution System</td>
<td>Open project aggregating the efforts of many contributors toward a common research problem</td>
</tr>
<tr>
<td>Virtual Community of Practice</td>
<td>Network of individuals sharing a research area and communicating online</td>
</tr>
<tr>
<td>Virtual Learning Community</td>
<td>Learning and knowledge building</td>
</tr>
<tr>
<td>Distributed Research Center</td>
<td>Distance-based research center</td>
</tr>
<tr>
<td>Community Infrastructure Project</td>
<td>Develop infrastructure to further work in a domain</td>
</tr>
</tbody>
</table>

Interestingly, different GRAND researchers perceived differently the main functions of GRAND as a collaboratory (Hayat, 2012). Their perceptions can be mainly defined as open community contribution systems and virtual communities of practice. These perceptions are in line with GRAND vision of establishing information resource which will be maintained by GRAND researchers (i.e., GRAND as an open community contribution system) as well as offering aggregation of the research efforts toward the solving of a common research problem (GRAND as virtual community of practice) (GRAND, 2009).

Previous studies have indicated that when studying collaboratories it is important to look at how researchers that are involved in the collaboratory perceive its function (Bos et al., 2007). By acknowledging the researchers’ perspectives, we can better understand both the context in which the researchers are working and how their involvement in the collaboratory can potentially affect their research work. Thus, I explicitly asked GRAND researchers about the functions GRAND serves for them. The researchers’ perceptions

28
helped me in the interpretation of my qualitative results articulated in Chapter 5, and are referred to in the discussion chapter.

2.1.4 Studying Research Networks

There are numerous ways to study research networks. These can be broadly divided into two types: the one focuses on the social dimension of the interaction and the other on the epistemic one (Pepe, 2011). The examination of the social and epistemic dimensions proposes a platform of investigation in which individuals are studied within the knowledge domains and discourse communities to which they belong (Hjorland & Albrechtsen, 1995). More specifically, I offer a framework to analyze specific social activities, as evinced by researchers’ social ties and communication patterns; and epistemic activities, demonstrated by the production of research outputs around the same research topics. I, then, examine how the social and epistemic dimensions can help in studying the structure, development, and outcomes of a given collaborative research network.

When studying the interactive patterns emerging within the GRAND research network, I am guided by studies looking at these two dimensions. The epistemic mechanisms of research knowledge production and the social processes of research collaboration are tightly coupled notions that are hard to disassemble and operationalize. Despite the difficulty and heterogeneity of the study of idea formation and collaboration, some distinct patterns can be identified in both research thinking and collaboration, and a number of ad-hoc indicators to study the nature of research collaboration have emerged in specialized literature.

Co-authorship is the most widely used indicator of collaboration in research circles. In specialized literature, co-authorship networks have been employed to study collaboration patterns within entire research domains and within more specialized research circles. Previous environment-specific studies of collaboration have delineated the population under study by relying on publication data contained in an institutional repository or domain-specific bibliographic databases to mine patterns of co-authorship that take place within a given institution or academic domain. Though co-authorship is considered the primary proxy for assessing epistemic ties (Pepe, 2011), it is worth noting that citation count also serves as a central indicator of epistemic ties (Leydesdorff, 2011);
however, as GRAND was only launched in mid-2010, and some of GRAND’s projects only started publishing their work during 2012, the measuring of their citation count was rendered ineffective.

Though I acknowledge the importance of co-authorship for the assessment of the epistemic ties among collaborating researchers, additional aspects are required for the studying of the research collaboration. Besides co-authorship, studies of research collaboration have also covered the importance of acquaintanceship, advice exchange, and communication patterns as the most relevant for the formation and management of the social dimension of collaborative projects (Olson et al., 2008b). While the literature covers many aspects of co-authorship, communication, acquaintanceship and advice exchange in the context of research communities, rarely has their relationship been examined in detail. This is because collecting data about communication practices, as well as acquaintanceship and advice exchange is a time-consuming, elaborate, and error-prone procedure, especially for large research networks. In this dissertation, I wish to address this gap by studying the research collaboration among GRAND members via manifestations of co-authorship, communication, acquaintanceship, and advice exchange while controlling the key relevant variables that were identified in the research collaboration literature (elaborated in the research method chapter).

2.1.5 Research Collaboration and Research Outcomes
Throughout the process of research collaboration, different research outcomes can emerge. Ideally, successful results from the collaboration emerge, and although it can happen that funding and other resources for the collaboration simply come to an end without any outcomes emerging, I wish to focus on the different types of outcomes that are produced as a result of research collaboration.

An important outcome of research collaboration, of course, is the creation of new knowledge, including new research questions, proposals, theories, and models (Stokols, Harvey, Gress, Fuqua, & Phillips, 2005). These are traditionally measured by publication and citation counts. Both of these measures fall within the broader research field known as “bibliometrics.” The coining of the term “bibliometrics” is frequently credited to Pritchard (1969), who proposed it to replace the rarely used and somewhat ambiguous term of “statistical bibliography.” Pritchard defined this as "the application of
mathematical and statistical methods to books and other media of communication" (p. 348). In the same year, Fairthorne (1969) widened the scope of bibliometrics to include the "quantitative treatment of the properties of recorded discourse and behaviour appertaining to it" (p. 341). Broadus (1987) defines it as the measurement of patterns in written communication whereas Borgman and Furner (2002) state that bibliometrics offers a powerful set of methods and measures for studying the structure and process of research collaboration.

Within the field of bibliometrics, co-authorship is a prominent indicator of research collaboration. According to the Oxford English Dictionary “bibliometrics” is “the branch of library science concerned with the application of mathematical and statistical analysis to bibliography; the statistical analysis of books, articles, or other publications” (Wright, 1989). It is worth mentioning that alongside co-authorship analysis, there are additional methods for the study of research activity indicators. These include broad categories of research in citation, co-citation, and acknowledgment networks (Borgman & Griffith, 1990). Yet, co-authorship patterns are the most studied indicator of research output especially for collaborative research.

Other research outcomes may be less visible than publication and citations counts but are nonetheless important. These include career, educational, administrative, tool, business and socio-political developments (Cummings & Kiesler, 2005; Sonnenwald, 2007). Researchers and staff may acquire new knowledge and skills during a collaboration that can lead to new career opportunities. This includes not only new scientific knowledge but also new knowledge regarding research methods, use of ICT, and project management. Educational results include students who successfully complete their educational programs and others who have been influenced by the project through outreach activities or as study participants. Educational results may also include the adoption of more effective teaching methods and practices that are shared among scientists across disciplines and distances or which emerge from innovative collaborative activities such as joint supervision of students across distances (Sonnenwald, 2007).

Administrative systems and practices may also be changed as a result of research collaboration. For example, when collaboration is inter-institutional and/or international, it may require new ways of working with respect to the administration of grants and
project accounting. Such changes within an institution may make it easier for subsequent, new forms of collaborations to be more easily established and sustained at that institution. Innovative tools and improvements to existing tools may also emerge from collaboration. These tools may be scientific, project management, collaborative or other research support tools. Also, economic or business results may include patents, licenses, and/or new products and services that are used to form start-up companies or enable growth opportunities for existing companies (Sonnenwald, 2007).

In the literature, research collaboration is mostly portrayed as an important enabler of science and technology development. It is considered to be ‘better’ than individualistic research in several respects. Many argue that research collaboration has greater epistemic authority (Beaver, 2004; Wray, 2002); facilitates diffusion of information and ideas; increases access to new knowledge and research tools; and offers visibility and feedback (Rigby & Edler, 2005). These are crucial elements for the use and production of new knowledge and technology. More importantly, most of the literature on the topic claims that research collaboration is an important source of creativity (Burt, 2004; Farrell, 2001; Levine & Moreland, 2004) which, in the right set of conditions, may increase: a) research productivity (Lee & Bozeman, 2005), b) research quality (Rigby & Edler, 2005), c) innovative capacity (Belderbos, Carree, & Lokshin, 2004), d) science and technology human capital (Bozeman & Corley, 2004), and e) the consolidation of research agendas and the expansion of research areas (Sonnenwald, 2007).

Others, however, warn about the negative impacts of research collaboration on productivity (Carayol & Matt, 2004; Cummings & Kiesler, 2005); output quality (Herbertz, 1995); innovative capacity (Gelijns & Thier, 2002); human capital (Behrens & Gray, 2001; Slaughter, Campbell, Holleman, & Morgan, 2002); and relevance of the research (Kleinman, 1998; Shrum, 2005). Risks and costs identified include the privatization and capture of traditional ‘public’ knowledge, the ‘mercantilization’ of knowledge and human capital as resulting from public-private research partnerships, opportunity costs, and crowding out effects. The following is the key literature found on the topic.
2.1.5.1 Positive Impacts

Landry et al. (1996), performed an econometric analysis using survey data from Canadian academic researchers of all research disciplines and found that collaboration, whether undertaken with universities, industries, or institutions, may indeed increase researchers' productivity. According to the authors, the effect of collaboration on productivity varies according to the field of research. However, Adams, Black, Clemmons, and Stephan (2005), who studied data derived from 2.4 million scientific papers written in 110 top U.S. research universities between 1981 and 1999, found that research outcome (as measured by a normalized number of publications) increases with team size. The authors conclude that since increasing team size implies an increase in the division of labor, these results suggest that research productivity increases with the increase in the division of labor.

Lee and Bozeman (2005) studied the differences in performance of foreign-born and native-born researchers in the USA with data from 443 curricula vitae and a survey of researchers and engineers. They found that research collaboration (measured by the number of self-reported collaborators the respondent had) had a positive impact on productivity (measured by a normalized number of publications) of researchers. In summary, Lee and Bozeman (2005) indicate that publication count of peer-reviewed journal papers is strongly and significantly associated with the number of collaborators (Lee & Bozeman 2005).

2.1.5.2 Negative Impacts

Critics argue that high transaction costs in collaborative activities reduce research productivity. Katz and Martin (1997) claim that research collaboration also increases costs on travel, administration, and time spent on keeping all collaborators informed of progress, deciding what to do next, developing new working relationships, resolving different opinions, and reconciling differences in management cultures, financial systems, determining rules on intellectual property rights, rewards systems, and promotion criteria. Recently, empirical work has provided support to these claims. Cummings and Kiesler (2005) investigated research collaboration across disciplinary and university boundaries to understand how different levels of coordination predicted success. Their sample of 62 research collaboration projects supported by the US National Science Foundation in 1998
and 1999 showed that projects with principal investigators from more universities were significantly less well coordinated and reported fewer positive outcomes than projects with principal investigators from fewer universities.

Carayol and Matt (2006) analyzed the research outcome of more than a thousand faculty members of Louis Pasteur University in France and found that the size of the lab negatively affects productivity, as measured by fractional counts. According to the authors, researchers publish more when they are in smaller labs. Negative effects associated with type of partner have also been reported. Additionally, Slaughter et al. (2002) studied interview data from 37 faculty members involved in university-industry relations in the USA and found that faculty members face difficulties and tensions centered on intellectual property and restrictions on publication of research results when they work on industrial or corporate projects.

Bonaccorsi, Daraio, and Simar (2006) studied the Italian system of universities and found that collaboration with industry may improve productivity, but beyond a certain level, the compliance with industry expectations may be too demanding and deteriorate the publication profile. Landry et al. (1996) found that researchers involved in collaboration aimed mostly at producing patented and unpatented products, scientific instruments, software and artistic production were less productive than their peers.

2.1.5.3 No Relationship

Landry and Amara (1998) investigated the factors explaining why university researchers choose a given institutional structure when they engage in collaborative research projects using survey data from 1566 Canadian university researchers from the disciplines of engineering, natural sciences, and health sciences. They found a trade-off between the benefits measured in terms of additional publications, research funds, and the coordinating costs of collaborative research. Mcdowell and Smith (1992) investigated the implications of research collaboration on productivity by studying 178 economics faculty members from twenty academic institutions between 1968 and 1975. By analyzing their publications as registered by the American Economic Association’s Index of Economic Articles, they found no significant effect of collaboration on productivity (Mcdowell & Smith, 1992). Cummings and Kiesler (2005) found that projects with principal investigators in more disciplines reported as many positive outcomes (e.g., publications,
submission of patent application, forming of new partnerships, etc.) as did projects involving fewer disciplines. Duque et al. (2005), who examined the ways in which the research process differs in developed and developing areas, found that collaboration is not associated with any general increment in productivity, the latter being measured by self-reported publication counts, and the former being measured by self-reported number of individuals the respondent worked with and the proportion of projects collaborated on by the respondents.

Based on the above discussed literature review, I offer Cummings and Kiesler (2005) framework for the assessment of research outcomes. When assessing research outcomes, Cummings and Kiesler (2005) offer to look at: (1) knowledge outcomes, (2) training outcome, (3) outreach outcome, and (4) collaboration outcomes. This framework offers a comprehensive look at the different research outcomes, and it is especially appealing as it relies on self-reported outcomes, such as reported list of publication, rather than citation counts. This is especially appealing in GRAND’s case. Due to the recency of the publication produced by GRAND’s researchers, measuring their citation count is futile. This framework offers items for measuring research outcomes. Table 2.4 presents the composites proposed by Cummings and Kiesler (2005). For instance, in their paper, Cummings and Kiesler (2005) offers to measure knowledge outcomes by listing seven possible specific outcomes related to gains in new knowledge. Cummings and Kiesler (2005) groupings of items is based on definitions from the Government Performance Results Act (GPRA) of 1993, as defined by NSF, and factor analyses from a previous study of the National Science Foundation programs (Cummings & Kiesler, 2005). Furthermore, this framework is commonly used both by funding agencies and academics when assessing research outcomes (Academies, 2012).
<table>
<thead>
<tr>
<th>Research Outcome</th>
<th>Items Used for Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge Outcomes</td>
<td>Started new field or area of research; developed new model or approach in field; came up with new grant or spin-off project; submitted patent application; presented at conference or workshop; published article(s), book(s), or proceeding(s); recognized with award(s) for contribution to field(s).</td>
</tr>
<tr>
<td>Training Outcomes</td>
<td>Grad student finished thesis or dissertation; grad student/post-doc got academic job; grad student/post-doc got industry job; undergrad/grad student(s) received training; undergrad(s) went to grad school.</td>
</tr>
<tr>
<td>Outreach Outcomes</td>
<td>Formed partnership with industry; formed community relationship through research; formed collaboration with researchers, established collaboration with high school or elementary school students; established collaboration with museum or community institution; established collaboration with healthcare institution.</td>
</tr>
<tr>
<td>Collaboration Outcomes</td>
<td>Started collaborations within people in your project team that will continue beyond that scope. Started collaborating with people who are not members of my project, and this collaboration will continue in the future. Shared data with other research projects.</td>
</tr>
</tbody>
</table>

Additionally, when asked how they define research outcomes, the answers given by GRAND researchers falls entirely within the categories proposed by this framework (Hayat et al., 2011). GRAND researchers mainly addressed the following as research outcomes: publications (i.e., knowledge outcome in the proposed framework), software/hardware development (i.e., tools outcome in the proposed framework), training of graduate students/ post-doc fellows (i.e., training outcome in the proposed framework),
establishing new collaboration, and networking with other researchers (i.e., outreach outcome in the proposed framework).

Thus, using this framework will enable me to both ground my work in a large body of literature and contribute to it with my results. Furthermore, previous work has found this framework applicable to the specific context of GRAND (Hayat et al., 2011).

Based on the literature, it seems that the effects of research collaboration on research outcomes depend on a set of mediating factors. These factors can be arranged into two key groups: 1. Factors related to the researchers’ characteristics participating in collaborative enterprises, including: a) age (Smeby & Try, 2005), b) sex (Prpic, 2002), c) level of education (Bozeman, Dietz, & Gaughan, 2001), d) professional experience (Melin, 2004). 2. Factors regarding the type of partners involved, including: a) sector of institution of affiliation (Cummings & Kiesler, 2005; Etzkowitz & Leydesdorff, 2000), and b) geographic and cultural proximity (Wagner, 2005). Thus, when looking at the interplay between the social structure and change of the GRAND research network, and their interplay with research outcomes, I will control for all these factors in my analysis.

2.1.6 Summary
In this section, I proposed the following definition for research collaboration: research collaboration is a social process, taking place in a social context in which researchers interact to share meaning, develop understanding, and perform tasks to achieve a mutually-shared superordinate goal that generally produces knowledge (Sonnenwald, 2007). This definition enabled me to ground my work in the extensive body of literature dealing with epistemic communities. Thus, I am better able to address the quandary relating to the fuzzy boundaries of researcher collaboration.

The literature dealing with epistemic communities helped me rationalize the decision to not make a distinction between the different levels of collaboration (e.g., individual, departmental, university levels), but rather to look at the individual while taking into account the characteristics of the other different levels to which he is affiliated. The epistemic communities literature was also useful in identifying two key dimensions wherein I will study the actual interactions among researchers (i.e., social and epistemic)
and the importance of incorporating into my study the change factors in order to address the different needs of researchers during the different stages of their research.

In this section I also introduced the notion of a collaboratory in order to theoretically frame the historical transition into a geographically dispersed collaboration among researchers. As discussed above, a substantial portion of today’s research collaboration is taking place among geographically dispersed collaborators. My case study (GRAND) can be seen as an example for this trend. The literature dealing with collaboratories also helped me to highlight the importance of supplementing my analysis of GRAND with addressing the issue of the different functions it serves for its different researchers.

Finally, I introduce the different types of interactions I wish to look at in order to operationalize the collaboration taking place among GRAND researchers. Based on the literature I chose to focus on the following types of ties: co-authorship, acquaintanceship, advice exchange, and communication. I conclude by introducing the notion of research outcomes and list the key variables that affect the research outcomes of researchers who are involved in research collaboration. I also offer a framework for the study of these outcomes. In the method chapter, I will discuss how I will study the interplay between research collaboration and research outcomes.

2.2 Literature on Social Network Analysis

Some trace the roots of social network analysis (SNA) to Auguste Comte who coined the term sociology and wrote of the laws of social interconnection (Freeman, 2004). Others point to Emile Durkheim, who studied members of society who were united by ties that extend deeper and far beyond the short moments during which exchange was made (Field, 2003). The story of modern SNA began with Jacob Moreno (Freeman, 2004) who invented the sociogram and termed the resulting field of study, sociometry. The former refers to the dots-and-lines diagrams now common in the visual depiction of networks. The latter was the direct precursor of social network analysis (Wasserman & Faust, 1994). The other modern network pioneer was anthropologist A. R. Radcliffe-Brown whose work inspired much of the early social network scholarship (Scott, 2000). Radcliffe-Brown made considerable advances in connecting mathematics with social theory.
SNA focuses on the structure of relationships among units, whether individuals, groups, or organizations, and on the way these relationships affect processes in a network (Wellman, 1988). The links in social networks depict various kinds of relationships including collaboration, kinship, shared ideologies, economic exchange, and communication. The basic assumptions and premises underlying SNA are: (1) nodes and their actions are interdependent on their relational structure and each node is not viewed as an independent autonomous unit; (2) links between nodes are channels for transfer or flow of resources (material or non-material); (3) the network structure is an environment that provides incentives, opportunities, or constraints on individual action; and, (4) network models conceptualize structure as a lasting pattern of links between individual nodes. This structure persists as a relationship beyond the time at which it formed (Wasserman & Faust, 1994).

Social Network Analysis is particularly useful in analyzing the typically informal network that characterizes the GRAND case study. My decision to utilize the SNA methodology is driven by two main motivations. First, I believe that no formal organizational chart could ever be meaningfully constructed of such a diverse network characterized by the absence of any formal hierarchy. Second, research collaboration networks are also characterised by a lack of clear boundaries (geographical, institutional, disciplinary etc.). Previous studies (e.g., Hayat & Lyons, 2010) indicate that SNA can offer a useful framework for studying the unique characteristics of research collaboration networks.

The SNA framework is most often used to analyze the overall structure of research networks (Fenner et al., 2007). A key example of this approach can be seen in a large scale study of the collaboration patterns in the biomedical and computer science research communities (Newman, 2001). In this study Newman (2001) found that research communities constitute ‘small world’ networks where the average distance between collaborating scientists is small but varies logarithmically with community size. Only five or six steps are necessary to get from one member of a community to another in most instances. This “smallness” is thought to be critical to social cohesion and collaborative development (Barabási, 2002) and has also been observed in other studies of research networks of various sizes (e.g., Morlacchi et al., 2005). These studies use an approach
that is commonly referred to as complete network analysis. Complete network analysis is helpful for initial visualizations of the examined network and for understanding the network structure, researchers’ position in the network, and the linkages between them.

I provide a more detailed study of the structure of the GRAND research networks by looking at the network structure of each researcher. In order to do so, I conducted an ego-network analysis of all GRAND researchers. Ego-network analysis deals with the relationships that exist from the perspective of a particular node which is referred to as an “ego” (Wasserman & Faust, 1994), in our case from the point of view of a specific GRAND researcher. Thus, I offer to build on previous SNA studies of research collaboration networks by closely examining aspects relating to the structure of researchers’ ego-networks. By doing so, I am able to understand the mechanisms that effect the formation and change of the ties among researchers.

I define ego-networks as networks consisting of a single actor (ego) together with the actors they are connected to (alters) and all the links among those alters. These networks are also known as the neighbourhood networks or first order neighbourhoods of egos (Wasserman & Faust, 1994). Ego-networks have a constrained structure which delivers a benefit in data collection and analysis. Techniques that have been used to analyze ego-networks are usually based on density, connectivity (e.g., Structural Holes; Burt, 1992b) or the attributes of the alters (e.g., Homophily) or combinations of all three. In an attempt to cover these three approaches, I study ego-networks in the context of GRAND from the perspective of degree centrality, betweenness centrality, and effective network. Table 2.5 summarize the six ego-level network measures I examine. The first column in this table describes the characteristics measured. The second column describes weather the proposed ego network measure addresses the density, connectivity or attributes of the alters. The third column presents the network measure name.
### Table 2.5: Ego level network measures used in this dissertation

<table>
<thead>
<tr>
<th>Description</th>
<th>Ego level Technique</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of alters that an ego is directly connected to, weighted by strength of tie.</td>
<td>Connectivity</td>
<td>Size / degree (Burt, 1983)</td>
</tr>
<tr>
<td>The number of times that ego falls along the shortest path between two other alters in the network.</td>
<td>Connectivity</td>
<td>Betweenness (Freeman, 1977)</td>
</tr>
<tr>
<td>A measure of the importance of a node in a network. It assigns relative scores to all nodes in the network based on the principle that connections to high-scoring nodes contribute more to the score of an ego than equal connections to low-scoring nodes. In essence it measures the extent to which an ego is connected to alters that are themselves high in eigenvector centrality.</td>
<td>Connectivity / Attributes of the alters</td>
<td>Eigenvector (Bonacich, 1972)</td>
</tr>
<tr>
<td>The variety of alters with respect to relevant dimensions (e.g., sex, age, occupation, talents).</td>
<td>Attributes of the alters</td>
<td>Heterogeneity (Burt, 1983)</td>
</tr>
<tr>
<td>(Requires attribute data on all nodes in addition to relational data).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The number of alters, weighted by strength of tie, that an ego is connected to, minus a &quot;redundancy&quot; factor.</td>
<td>Connectivity / Attributes of the alters / Density</td>
<td>Effective Size (Burt 1992)</td>
</tr>
<tr>
<td>The proportion of pairs of nodes that are connected.</td>
<td>Density</td>
<td>Density (Coleman, 1988)</td>
</tr>
</tbody>
</table>
When examining the network in such a way, there is an implicit assumption that the structure of the network makes it worthy of research attention. For example, Kilduff and Tsai (2003) claim that the structure of an ego-network may have important consequences for the success or failure of the research. Furthermore, it has been proposed that together, social capital and social network analysis can yield richer theory and better insights on the operation and potential future success of a collaborative research network (Baker & Faulkner, 2009). But alongside the increased usage of social capital and social network analysis frameworks in the study of research collaboration, the structural determinant that can foster high social capital, and whether it enables productive benefits or has the potential to cause negative outcomes is a source of lively debate in the research collaboration literature (Hayat & Lyons, 2010). Yet, it is widely acceptable that social capital varies in different social network structures (Trier & Molka-Danielsen, 2013).

2.3 Literature on Social Capital

2.3.1 Defining Social Capital

There is no firm, commonly agreed upon definition of “social capital” and the particular definition adopted by a study is dependent on the discipline and level of investigation. In its simplest form, “social capital” can be defined as the social networks or connections through which one gains access to resources, including human and economic capital (Bourdieu, 1986). Pierre Bourdieu defined social capital as “the aggregate of the actual or potential resources that are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance and recognition” (Bourdieu, 1986, p. 248). In his work, Bourdieu stated that social capital has two elements: social relationships, which allow people to access resources possessed by other people, and the amount and quality of these resources (Portes, 1998).

The two sociologists often credited with developing the theoretical concept of social capital are Bourdieu and Coleman (Portes, 1998). However, they also have different views of the theory. In their extensive review of the literature on social capital and research work, Dika and Singh (2002) noted that while both Bourdieu (1986) and Coleman (1988) studied the benefits of an individual’s ties with others, they differed in many aspects. Bourdieu’s concept of social capital was mainly concerned with social
reproduction theory and the inequities that exist within social structures. He described how exchange and reciprocity within one’s networks were investments in future resources. One would invest time and energy into maintaining a contact, even if the payoff was not necessarily guaranteed in the end. This is considered a social obligation, and Bourdieu (1986) considered it to be an essential characteristic of social capital. Bourdieu (1986) also focused on the volume of social capital and posited that the size of the network of connections that one can effectively mobilize would lead to a greater amount of social capital.

On the other hand, Coleman (1988) was less interested in volume and more interested in how social capital influenced compliance with norms and values. Coleman (1988) specifically wrote about how information channels were a form of social capital. Both scholars, however, viewed social capital as network based, which is the key premise for the purpose of my dissertation. The general premise that social capital is network-based was also acknowledged by other scholars who contributed to the discussion on social capital (Burt, 1992a; Erickson, 1996; Lin, 1982; Putnam, 1995; Wellman, 1979).

While both interpretations of social capital represented by Bourdieu and Coleman are important, other researchers have argued for different definitions. Most notably, Lin (2001) developed a notion of social capital that is understood as an investment in social relations. Lin and Erickson (2008) pushed this definition a step further by defining social capital as being “rooted precisely at the juncture between individuals and their relations and is contained in the meso-level structure or in social networks” (p. 4). The relationships of individuals are the basis of social capital, and these relations further generate simultaneous consequences for individuals and for the collective.

In his seminal work Putnam (2005) indicates that whereas physical capital refers to physical objects and human capital refers to the properties of individuals, social capital refers to connections among individuals – social networks and the norms of reciprocity and trustworthiness that arise from them. In that sense social capital is closely related to what some have called civic virtue. The difference is that social capital calls attention to the fact that civic virtue is most powerful when embedded in a sense network of reciprocal social relations. A society of many virtuous but isolated individuals is not necessarily rich in social capital. In other words, interaction enables people to build
communities, to commit themselves to each other. A sense of belonging and the concrete experience of social networks (and the relationships of trust and tolerance that can be involved) can bring benefits to people.

These differing definitions demonstrate several common attributes of social capital, mainly: the individual is also referred to as an actor; the relationship between these actors can be characterized by any type of link or interaction between actors; and there is a network structure that forms because of the actors and the relationships that connect them to each other. Each of these definitions also describes an important feature of social capital: the relationships and network formations amongst the individual actors create value for the members of these social structures. Building from these common attributes, I use the following definition for social capital: Social capital is the sum of the actual and potential resources embedded within, available through, and derived from the network of relationships possessed by an individual. It comprises both the network and the assets that may be mobilized through the network (Nahapiet & Ghoshal, 1998).

Nahapiet, and Ghoshal's definition echo the general agreement that exists among scholars, social capital metaphor in which social structure is a kind of capital that can create for certain individuals an advantage in pursuing their ends. Better connected people enjoy higher returns. The disagreement regarding this statement begins when the metaphor is made concrete in terms of network mechanisms that define what it means to be "better connected." Connections are grounded in the history of the examined environment (e.g. certain people have met frequently in the past; certain people have sought out specific others; and certain people have completed exchanges with one another). There is at any moment a network, which individuals are variably connected to one another as a function of prior contact, exchange, and attendant emotions. In the next section I will discuss how the social network analysis framework can be used for the study of such network aspects. My main argument is that while the social capital literature offers extensive theoretical discussion of the resources one can access through his ties, social network analysis enables an empirical analysis of the network structure and the advantages/disadvantages such structures put forwards for resource access.

It is important to note that social capital has been found to be a key factor in the study and understanding of research collaboration (Bourdieu, 1988). Furthermore, studies that have used the social capital framework for the study of research collaboration have
highlighted the need to study both the processes by which collaborators work together and the structures that emerge from these interactional processes (Maton et al., 2006; Schensul et al., 2006). These type of studies considered the nature of the social networks that collaboration brings about, including the social networks of researchers, and more specifically the collaborative network of specific collaborative groups (e.g., within a given discipline or collaborative research project). Work on the nature and structure of research networks is part of a growing body of literature that examines the nature and characteristics of complex adaptive systems in which network structures play a fundamental role. In the majority of these studies, social network analysis is used to study the networks’ structure.

2.3.2 Social Capital and Social Network Analysis
Nahapiet and Ghoshal (1998) proposed three main dimensions for the study of how network structure can interplay with the benefits associated with greater social capital: structural, relational, and cognitive. This widely used conceptualization has also been adopted in the study of research collaboration (Robert, Dennis, & Ahuja, 2008; Trier & Molka-Danielsen, 2013), and these three dimensions guided this study of the interplay between network structure and the benefits of greater social capital (i.e., access to information and political resources, and mutual trust).

2.3.2.1 Network Structures
Building from Granovetter’s (1973) work, (Nahapiet & Ghoshal, 1998) introduced the notion of structural embeddedness. Structural embeddedness addresses the properties of the social system and of the network of relations as a whole. The term describes the configuration of linkages between people or units and refers to the overall pattern of connections between actors, that is, who you reach and how you reach them (Burt, 1992). The structural dimension captures the overall patterns of ties among the actors (i.e., the network structure), and it reflects the ‘who knows whom’ as a potential resource available to the actors (Nahapiet & Ghoshal, 1998).

The benefits of embeddedness in social network structures have been conceptualized by Burt (1992) who defines social capital as brokerage opportunities. This idea is related to the economic notion of monopoly power – those who can control information flow
across networks or groups have more power; therefore, social capital is created by a network in which people can broker connections between otherwise disconnected segments (Burt, 2002). A major concept that Burt developed is effective size of network or redundancy in networks (Burt, 1992a). As an extension of Granovetter’s hypothesis of weak ties (1973), Burt (1992a) shed light on the relationship between information flow and redundancy in networks. For instance, when an individual, James, has many strong ties with other network members, it is likely that strong ties are consequently formed among these members; however, when another individual, Robert, has mostly weak ties, the network members are less likely to be connected to each other (Granovetter, 1973). In the former case, although James’ contacts tend to know each other, the network is redundant because when James disseminates a piece of information in the network; his contacts are likely to receive it repeatedly from multiple network members. In the latter case, where Robert’s contacts mainly know Robert but not other contacts, the network is more effective because the message is passed only once between the sources and the receivers through a certain path (Burt, 1992a, 2002).

Trier and Molka-Danielsen (2013) suggest that in order to benefit from structural holes, individuals need to strive for an overview of others and their collaborations. Thus, it is not enough to simply be positioned as a structural hole, one should also know what the people he is connected to are working on. Such a preference favours building up loose, large networks that increase the chances of mediating between different dense regions. Burt (1992) also argued that network positions are especially beneficial if the linked regions have a high diversity. It is more significant to connect people from different backgrounds who are not connected to one another than different groups of people coming from the same background. A similar, and possibly more convenient, enhancement is likely to result if the researcher is actively connecting between related contacts (Hayat & Lyons, 2013).

2.3.2.2 Relationship Quality

The above two theories (Granovetter, 1973; Burt, 1992) seem to favour loose large networks over strong intimate and rich relationships. In contrast, the term "relational embeddedness" describes the kind of personal relationships people have developed with each other through a history of interactions (Granovetter, 2005). This concept focuses on
the particular relations people have, such as respect and friendship, that influence their behaviour. For example, two researchers may occupy equivalent positions in similar network configurations, but if their personal and emotional attachments to other network members differ, their actions also are likely to differ in important respects. For instance, although one actor may choose to continue working with his peers because of his attachment to them, despite logistic and financial barriers, another without such personal bonds may discount the working relationships.

A key advocate of this approach is Coleman (1988) in his social closure theory which proposes that cohesive networks that are densely connected networks, as shown in Figure 2.1, can provide greater value because the members are more tightly bound by trust, thereby leading to the assumption that members of the group will help each other by sharing knowledge and resources. The key elements of Coleman’s social closure theory are trust, expectation, and reciprocal obligation.

![Figure 2.1: Example of dense network](image)

Johanson’s (2001) approach identifies with the social closure theory by advocating that cohesive networks are able to foster trust and mutual obligation among members within a network (Coleman, 1988; Putnam, 1995). The value or benefit that social networks generate according to the social closure theory is associated with the number of reciprocal relationships that form between members in a network. As these reciprocal associations increase within the network, the network is able to provide greater social capital to its members.
In Coleman’s theory of social closure, social capital cannot be generated without trust; therefore, trust is an integral component in the development of social capital. Nooteboom (2002) also shows that trust among members of the network allows for expectation and obligation of reciprocal behaviour, which helps reduce transaction costs since the need for formal or legal contracts, monitoring, and enforcing functions are reduced by the nature of the cohesive social network. Trust is not a commodity that can be purchased, and it is not something that can be explicitly imposed upon people in any social environment; therefore, achieving favourable network conditions conducive to trust is important towards creating social capital. Social norms and organizational culture help enable the cohesive network to impose and enforce the implicit rules of expectation, and obligation (Portes, 1998). Because of the sense of security that these social norms and culture provide in a cohesive social network, members of the network have less need to feel threatened or worried that other members will not reciprocate or contribute to the community, as such, this security allows trust to develop among members within the social community. If this trust was to be abused by a particular member, either by using network resources and not reciprocating, or by some other unethical behaviour that goes against the social norms of the cohesive network, then that individual would face the consequences and no longer be welcome to participate in that social network (Ferrary, 2003).

In addition, Pescosolido and Georgianna (1989) have shown that networks that are more cohesive provide greater social support mechanisms than non-integrated networks that lack strong social cohesion among its members. The presence of these social support mechanisms provides resources that help counteract the social and psychological stresses that arise in turbulent work environments (Lin & Ensel, 1989). In addition, individuals who receive greater social support from their network increase their propensity to generate radical innovation (Monge & Contractor, 2003). These benefits provide significant value to the individual members and to the network as a whole. Thus, a supportive social network can potentially foster social capital.

Building from Coleman’s work, Monge and Contractor (2003) propose the Homophily Theory. According to the Homophily Theory, individuals prefer to interact with others that have similar properties in order to reduce psychological discomfort and
foster reciprocity. Individuals actively seek to reduce dissonance and build an emotional balance with the partners in their network (Heider, 1946). Thus, in the context of research collaboration we can expect that researchers will prefer to establish links with people of a similar culture such as found in the same country, same university or with similar personal values (Wellman, White, & Nazer, 2004). This gives rise to the expectancy that affective relational aspects, such as a focus on sympathy and positive experience, can help foster higher social capital.

Heider (1946) found that the connections people establish prior to entering a new network will largely define where they enter the network and how well they perform in the network once they are members. Correspondingly, individuals who have established a strong relationship by working together, sharing the same topics or having previously collaborated in projects, are likely to maintain these links in the collaboration network. Subsequently, Trier and Molk-Danielsen (2013) offer the maintenance of current relationships as another proponent of the relational view.

### 2.3.2.3 Cognitive Dimension

The third aspect of social capital is the cognitive dimension (Nahapiet & Ghoshal, 1998) which refers to the resources providing shared representations, interpretations, and systems of meaning among parties (Cicourel, 1973). Nahapiet and Ghoshal have identified this cluster separately because they believe “it represents an important set of assets not yet discussed in the mainstream literature on social capital” (1998: p. 244). This dimension recognizes the important role of the actual contents of the interaction, the common understandings, and concepts. Such ‘shared mental models can be developed when members have similar experiences’ (Robert et al., 2008). If such a cognitive fit exists, members can better anticipate what others need to accomplish their tasks without much communication activity. Actors have a better cognitive map (of others) helping them to organize information to accomplish tasks more effectively (Robert et al., 2008).

In the research collaboration context, the cognitive perspective suggests several theoretical drivers. The strategic actor could use knowledge about other researchers’ research domains to yield high levels of collaboration effectiveness. Further, actors may strive for sharing common ideas and high levels of ‘cognitive fit,’ This results in a topic-oriented focus when it comes to selecting collaboration partners and then working with
them. Thus, Trier and Molka-Danielsen (2013) suggest to also include the notion of feedback and discussion of work when addressing the cognitive dimension, as both the feedback and discussion can foster better exchange of contents and concepts among collaborators.

As evident in Table 2.6, I structured my framework by identifying key notions about network features, and their interplay with social capital. I categorized these notions into one of Nahapiet’s and Ghoshal’s (1998) three social capital dimensions. This approach offers an integrated view of the different dimensions that constitute individuals’ networking behaviour. It addresses the network structure, the quality of the relationships within this structure, and cognitive resources (i.e., the shared representations, interpretations, and systems of meaning among the actors). The notions I offer guided me in my data collection process, as will be discussed in Chapter 3.

Table 2.6: Framework for studying the interplay between network features, and social capital

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Network structures (i.e., network of relations as a whole)</td>
<td>Match making between related contacts</td>
</tr>
<tr>
<td></td>
<td>Building large networks with rather weak relations</td>
</tr>
<tr>
<td></td>
<td>Variety and heterogeneous backgrounds of contacts</td>
</tr>
<tr>
<td>Relationship quality (i.e., the kind of personal relationships people have developed with each other)</td>
<td>Actively building and improving relationships</td>
</tr>
<tr>
<td></td>
<td>Sympathy as a driver of selecting collaboration relationships</td>
</tr>
<tr>
<td></td>
<td>Working primarily with already existing ties</td>
</tr>
<tr>
<td>Cognitive dimension (i.e., shared representations, interpretations, and systems of meaning among the actors)</td>
<td>Learning about other researchers’ embeddedness and topics</td>
</tr>
<tr>
<td></td>
<td>Discussing and developing work with a collaborator</td>
</tr>
</tbody>
</table>
It is important to emphasize that Nahapiet and Ghoshal (1998, p. 243) noted the three dimensions of social capital theory “are, in fact, highly interrelated.”

The challenge of studying social capital in light of these three dimensions leads to an increased tendency of employing both quantitative and qualitative methods in the quest for research designs best suited for assessing social capital research networks (Hayat & Lyons, 2010). Integration of complementary methodologies is a fruitful strategy for several reasons: to enhance confirmation or corroboration of varying methodologies via triangulation; to elaborate or develop analysis, providing richer detail; and to initiate new lines of thinking through attention to surprises or paradoxes (Rossman & Wilson, 1985).

The growing body of literature on social capital has generated significant sources of SNA oriented studies that offer refined quantitative indicators for social capital. Qualitative methods, including interviews, and focus group research, have long been used to elucidate values, perceptions, attitudes, and opinions of both individuals and groups of people, providing in-depth examination of relationships and behaviours. These “social representations” can help to better encompass the nuances of social capital and the types of trust networks that exist in research networks; analysis of social representations, coupled with results from validated SNA data, can provide a broader understanding of social capital within research networks (Lin & Erickson, 2008). Similarly, qualitative methods are used in a variety of disciplines, including organizational management studies, evaluation research, and sociology, to assess the organizational dynamics of both formal and informal institutions, key aspects of structural social capital. SNA data generate a broad overview of the institutional framework that exists in a particular research network; while interviews can provide a more nuanced understanding of institutional characteristics and context that can help to better understand the meaning and context behind the relationships that exist within the network, and whether they actually foster social capital.

2.3.3 Summary

In this section I have discussed the different definitions of social capital, and I have highlighted the three main attributes of social capital as portrayed by these definitions (i.e., individual which is also referred to as an actor; relationship between different actors;
and the network structure that forms because of the actors and the relationships that connect them). Building from these fundamental attributes, I presented the definition of social capital used in this dissertation: social capital is the sum of the actual and potential resources embedded within, available through, and derived from the network of relationships possessed by an individual. It comprises both the network and the assets that may be mobilized through the network (Nahapiet & Ghoshal, 1998).

I have stressed that social capital has been found to be a key factor in the study and understanding of research collaboration (Bourdieu, 1988) and further indicated that the combination of social capital and social network can yield richer theory and better insights when studying research collaboration (Baker & Faulkner, 2009). Following which, I have explained the SNA framework, while specifically focusing on ego network analysis which is employed in this dissertation. I have also addressed the appropriateness of SNA for the study of research collaboration.

I concluded with highlighting the three dimensions that will guide me in my analysis of the relation between social network structures and social capital, while specifically focusing on how research networks structure can either foster or discourage social capital. These dimensions, proposed by Nahapiet and Ghoshal (1998), are: network structures, relationship quality, and the cognitive dimension. I’ve also stressed how these dimensions interplay with the benefits associated with greater social capital, and the importance of combining quantitative and qualitative methods in the assessment of researchers’ social capital.

2.4 Literature Review Summary

In this section I discussed the literature surrounding research collaboration and social capital which are the theoretical pillars of this dissertation. Figure 2.2 offers a depiction of the theoretical framework used in this thesis. As depicted in Figure 2.2 (Block 1), the body of literature dealing with research collaboration enables me to conceptualize the two key dimensions of collaboration (i.e., social and epistemic). The research collaboration literature has also allowed me to identify and categorize the elements that interplay with the formation and change of the social and epistemic dimensions (i.e., researcher’s characteristics as depicted by edge ‘a’, and the factors of partners involved as depicted by edge ‘b’), and it has enabled me to broadly conceptualize the key research outcomes,
specifically the research outcomes which are relevant for the study of GRAND researchers as depicted in Figure 2.2 (Block 3).

In contrast, the social capital literature has enabled me to conceptualize the three main dimensions of interplay between network features and social capital in the context of research work. As evidenced in Figure 2.2 (Block 2), I argue that researchers’ social capital should be studied according to three dimensions: network structures, relationship quality, and cognitive resources.

The social capital literature also helped me map the potential interplay between the structures of researchers’ social and epistemic ties, each of the benefits associated with high social capital (i.e., edges ‘c’, ‘d’ and ‘e’ in Figure 2.2), and researchers’ research outcomes (i.e., edges ‘f’, ‘g’, and ‘h’ in Figure 2.2). My review of the literature also highlighted the inconsistency of the findings trying to bridge researcher’s ties structure with their research outcomes, a gap addressed in this dissertation. In the next chapter, I will discuss how I operationalize researcher’s social and epistemic ties (and their change over time) which addresses my first two research questions:

RQ #1. Which types of structures can be detected in the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers?

RQ #2. What collaboration changes can be evinced from the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers?

I will discuss how I operationalize research outcomes and test the interplay between these outcomes and social and epistemic ties (and their change) as depicted by edge ‘i’ in Figure 2.2, thus addressing my third research question:

RQ #3: How do the structural features of the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers, and the change of these features over time interplay with the researchers’ research outcomes?
Finally, I will discuss how I relied on Nahapiet & Ghoshal’s (1998) proposed three main dimensions (structural, relational, and cognitive resources) for the study of social capital to frame my usage of the social capital theory when examining the interplay between the structural features of the social and epistemic ties and their change over time (i.e., the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers), and their interplay with the researchers’ research outcomes (as depicted by “Block 2” in Figure 2.2) which addresses my fourth research question:

RQ #4: How can the social capital literature be used to interpret the interplay between research outcomes and the structural features of the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers, as well as the changes of these features over time?

Figure 2.2: Theoretical framework
Chapter 3: Methods

This section describes the methods used in this dissertation. It will discuss the GRAND case study, the data collection procedures, and the data instruments use. Following this, a discussion of the data analysis is offered and the limitations of the methodology are examined.

3.1 The GRAND Case Study

GRAND is part of the Networks of Centres of Excellence (NCE) program, a key part of the Canadian government’s strategy to encourage knowledge creation and innovation (Atkinson-Grosjean, 2006), specifically in support of research that fosters socially and commercially relevant research (Atkinson-Grosjean, 2006). It funds multidisciplinary and nation-wide research collaborations as well as multi-sectoral partnerships between academia, industry, government, and non-profit organizations.

GRAND was formed at the beginning of 2010 to serve as a catalyst for research and innovation in the field of new media and information technologies. Its mandate is to encourage innovation in information-intensive industries, increase Canada’s capacity to deploy ICT infrastructure, and contribute to the development of its knowledge-based economy (GRAND, 2009). As with all NCEs, GRAND was aimed at creating a flexible networked organizational form based less on formal ties and more on boundary-spanning flows and permeable boundaries (Wellman, Dimitrova, Hayat, & Mo, 2014). It is a loosely connected network of academics, government and industry decision-makers and researchers, NGOs, and other stakeholders that are united by shared research interests.

The recruitment and structure of GRAND is intended to encourage multidisciplinary, multi-university, and inter-provincial collaboration. The diversity of researchers’ disciplines, institute affiliations, and locations creates the precondition for boundary-spanning flows (Wellman et al., 2014). Moreover, GRAND’s formal rules and procedures aim to create links across projects, organizations, disciplines, and locations. For example, as previously mentioned, each project should contain three or more researchers from three or more universities. Furthermore, every Principal Network Investigators (PNI) in GRAND must be in three or more projects. Collaborating Network Investigators (CNI) are also encouraged to participate in more than one project.
When launched in 2010 GRAND consisted of 144 researchers (88 CNIs and 56 PNIs), and in 2013, GRAND consisted of 208 researchers (133 CNIs and 69 PNIs). These researchers are affiliated with 26 institutions across Canada and work on 34 different research projects divided into five themes: New Media Challenges and Opportunities; Games and Interactive Simulation; Animation, Graphics and Imaging; Social, Legal, Economic and Cultural Perspectives; and Enabling Technologies and Methodologies.

GRAND members are expected to work in a collaborative fashion across different projects (and across themes), thereby pooling resources and information. Furthermore, GRAND holds an annual conference in which GRAND researchers meet in official project meetings, showcasing posters and demos based on their research. Furthermore, each project presents a summary of the work conducted by its members in the preceding year.

It is also important to note that GRAND is funded for a limited time period (5 years that may be renewed). In short, while membership in GRAND is more formal than participation in informal research networks (such as discussion groups), both the project and network boundaries are flexible and temporary.

The composition of the network is also diverse in terms of disciplinary background, ranging from Computer Science and Engineering to Art and Design, from Information Science and Journalism to Social Sciences and Humanities. As can be seen in Figure 3.1, according to GRAND administrative records, GRAND’s 208 researchers are divided as follows: 96 come from a computer science background, 27 come from an information science background, 26 come from arts and technology background, 15 come from a social science background, 13 come from a humanities background, 13 come from a professional program background (e.g., journalism), 12 come from an engineering background, and 6 come from a medicine background.
Table 3.1 presents the distribution of GRAND researchers according to geographic location. Almost two thirds (64%) of GRAND researchers come from Ontario and British Columbia, and the rest are from Quebec, Alberta, Manitoba, Saskatchewan, Nova Scotia, and other (USA and New Zealand).

Table 3.1: GRAND members by province

<table>
<thead>
<tr>
<th>Province</th>
<th>Number of GRAND members*</th>
<th>% of GRAND members</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ontario</td>
<td>78</td>
<td>38%</td>
</tr>
<tr>
<td>Quebec</td>
<td>33</td>
<td>16%</td>
</tr>
<tr>
<td>British Columbia</td>
<td>55</td>
<td>26%</td>
</tr>
<tr>
<td>Alberta</td>
<td>27</td>
<td>13%</td>
</tr>
<tr>
<td>Manitoba</td>
<td>3</td>
<td>1%</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>4</td>
<td>2%</td>
</tr>
<tr>
<td>Nova Scotia</td>
<td>6</td>
<td>3%</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>208</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

*Taken from GRAND administrative records
GRAND is administratively divided into two groups, Principal Network Investigators (PNI) and Collaborating Network Investigators (CNI). PNIs are usually referred to as project leader (or co-leader), and they have direct responsibility for completion of a funded project, directing the research and reporting directly to the GRAND board of directors. The PNIs are typically the ones who either conceived of the investigation, or selected by a team to obtain the best strategic advantage for the project (Atkinson-Grosjean, 2006). CNIs are usually the researchers who are conducting the research work and are less involved in managerial aspects of the project. Lastly, according to GRAND records, GRAND has 148 (71%) male researchers, and 60 (29%) female researchers.

3.2 Data Instruments

In order to answer the four research questions, data was collected through: (1) two online surveys of GRAND researchers, (2) an outcomes survey of GRAND researchers, (3) the GRAND online forum, and (4) semi-structured interviews.

3.2.1 Online Surveys

In order to collect data about the structure and change of the communication, acquaintanceship, and advice exchange networks of GRAND members, I used data collected through two online surveys (this data was then used to address research questions 1, 2, 3, and 4). The surveys were aimed at collecting general demographic data about the researchers (e.g., age, gender, discipline, affiliation, etc.) and data on the social and professional relations among GRAND members.

The two online surveys were circulated among GRAND members by the NAVEL team. All GRAND members were asked to participate in both surveys via an invitation e-mail. Respondents were given a roster of GRAND members and asked to identify GRAND members with whom they collaborate, exchange advice and ideas, network, and are friends, and whom do they just know. In addition, the survey asked about the use of communication media such as landline phones, mobile phones, emails, or instant messages (see Appendix A for the complete survey).
In order to make the completion of the survey easier, the respondents were first asked to identify all of their acquaintances (out of the entire population of GRAND researchers). In the remaining sections of the survey dealing with communication patterns and advice exchange the respondents were asked to provide information about those individuals that they identified as acquaintances. Furthermore, in order to make it easier for the respondents to select their acquaintances, they received a suggested list of people they ‘might know’ based on the projects in which they are involved (i.e., a researcher working on the NADEL project gets a list of the other researchers who are part of NADEL). Respondents were then able to easily add or remove people to this suggested list. Furthermore, in order to make the completion of the communication section easier, the survey contained a ‘hot list’ feature that enabled the respondents to mark a group of researchers they communicate with using the same media (rather than repeatedly filling the same media for each of these researchers separately). This approach for collecting data on the social and professional relations among individuals, starting with a roster of members, is an established procedure in social network analysis surveys (Wasserman & Faust, 1994).

As GRAND members are dispersed across the country, an online survey provided a secure and convenient access platform for all GRAND members. Using the open source software ‘Lime Survey’ (Demiaux, 2010) the first round of the survey was conducted between September and November 2010, a few months after GRAND received formal approval. All GRAND members at that time (144) were invited via e-mail to participate, and we followed Schaefer and Dillman’s (1998) suggestions for increasing survey responses by employing emails and phone call reminders. A total 101 respondents completed the survey (respondent rate of 70%). The second round of the survey was conducted between September 2012 and March 2013. With the purpose of improving the response rate, the survey was re-programmed and posted on the GRAND website (the survey coding was done by Prof. Eleni Stroulia and PhD student Denis Golovan). Although the format of the second survey was slightly changed as a result, the same questions were used to maintain consistency between the data obtained in both survey rounds. As the survey respondents are identifiable (i.e., the data included their full name), the second survey provides longitudinal data and makes it possible to examine the change
of the GRAND network over time. All GRAND members were invited via e-mail to participate in the second survey (as additional researchers joined GRAND at this point there were 208 GRAND members), and 124 of them completed the survey (respondent rate of 60%). The data gathered by both online surveys enabled the construction of longitudinal data for 142 researchers. This was done using the reconstruction imputation method (Stork & Richards, 1992). This procedure is discussed in section 4.1: Sample description. The invitation e-mail and consent form for both surveys are available in Appendix B.

3.2.2 GRAND Forum

Another important source for data collection was the GRAND online forum. The purpose of the GRAND forum is to provide a central repository for up-to-date information about the GRAND community, as well as on activities and events of interest to GRAND members. In addition, the GRAND forum provides the means to “collect and disseminate content as necessary for the collaborative and reporting activities of the network, and analysis tools through which to examine the evolution of the network community” (GRAND, 2009).

The forum contains extensive content about the research conducted by GRAND members, this includes: theme-description pages; main project pages; and researchers’ pages. The researchers’ pages on the GRAND forum include, among other things, the researchers’ publications (self-reported) that were produced during their work in GRAND (Forum, 2012). GRAND researchers are requested to regularly update their GRAND forum page. With the help of Prof. Eleni Stroulia and PhD student Denis Golovan, the information on the researchers’ publications was extracted from the forum and then used to construct the ego co-authorship networks of GRAND members. This data was then used to address research questions 1, 2, 3, and 4.

3.2.3 Outcomes Survey

During the 2013 GRAND annual meeting, the NAVEL team distributed a paper-based questionnaire (survey) aimed at evaluating the research outcomes that GRAND researchers had generated during their involvement in GRAND. The NAVEL team also sent an online version of the survey to the GRAND members who were unable to attend the annual meeting. The survey was based on the Cummings and Kiesler (2005)
framework (see Chapter 2.1.5) that looks at the following self reported research outcomes: (1) knowledge outcome; (2) training outcome; (3) outreach outcome; and (4) collaboration outcomes. In total, all 208 GRAND members were invited to complete the survey, and 114 of them did so (response rate of 55%). Out of these 114, 101 researchers also completed the two online surveys.

### 3.2.4 Semi Structured Interviews

In order to answer my fourth research question regarding how the social capital literature can help in interpreting the way features of structure and change of the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers interplay with the researchers’ research outcomes, a qualitative analysis of data from semi-structured interviews with 50 GRAND members that was conducted as part of my involvement in NAVEl was used. These interviews were aimed at gaining a deeper understanding of the researchers’ perceptions relating to their involvement in GRAND. In order to get as broad a perspective as possible diverse samples were identified, ensuring representation of people from different provinces (see Figure 3.2), disciplines (see Figure 3.4), formal positions within GRAND (28 of the interviewees were CNIs and 22 were PNIs), and gender (32 of the interviewees were men, and 12 were women).

![Figure 3.2: Provinces from which the respondents are coming](image)

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61
Prior to the interviews, a pre-interview file was prepared for each interviewee and used to identify probing questions. I studied the file pertaining to each interviewer prior to conducting the interview, and the file included:

1. Four graphs depicting the interviewee’s communication, advice, acquaintanceship and co-authorship ego networks. Each node in these networks indicated the name of the researcher as well as his/her institutional affiliation and disciplinary background (this data was prepared based on the first online survey and the GRAND online forum data).

2. The network measures of the interviewee, i.e., degree centrality, betweenness centrality, eigenvector centrality, heterogeneity measure, network effective size, and network density (this data was prepared based on the first online survey and the GRAND online forum data).

3. Names and descriptions of the project(s) in which the researcher is involved (this data was prepared based on the GRAND online forum data).

In addition to the probing questions identified from information in the pre-interview file for each interviewee, a general script was used to ask questions about how the interviewee got involved in GRAND, their work with other GRAND members, their networking practices and how they manage their relationships with other GRAND members, their coordination and communication practices, and research outcomes.
These topics were chosen as they were found to be central for the understanding of daily work of researchers within NCEs in general (Atkinson-Grosjean, 2006), and specifically in GRAND (Wellman et al., 2014).

The interview questions provided the general structure for the interview, whereas the specific probing questions were especially helpful for addressing the specific topics discussed by the interviewee. While probing, I specifically tried to address the three dimensions discussed by Nahapiet and Ghoshal (1998) in their suggested framework for studying the interplay between network features and social capital (see section 2.3.2): 1) the structural dimension; 2) the relational dimension; 3) the cognitive dimension. As the interview neared conclusion, I specifically tried to probe the interviewees about the different types of research outcomes they have produced as part of their involvement in GRAND and their perceptions of how their involvement in GRAND either fostered or discouraged these outcomes.

The vast majority of the interviews (46) were carried out face-to-face during four GRAND annual meetings: the GRAND 2010 annual meeting that took place in Ottawa, Canada on June 2-4; the GRAND 2011 annual meeting that took place in Vancouver, Canada on May 12-14; the GRAND 2012 annual meeting that took place in Montréal, Canada on May 2-4; and the GRAND 2013 annual meeting that took place in Toronto, Canada on May 14-16. The remaining four interviews were conducted using a video Skype call which allowed for conducting an interview that resembled a face-to-face interview as much as possible, given the distance constraints. Interviews lasted an average of 47 minutes, with a range of 32 to 75 minutes, depending upon the extent of the interviewee’s participation in GRAND and his/her time constraints.

The data gathered in the interviews were transcribed and analysed thematically, using the Nvivo software (Bringer, Johnston, & Brackenridge, 2004) while specifically focusing on:

1. Nahapiet and Ghoshal’s (1998) dimensions of social capital, i.e., network structures, relationship quality, and the cognitive dimension.

2. The four dimensions of research outcome (Cummings & Kiesler, 2005) (see section 2.1.5).
In order to ensure informant anonymity when discussing what was said in the interviews, I use pseudonyms in the reminder of this dissertation. Furthermore, due to the small size of GRAND I did not provide detailed information on the background of each interviewee as when combined with the information provided in the quotes such information could be seen as an invasion of privacy by leading to the re-identification of interviewees.

3.2.5 Variables in the Study

This section discusses the quantitative variables used in this dissertation. First the variables pertaining to the interplays addressed in research questions 1, 2, 3 will be discussed (advice exchange, acquaintanceship, communication, co-authorship, and research outcome indexes), then the control variables will be discussed.

**Advice exchange**: For each GRAND researcher (R), there is a binary and directed tie with other GRAND researchers to whom R gives advice, and from whom R receives advice (not necessarily related to GRAND). The advice exchange data was collected from the researchers’ answers to section 3 of the first and second online surveys.

**Acquaintanceship**: There is a binary and directed tie between R and each researcher in GRAND whom R knows. The acquaintanceship data was collected from the researchers’ answers to section 2 of the first and second online surveys.

**Communication**: The weighted and directed communication ties among GRAND researchers indicate both the media used and the frequency in which it is being used for communication. Each GRAND researcher was asked to indicate the top three media they used for communicating with each other person in GRAND (i.e., in person, email, mobile phone – one-to-one, texting, landline phone – one-to-one, voice over IP (e.g., Skype, Google Talk) – one-to-one, audio or/and video-conferencing, online forum, social networking sites (e.g., LinkedIn, Facebook), instant messaging or chat (e.g., MSN Messenger, Skype), or other).

Frequency of communication was also gathered for each of the three media reported by the respondents who were asked to report how often they use each of the top three media (i.e., several times a day, about daily, weekly, monthly, a few times a year, yearly, less than once a year). The communication media and frequency data was collected from the researchers’ answers to section 5 of the first and second online surveys.
Co-authorship: This weighted and non-directed relation measures each GRAND researcher’s authorship patterns with other GRAND members. The ties that exist among an author and his/her immediate neighbors (i.e., co-authors) as well as the ties that exist among these neighbors were analyzed. Each link indicates that a co-authorship tie exists among the two adjunct nodes. The co-authorship data was gathered from the GRAND forum for each publication that was reported by GRAND members from 2010 to 2013 including title, year, and authors’ names. The data extracted was imported into a Microsoft Access database.

Research outcome indexes: In the research outcome survey, the respondents were asked to rate how they assess their performance in each of the four outcomes (knowledge outcome; training outcome; outreach outcome; and collaboration outcomes) using a Likert scale ranging from 1 (Very low outcomes), to 7 (Very high outcomes). A list of potential research outcomes was included in the survey in order to help respondents to assess their performance, (e.g., for knowledge outcomes); it indicated the following: “if you developed/achieved (1) new model or approach in field; (2) new grant or spin-off project; (3) patent application; (4) conference presentation; (5) new publications; (6) awards for contribution to fields.” These potential research outcomes were aimed at helping the researchers to evaluate their own research outcomes and then select the appropriate score on the Likert scale. See Appendix C for the full survey.

Control variables: Apart from the aforementioned relational variables (tie-level variables), individual-level information was collected that was identified as significant control variables from the literature review. These variables include: the geographical location of the institute to which the researcher is affiliated, gender (men and women); academic status (Assistant Professor, Associate Professor, Professor, and not relevant); position within GRAND (CNI, PNI); and age. All these variables were gathered in section 1 of the online surveys. Additionally, based on GRAND administrative records, the disciplinary background of each researcher (computer science, information science, arts and technology, social science, humanities, professional program, engineering, and medicine) was gathered.

Table 3.2 summarizes the variables examined in this study, and the data source used to measure them.
Table 3.2: Variables examined in this study, and the data source used to measure them

<table>
<thead>
<tr>
<th>Variable</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advice exchange</td>
<td>The advice exchange data was collected from the researchers’ answers to section 3 of the first and second online surveys.</td>
</tr>
<tr>
<td>Acquaintanceship</td>
<td>The acquaintanceship data was collected from the researchers’ answers to section 2 of the first and second online surveys.</td>
</tr>
<tr>
<td>Communication</td>
<td>The communication media and frequency data was collected from the researchers’ answers to section 5 of the first and second online surveys.</td>
</tr>
<tr>
<td>Co-authorship</td>
<td>The co-authorship data was gathered from the GRAND forum.</td>
</tr>
<tr>
<td>Research outcome indexes</td>
<td>The research outcome data was gathered from the research outcome survey.</td>
</tr>
<tr>
<td>(knowledge; training; outreach; and collaboration)</td>
<td></td>
</tr>
<tr>
<td>Control variables</td>
<td>The control variables were gathered in section 1 of the first and second online surveys, and from the GRAND administrative records.</td>
</tr>
</tbody>
</table>

3.3 Quantitative Data Analysis

The social network analysis of the advice exchange, acquaintanceship, communication, and co-authorship data was conducted using ORA (Carley, Pfeffer, Reminga, Storrick, & Columbus, 2012) and UCINET (Borgatti, Everett, & Freeman, 2002)social network analysis software. After coding the network data according to the software’s format requirements, I used both software packages to compute and export the
following network properties for each GRAND member: degree centrality, betweenness centrality, eigenvector centrality, heterogeneity, effective network size, and density measures for each researcher network (see Table 3.3). UCINET also produced visual representations of networks, some of which are presented in figures in Chapter 4. NetDraw (Borgatti, 2002) was used to create visualizations of the communication, advice, and acquaintanceship ego networks and is presented in figures in Chapter 4.

It is important to remember that I am studying four different ego-networks for each GRAND member (co-authorship, communication, acquaintanceship, and advice exchange). Thus, each of the network measures presented in Table 3.3 was calculated for the four examined networks, generating 24 network measures (four different networks times six measures for each of the networks). Furthermore, as I am also interested in the changes of the network over time, I look at the changes in these measures over time (i.e., the network measures calculated based on the results of the first survey as compared to the network measures calculated based on the results of the second survey). Thus, I also have 24 network measures representing the changes of the examined network measures.

I exported the network data into SPSS along with the research outcome indices data and control variables. By doing so, I was able to construct one consistent data set containing all of my quantitative data about GRAND members. Using the 24 network measures produced from the first online survey, I was able to answer my first research question “which types of structures can be detected in the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers?” prior to comparing the 24 network measures (measured by the first and second online surveys). To compare scores across networks, I utilized repeated measures t-tests in SPSS. Thus, I was able to answer my second research question: what collaboration changes can be evinced from the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers?

I also successfully conducted correlation analysis between 1) 24 network measures, and the 24 network measures representing the network changes and 2) the four outcome indices: knowledge outcome; training outcome; outreach outcome; and collaboration outcomes (while controlling for my control variables). The correlation analysis used at this stage of the research was the most appropriate strategy to uncover the multiple
unknown dependencies between the different network measures and the research outcome indices. As my data on research outcome were collected based on an ordinal Likert-scale and Kolmogorov–Smirnov tests indicated the absence of normal distribution, I applied a statistical test, using ordinary least squares regression.
<table>
<thead>
<tr>
<th>Name</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size / degree centrality</td>
<td>Degree centrality of a node $v$ is calculated as (Wasserman and Faust, 1994): $C_D(v) = \frac{d(n_i)}{g-1}$</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Where $d(n_i)$ is the number of researchers connected to researcher $i$ and $g$ is the number of GRAND members.</td>
</tr>
<tr>
<td>Betweenness centrality</td>
<td>Betweenness centrality for a node $v$ with is calculated as (Wasserman and Faust, 1994): $c_B(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}$</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Where $\sigma_{st}$ is the total number of shortest paths from node $s$ to node $t$ and $\sigma_{st}(v)$ is the number of those paths that pass through $v$</td>
</tr>
<tr>
<td>Eigenvector centrality</td>
<td>Eigenvector centrality for a node $v$ is calculated as (Bonacich, 1972): $\lambda \nu = A \nu$</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Where $A$ is the adjacency matrix of the graph, $\lambda$ is a constant (the eigenvalue), and $\nu$ is the eigenvector. The equation lends itself to the interpretation that a node that has a high eigenvector score is one that is adjacent to nodes that are themselves high scorers.</td>
</tr>
<tr>
<td>Heterogeneity</td>
<td>Heterogeneity is calculated as (Blau, 1977): $H_B = \sum p_i^2$</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Where $p_i$ is the proportion of group members in a category $i$ for each different categories of the feature across all groups. If a group is homogeneous with regard to the feature in question (i.e., if all group members have the same nationalitiy, the Blau Index of the group for nationality is 0. If all members of the group have a different nationality, the Blau Index of that group for nationality approaches 1).</td>
</tr>
<tr>
<td>Effective network size</td>
<td>Effective network size is calculated as (Burt, 1992b): $\Sigma_i [1 - \Sigma_k p_{tk} m_{jk}]$</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Where $m_{jk}$ is $j$’s interaction with $k$ divided by $j$’s strongest relations with anyone. $p_{tk}$ is the proportion of $i$’s energy invested in relation with $k$.</td>
</tr>
<tr>
<td>Density</td>
<td>Density is calculated as (Coleman &amp; Moré, 1983): $D = \frac{2</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The maximum number of edges is $\frac{1}{2}</td>
</tr>
</tbody>
</table>
3.4 Qualitative Data Analysis

The qualitative data analyzed consisted of transcripts from the semi-structured interviews transcribed by three transcribers. After receiving the transcripts, I reviewed each transcript for accuracy and fidelity to the audio recordings. Completed transcripts were imported into NVivo 9 research software, a particular type of computer assisted qualitative data analysis software that allows the researcher to effectively and efficiently manage, organize, and analyze data (Bringer, Johnston & Brackenridge, 2004) by making these tasks less time consuming and facilitating more meaningful interaction with the data.

To reduce the data into a more manageable and recallable form, I began to code and sort the data based on predetermined themes initially identified in the literature review (deductive analysis) and then began to code and sort the data based on new themes that arose as I examined the data (inductive analysis). Coding is defined as the act of identifying similar data units and assigning an identification code to represent concepts, categories or themes (LeCompte & Schensul, 2010). NVivo utilizes nodes—containers for specific topics or references—to assist the researcher in his/her coding efforts. These codes become the terms and themes by which the researcher begins to sort through and clean up the data (Campbell Galman, 2007).

The five primary themes that arose during the data management and the initial sorting or coding process are displayed in Figure 3.4, along with a description of each node to ensure that data being assigned to each node remained consistent throughout the study.

![Figure 3.4: NVivo – primary themes](image)

An analysis of the data occurred next. As mentioned briefly to this point, I proceeded to conduct two forms of coding and analysis utilizing NVivo and employing these node
structures. The first form of data analysis is referred to as deductive analysis. The second form of data analysis is referred to as inductive analysis. Deductive analysis is the act of organizing data based on predetermined themes, concepts, and theories derived from literature reviews and research questions (Campbell Galman, 2007). For example, I knew from the beginning of the research study that one of the goals of the research study would be to collect data related to social networks and of social capital dimensions, as these were elements of outlined in my literature review and included in my research questions. The initial literature derived node tree, presented in Figure 3.4, served only as a starting point and was significantly expanded and refined throughout the process of data analysis. Nonetheless, it served as an important starting place in the beginning stages of data analysis.

Inductive analysis—the act of coding the data based on new themes generated through an examination of the data—was conducted as well (LeCompte & Schensul, 2010). This process allowed me to discover through analysis that a particular theme or node fits better into a new or emerging theme instead of an existing one (Heit & Rubinstein, 1994). For example, I found ample references to different levels of collaboration as being a central context for the understanding of researchers’ social capital. This resulted in new nodes being added to the initial node structure (see example below in Figure 3.5). This process of inductive analysis enabled the identification of new insights not included in the literature; it allowed me to take into account ideas that may not have been initially considered. The discussion presented in section 6.2.4 of this dissertation about complementary and integrative research collaboration is one of the results of this process.

I began to sort through the data and assign it to different nodes. NVivo’s analysis capabilities allowed me to catalogue data into hierarchical node structures, moving from a general theme to more specific categories, and vice versa. As previously mentioned, each node acts as a container that houses the data that the researcher chooses to place in it or assign to it. The highest data reference or node in a hierarchy is referred to as a parent node; the nodes contained under the parent node are referred to as child nodes. An example of this is provided in Figure 3.5.
The parent node located at the top of the node structure in Figure 3.5 is social capital dimensions, a prominent theme identified in the literature review and related to my fourth research question. Located directly under the parent node is a child node entitled the structural dimension of social capital, again, another prominent element of social capital discussed in the literature. Secondary, and more specific child nodes, exist under the structural dimension of social capital node: brokerage and structural holes, closure, heterogeneity and homogeneity, large network focus, and ties to well connected researchers.

In other words, Figure 3.5 shows that there are three main dimensions for the study of social capital. One of these dimensions is the structural dimension of social capital. The structural dimension of social capital was discovered in the interview data as being affected by brokerage and structural holes, closure, heterogeneity and homogeneity, large network focus, and ties to well connected researchers. Assigned specifically to each of these child nodes is the actual data I obtained through the semi-structured interviews. For instance, if I read through an interview with a GRAND PNI transcript and noted a quote about or reference to heterogeneity within his/her communication network, then that particular quote or reference was placed within that specific container or assigned to that
specific child node. Coding continued until I felt confident that all data had been thoroughly considered.

When analyzing the coded data, I did not merely inspect data to label interesting points, but analyzed them in a systematic matter through an iterative process. I made comparisons between text segments and across participants, to discern conceptual similarities and differences and to discover patterns. I also interconnected text segments and codes to produce relations or cross-settings of categories. I travelled back and forth between each piece of data and an emerging narrative describing the construction of research collaboration among GRAND researchers evolved. In fact, I developed a narrative to unify events into a single story. In doing so, I was able to find out which aspects suggested by the literature were grounded in evidence produced by my interviews, and which new aspects emerged.

My understanding of collaboration among GRAND researchers emerged through a constant interplay between my act of writing and what I read in the interview transcriptions. Writing was part of “getting close to the data,” because constructing a plot through written text and the use of data sources and memos helped illuminate important patterns that could otherwise go unnoticed. The data analysis process is outlined in Table 3.4.
Table 3.4: Interview data analysis process

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transcription of interviews</td>
<td>Recording interview data in Microsoft Word.</td>
</tr>
<tr>
<td>Reading of transcriptions</td>
<td>Achieving a sense of the whole, and selecting smaller data sets to work on.</td>
</tr>
<tr>
<td>Limiting the data sets</td>
<td>Selecting relevant parts of the transcriptions.</td>
</tr>
<tr>
<td>Creating nodes in Nvivo 9 and coding segments from transcriptions</td>
<td>Creating a simple database for categorizing data and writing memos.</td>
</tr>
<tr>
<td>Segmenting narratives into relevant and meaningful units according to: dimensions of social capital.</td>
<td>Thorough reading of sentence-by-sentence and word-by-word to identify dimensions of social capital, benefits associated with social capital, and research outcomes within the transcriptions.</td>
</tr>
<tr>
<td>Using Nvivo 9 sorting function for sorting data by dimensions of social capital codes, benefits associated with social capital codes, and research outcome codes. Gathering groups of statements in a sequence that allows the identification of patterns.</td>
<td>Highlighting signs for interplay between (a) network structure and social capital, (b) social capital and research outcomes, in the setting under study. Writing memos.</td>
</tr>
<tr>
<td>Constant comparison of the statements.</td>
<td>Making comparisons across entries and participants to identify conceptual similarities and patterns. Interconnection of text segments and codes to produce relations or cross-settings of categories.</td>
</tr>
<tr>
<td>Consolidating data and memos in a narrative into a coherent argument.</td>
<td>Developing a narrative to unify relevant statements into a single story. Identifying how, and if, the social capital literature can help interpreting the interplays addressed by research question 4.</td>
</tr>
</tbody>
</table>

The main goal of the analysis described in Table 3.4 was to use the data to reconstruct the interviews given by GRAND members in a way that will address research question 4. These findings will be presented in Chapter 5.
3.5 Limitations

Little academic work has been done on the issues of validity, reliability, and measurement error in social network data (Wasserman & Faust, 1994). One challenge in assessing the value of such data is that it is difficult to ascertain whether the reported networks are the same as the ‘true’ or ‘actual’ networks (Holland & Leinhard, 1973). Knowledge of the actual network is usually very difficult to obtain. The literature does offer recommendations for how to best use name generators and survey design tools to maximize informant accuracy (Marsden, 2005). Lessons learned from these recommendations were incorporated in the survey portion of the study. Also, to increase the degree of trust in the network data collected, several steps were taken which are described in detail in section 3.2 of this chapter.

An additional limitation is that any attempt to measure social capital can be challenging. Social capital is notoriously difficult to locate and measure, as it consists not of a quantifiable resource, but of a series of processes and interactions (Bankston III & Zhou, 2002). Furthermore, some of these processes and interactions can appear to positively impact social capital on the surface, but might actually be a liability. In addition, different forms of social capital and social networks may prove beneficial to some groups of people but not to others (Bankston & Zhou, 2002). This limitation was addressed by including semi-structured interviews with a diverse sample of GRAND researchers. The interviews were designed to elicit more information about how the processes and interactions impact social capital and in what ways. Furthermore, the pre-interview files and the probing questions that were constructed based on these files helped in better understanding the processes and interactions that could lead to greater social capital, and how the interviewees perceive these processes and interactions.

Another important limitation of my method arises from the fact that I was a participatory researcher. I served as an ‘instrument’ for data collection and data analysis, and I was also a member of GRAND (through my involvement in the NAVEL team as a doctoral student). This involvement could potentially lead to biases that can impact my work; rather than trying to eliminate these biases, it was important to identify them and monitor how they shaped the collection and interpretation of data (Merriam, 2002). I reflect on these aspects throughout chapters 4 (results) and 5 (discussion).
Lastly, this dissertation was restricted in scope to a specific research network, GRAND. Therefore, the analysis did not focus on the causal relationships that could have been generalized to various populations of researchers, settings, and times. Rather, I focused on gaining a deeper understanding of the structure and change of one research network and its interplay with research outcomes. As will be discussed in chapter 6, I hope that a research study of broader scope can be undertaken in the future to further explore the generalizability of the themes and findings presented in this dissertation.
Chapter 4: Findings - Network Topology, Change, and Research Outcomes

This chapter is divided into three major sections to address my first three research questions. The first section describes the actors, ties, and the structure of the GRAND researchers’ ego-network structure (RQ1). The second section examines how the network structure changes over a four year period (RQ2). The third section studies the interplay between the structure and changes of the GRAND researchers’ ego-network and their research outcomes (RQ3).

4.1 Sample Description

Ideally, my analysis would have been based on complete data (i.e., my dataset would contain information on all GRAND researchers and all the ties that connect them). However, data analysis in social sciences is often hampered by non-response. In the analysis of social networks, non-response results in missing network information. This means that ties from one actor to another are not observed and/or information on actor attributes is not available (Huisman & Steglich, 2008). It is often argued that network analysis is less forgiving of missing data than other forms of research. Nevertheless, recent studies have supported the robustness of network measures under conditions of imperfect data (Borgatti, Carley, & Krackhardt, 2006). This is especially the case when the conducted analysis is an ego-network analysis in which all ties of a given type connected to a sampled node are collected (Borgatti et al., 2006).

In this dissertation, I rely on a longitudinal network study (i.e., two online surveys in two different points in time). In such a situation, it is permitted that some of the studied population only completed either the first survey or the second survey. Thus, I need to address that in my discussion of the sample used in my analysis, especially for the network data collected through these surveys (i.e., acquaintanceship, advice exchange and communication).

Figure 4.1, taken from Huismana and Steglich’s paper (2008), shows the socio-matrices of a network at two observations moments. As the rows and columns of the matrices represent the actors, the subsets of actors distinguish mutually exclusive subsets of rows and columns. The observed missingness patterns consist of four set of actors: A1,
actors observed at both time points, A2, actors observed at T1 and missing at T2, A3, actors missing at T1 and observed at T2, and A4, actors missing at both time points. In my analysis I include the following groups of actors: A1 and A2 while omitting groups A3 and A4. As group A4 contained no data about the users in both time slots, it is clear why I was not able to address these actors in my analysis. The reason for omitting group A3 is that I did not have baseline data (i.e., observation in T1), thus making any analysis of the changes between T1 and T2 prone to mistakes.

I have turned to use the reconstruction imputation method (Stork & Richards, 1992) to impute incoming ties for missing outgoing ties. Based on this method, using the data gathered in the first online survey, I was able to construct the ego networks of 144 GRAND researchers. Based on the data gathered in the second online survey, I was able to construct the ego networks of 178 GRAND researchers (for full discussion of the procedure see (Stork & Richards, 1992)).

My analysis requires the ego networks of the studied researchers, as reflected in the results of both the first and second online survey. The overlap between the data in these two surveys consists of 142 researchers for which I was able to construct an ego networks in both points in time. I also had the longitudinal co-authorship data (collected from GRAND forum) and control variables (as collected through the social network survey).
for these 142 researchers. Out of these 142, 101 researchers also completed the outcomes survey. Thus, the results presented in this section are based on the analysis conducted on this sample of 101 GRAND researchers.

As all the results presented in this section were gathered through surveys, Harman’s one-factor test and confirmatory factor analysis, post hoc statistical tests, were conducted to test the presence of common method effect (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003). All the studied variables were entered into an exploratory factor analysis, using unrotated principal components factor analysis, principal component analysis with varimax rotation, and principal axis analysis with varimax rotation to determine the number of factors that are necessary to account for the variance in the variables. According to Podsakoff, MacKenzie, and Lee (2003) if a substantial amount of common method variance is present, either (a) a single factor will emerge from the factor analysis, or (b) one general factor will account for the majority of the covariance among variables.

The unrotated principal component factor analysis, principal component analysis with varimax rotation, and principal axis analysis with varimax rotation all revealed the presence of three distinct factors with eigenvalue greater than 1.0, rather than a single factor. The three factors together accounted for 58 percent of the total variance; the first (largest) factor did not account for a majority of the variance (22%). Thus, no general factor is apparent. While the results of these analyses do not preclude the possibility of common method variance, they do suggest that common method variance is not of great concern and thus is unlikely to confound the interpretations of my results. Out of the 101 examined researchers, 39 of them are project leaders holding the title of Principal Network Investigators (PNI) while the remaining 62 are Collaborating Network Investigators (CNI). This sample is diverse in terms of composition of the network, locations, and disciplines. The researchers in this sample come from 26 institutions of higher education dispersed in seven Canadian provinces. Their disciplinary background includes: 46 from computer science, 14 from information science, 13 from arts and technology, 7 from social sciences, 6 from the humanities, and 15 from medicine and other professions. Lastly, 65 of these researchers are male researchers and 36 are female.
4.2 Findings Concerning Network Topology: Research Question 1

The previous chapter details the construction of four networks that embody collaboration activities at GRAND: how researchers write papers, how they communicate, how they are acquainted with one another, and how they exchange advice. This section presents the results of a comparative structural analysis of these networks. This section addresses the first research question of this dissertation, restated here:

RQ 1: Which types of structures can be detected in the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers?

This section also examines existing ties of GRAND researchers at the early days of GRAND. It shows how GRAND members connect to their colleagues in the network regardless of whether these colleagues are affiliated with their own projects. GRAND members are connected by a range of social and professional relationships, the ones I will be looking at are: co-authorship, communication, acquaintanceship, and advice exchange. As discussed in sections 2.1.4 and 3.3, these relationships capture a great deal of the professional exchanges among researchers.

GRAND members completed the first social network survey before project work had started; at the time, many of them had not yet met their project team members. To a great extent, the first social network survey can be regarded as the baseline survey, mainly capturing ties predating GRAND. Research networks are often well connected because members meet at conferences, exchange graduate students, or write grant proposals together. However, GRAND is a special professional community because its members come from a wide range of disciplines, institutions, and geographic locations. As discussed in the literature review, professional ties across disciplinary, institutional, and geographic boundaries are difficult to develop in the normal course of research activities.

4.2.1 Density

To assess how connected the overall GRAND network is and how numerous ties in it are, I calculated density measures. Density is the proportion of ties that are actually present in a network out of all ties that could possibly be in the network. Density is calculated for each type of relationship separately since one type of relationship does not
necessarily lead to another. For instance, the members of a network may know each other but may not exchange advice; therefore, density for the acquaintance ego-networks is not necessarily identical to the density for the advice ego-network.

Comparing these four different relationships shows that at the initial stage of GRAND, the simple ties of just knowing someone in the network are by far the most numerous. The density value for the acquaintance network (0.11) is the highest among all the networks (Table 4.1). The next highest density ties are advice and the lowest density is the co-authorship ties. Recruitment practices in GRAND may have contributed to the relatively strong presence of acquaintance ties: members are recruited in a snowball process where the core group of researchers invited their long-term collaborators who in turn invited their own collaborators. As discussed in section 4.2.5, due to the nature of GRAND, these findings are mainly insightful when: (a) comparing different manifestations of interactions (e.g., acquaintance, co-authorship, communication and advice) among the involved researchers or (b) used for evaluating the changes in the network structure over time. In this section, I have tried to present the former, and in section 4.3 I will address the later.

Table 4.1: Average density of GRAND researcher’s ego-networks

<table>
<thead>
<tr>
<th>Density</th>
<th>Acquaintance (StDev)</th>
<th>Advice (StDev)</th>
<th>Co-author (StDev)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.11 (.02)</td>
<td>.03 (.01)</td>
<td>.01 (.01)</td>
<td></td>
</tr>
</tbody>
</table>

Differences in connectivity can also be illustrated in diagrams mapping the connections among GRAND members. Since each line represents a connection between members, the density of lines on the diagram illustrates the density of ties among GRAND members (the one calculated in Table 4.1). Figure 4.2 and Figure 4.3 visually represent the two networks with extreme density in the acquaintance network where ties are most numerous, and the co-authorship publication network, where ties are the most spars. The figures vividly demonstrate the findings presented in Table 4.1 insofar as they illustrate the differences in connectivity between the two networks and, in addition, remind us that according to this baseline data, not every researcher in GRAND has co-
authored publications with other GRAND members. Contrastingly, quite a few of the
GRAND members are not connected to anyone and appear as isolates in Figure 4.3.
Since GRAND researchers come from across Canada, they often have to communicate from a distance. At the early stage of the network formation, communication mainly takes place through email and in-person interactions. Of all communication networks, email ego-networks are the densest (average density of .35, SD .02). Researchers use email in all their relationships (Hayat & Mo, forthcoming), and the data gathered through this baseline survey indicates that even before GRAND researchers have started to work on GRAND related work, they already had an established e-mail communication network. Face-to-face communication closely follows email (mean density of .28, SD .01). As the survey asked the researchers to indicate their ties with other GRAND researchers even when these ties are not on GRAND related topics, it only makes sense that some of the GRAND researchers will have face-to-face ties. While the network as a whole, and project teams, are geographically dispersed, some GRAND researchers have colleagues from GRAND located in their own university.

In the baseline survey, less than 5% of the respondents indicated that they use other communication media, thus making it irrelevant to include this data in the statistical models because with over 95% of the researchers having no connections to other researchers, it is not constructive to discuss their network structure. This finding is in line with past work (Hayat & Mo, forthcoming) which found that email and face-to-face communication are perceived as most important for research work-related purposes. Thus, I will focus in my analysis on email and face-to-face communication.
4.2.2 Centrality Measures

In a network, all participants are ultimately connected but not all participants are connected equally. Members with more connections tend to be more active and contribute more to the network because they occupy central positions in it. Centrality measures capture the level of activity and the contribution of network members to the network. The central position of a member is contingent on the specific network under consideration. Some network members may know many colleagues but exchange advice with few and therefore will have different centrality ranking in the work and advice networks.

The discussion in this section is based on the size / degree centrality (Burt, 1983), betweenness centrality (Freeman, 1977), and eigenvector centrality (Bonacich, 1972) calculated for the co-authorship, advice exchange, email, and face-to-face communication networks.
Table 4.2: Average centrality of GRAND researcher’s ego-networks

<table>
<thead>
<tr>
<th></th>
<th>Email (StDev)</th>
<th>Face-to-face (StDev)</th>
<th>Acquaintance (StDev)</th>
<th>Advice (StDev)</th>
<th>Co-author (StDev)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree centrality</td>
<td>.32(.04)</td>
<td>.22(.06)</td>
<td>.18(.01)</td>
<td>.06 (.01)</td>
<td>.01 (.01)</td>
</tr>
<tr>
<td>Betweenness centrality</td>
<td>.28(.07)</td>
<td>.24(.03)</td>
<td>.19(.04)</td>
<td>.04 (.02)</td>
<td>.02(.01)</td>
</tr>
<tr>
<td>Eigenvector centrality</td>
<td>29(.09)</td>
<td>.21(.08)</td>
<td>.18(.08)</td>
<td>.04 (.01)</td>
<td>.02(.01)</td>
</tr>
</tbody>
</table>

Due to GRAND’s aim to foster ties among previously unconnected researchers who are geographically dispersed (GRAND, 2009), it is not surprising that the communication ego-networks are the ones with the highest average centrality. As many GRAND researchers did not work with one another prior to joining GRAND, their advice and co-authorship centrality are low. As shown in Figure 4.4, email communication has the highest degree centrality of .32, betweenness centrality of .28, and eigenvector centrality of .29. Researchers use email in all their relationships and are particularly likely to use email with the people they work with. Face-to-face communication follows with a degree centrality of .22, betweenness centrality of .24, and eigenvector centrality of .21. As stated above, some GRAND researchers have collaborators or colleagues from GRAND located in their own university. Some of the work and information exchanges in GRAND, therefore, take place in person.

Following, in terms of centrality measures, is the simple ties of just knowing someone, i.e., acquaintanceship, with a degree centrality of .18; a betweenness centrality of .19; and an eigenvector centrality of .18. The next higher centrality measures are for advice with a degree centrality of .06; a betweenness centrality of .04; and an eigenvector centrality of .04. The lowest centrality measures are the co-authorship ties with a degree centrality of .01, a betweenness centrality of .02, and an eigenvector centrality of .02.

4.2.3 Heterogeneity

Heterogeneity was based on the disciplinary background categories provided in GRAND administrative records. These categories were produced in collaboration with the NAVEL team. In the first online survey, GRAND members were asked to report their disciplinary background and 39 disciplines were reported, each consisting of between one
to 46 GRAND researchers. Given that certain disciplines are closer to each other because of their common ground, such as “systems and computer engineering” and “software and IT engineering,” the closer disciplines were grouped into broader categories at a higher level.

In some cases, the grouping was fairly intuitive, but in other cases it required looking through GRAND members’ CVs (especially focusing on their publications and funding sources) to determine their grouped disciplinary background. This process was done collaboratively among the NAVEL team members and the GRAND administrative team. This process concluded with the definition of eight disciplinary categories: computer science, information science, arts and technology, social science, humanities, professional program, engineering, and medicine. The results presented in this section are based on these eight categories and are calculated based on Blau’s (1977) heterogeneity index for the co-authorship, advice exchange, acquaintanceship, email, and face-to-face communication networks. Higher heterogeneity score indicate higher diversity in the network, score of 1 means that all the researchers in the network come from different disciplinary backgrounds.

Table 4.3: Average heterogeneity of GRAND researcher’s ego-networks

<table>
<thead>
<tr>
<th></th>
<th>Email (StDev)</th>
<th>Face-to-face (StDev)</th>
<th>Acquaintance (StDev)</th>
<th>Advice (StDev)</th>
<th>Co-author (StDev)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heterogeneity</td>
<td>.21 (.03)</td>
<td>.16 (.04)</td>
<td>.08 (.02)</td>
<td>.02 (.01)</td>
<td>.005 (.001)</td>
</tr>
</tbody>
</table>

Not surprisingly, the communication ego-networks are the ones with the highest heterogeneity scores. As shown in Table 4.3, email communication has the highest heterogeneity score of .21, following with face-to-face communication with a heterogeneity score of .16. As indicated above, researchers use email and face-to-face communication as their main channels of email communication. These two forms of ties has the highest density measures (see Table 4.1) and centrality measures (Table 4.2); thus, they offer more opportunities (when compared with the acquaintance, advise and co-authorship networks) to establish an ego-network with higher heterogeneity.
In terms of heterogeneity scores, the simple ties of just knowing someone follows (i.e., acquaintanceship) with a heterogeneity score of .08. The next higher heterogeneity measure is for advice with a heterogeneity score of .02. The lowest heterogeneity measure is for the co-authorship ties with a heterogeneity score of .005.

### 4.2.4 Effective Size

The idea of network effective size is that ego is the go-between for pairs of other actors. By definition, in an ego network, ego is connected to every other actor (Hanneman & Riddle, 2005), therefore, in order to measure his/her effective size, we need to look at the connections among alters. If none of these alters are connected to one another, the effective size of the ego is 1, if they are all connected to one another than the effective size is 0. Using effective size measure has the potential for elaborating on ways of looking at positional opportunity and constraints of individual actors. Burt's (1992) formalization of these ideas, and his development of a number of measures, has facilitated further thinking about how and why the ways an actor is connected affects his/her constraints and opportunities.

**Table 4.4: Average effective Size of GRAND researcher’s ego-networks**

<table>
<thead>
<tr>
<th></th>
<th>Email (StDev)</th>
<th>Face-to-face (StDev)</th>
<th>Acquaintance (StDev)</th>
<th>Advice (StDev)</th>
<th>Co-author (StDev)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Size</td>
<td>.12 (.01)</td>
<td>.09 (.02)</td>
<td>.07 (.01)</td>
<td>.03 (.01)</td>
<td>.01 (.001)</td>
</tr>
</tbody>
</table>

Again, not surprisingly, the communication ego-networks are the ones with the highest effective size scores. As shown in Table 4.4, email communication has the highest effective size score of .12, following with face-to-face communication with an effective size score of .09. As indicated above, researchers use email and face-to-face communication as their main channels of communication. In terms of effective size score, the simple ties of just knowing someone follows (acquaintanceship) with an effective size score of .07. The next higher effective size score is for advice with a score of .03. The lowest effective size score is for the co-authorship ties with an effective size of .01.
4.2.5 Summary

By themselves, the network measures discussed in this section are not very insightful. As discussed in other studies that have utilized the social network analysis for the study of other NCEs (e.g., Klenk, Hickey and MacLellan (2010) in their study of the Forest Management Network (SFMN) NCE and Dimitrova and Koku (2010) in their study of the Water Agency NCE), due to the unique nature of different NCEs, their network measures are not helpful for the purposes of NCEs comparison. Thus, rather, than looking at what is a typical or “normal” measure, these measures are helpful in: (a) comparing different manifestations of interactions (e.g., communication and advice) among the involved researchers or (b) used for evaluating the changes in the network structure over time. In this section, I have tried to present the former, and in the next section (4.3) I will address the later.

As can be seen in Table 4.5, when comparing the measures discussed in this section, we can see that in this baseline data, the most numerous ties that hold the GRAND network together are email and face-to-face communication, followed by acquaintanceship ties, advice exchange ties and lastly co-authorship (as can be learned from both the density and degree centrality measures). The preponderance of these types of ties is consistent with the recruitment practices and with the goals of the network. The researchers that were recruited knew each other to some extent (which explains the high email, face-to-face, and acquaintanceship ties), though we can see that they have not been exchanging much advice in this stage. They also rarely co-authored with one another.

Table 4.5: Average measures of all GRAND researcher’s ego-networks

<table>
<thead>
<tr>
<th></th>
<th>Density (StDev)</th>
<th>Degree centrality (StDev)</th>
<th>Betweenness centrality (StDev)</th>
<th>Eigenvector centrality (StDev)</th>
<th>Heterogeneity (StDev)</th>
<th>Effective Size (StDev)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Email</td>
<td>.35(.04)</td>
<td>.32(.04)</td>
<td>.28(.07)</td>
<td>29(.09)</td>
<td>.21 (.03)</td>
<td>.12(.01)</td>
</tr>
<tr>
<td>Face-to-face</td>
<td>.28(.03)</td>
<td>.22(.06)</td>
<td>.24(.03)</td>
<td>.21(.08)</td>
<td>.16 (.04)</td>
<td>.09(.02)</td>
</tr>
<tr>
<td>Acquaintance</td>
<td>.11(.02)</td>
<td>.18(.01)</td>
<td>.19(.04)</td>
<td>.18(.08)</td>
<td>.08 (.02)</td>
<td>.07 (.01)</td>
</tr>
<tr>
<td>Advice</td>
<td>.03(.01)</td>
<td>.06 (.01)</td>
<td>.04 (.02)</td>
<td>.04 (.01)</td>
<td>.02 (.01)</td>
<td>.03 (.01)</td>
</tr>
<tr>
<td>Co-author</td>
<td>.01(.01)</td>
<td>.01 (.01)</td>
<td>.02(.01)</td>
<td>.02(.01)</td>
<td>.005 (.001)</td>
<td>.01 (.001)</td>
</tr>
</tbody>
</table>

In the following sections, I will present results about: (1) how these measures develop with time and (2) how they correlate with the researchers’ outcomes and discuss the correlation patterns.
4.3 Findings Concerning Network Changes: Research Question 2

In the previous section, I reported a comparative structural analysis of five different networks of research collaboration at the start of GRAND, looking at how researchers organize themselves in communities of scholarly, communicative, and social interaction. In this section, I shift my analysis to the change of these networks, in order to address the second research question, restated here:

RQ 2. What collaboration changes can be evinced from the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers?

The structural analysis of the GRAND researchers’ ego-networks, presented in the previous section, is based on the first online survey (data collection was concluded in October 2010). Thus, the network I have analyzed until now represents the initial data regarding GRAND researchers’ co-authorship, communication (email and face-to-face), acquaintanceship, and advice exchange. As discussed in section 3.2.1, two rounds of online surveys were conducted. The second round of the survey was concluded in March 2013. To do longitudinal network analysis, it is necessary to compare the results of the first and second online surveys. As discussed in previous chapters, all data studied in this dissertation contain some temporal information: the bibliographic record contains the date of publication of papers; the communication, advice exchange, and acquaintanceship data was collected at two time periods.

As discussed in section 4.1, the sample size used for the analysis discussed below is 101. More often than not, having a small sample size would preclude achieving significance. When N is small, only very large effects could be statistically significant. An effect that fails to be significant at a specified level alpha in a small sample can be significant in a larger sample (Moore, McCabe, & Craig, 2012). Although the majority of the findings presented in this section are not statistically significant, and thus do not offer a generalizable results, I will still discuss them. As discussed in my research statement (section 1.4), the findings of this dissertation are not aimed at offering generalizable lessons from which to draw. Rather, it suggests ways of looking at network
structures properties and their change over time. These findings can then be used in framing interview probing questions (as discussed in section 3.2.4) and in getting a better sense about the change of GRAND (as will be discussed in section 6.1.2).

In sections 4.3.1 – 4.3.4 I will present the results of my analysis, and in section 4.3.5 I will summarize the results and discuss their meaning.

4.3.1 Density Changes

Table 4.6 presents the densities of each of the five networks in 2010 and 2012. As is evident in both 2010 and 2012, the densities of the networks are ranked the same. Email ego-networks has the highest density in both (.35 in 2010 and .38 in 2012), followed by face-to-face (.28 in 2010, and .31 in 2012). The acquaintanceship ego-networks follows (.11 in 2010, and .19 in 2012); this was the only difference that was found to be of significance ($t(99)=5.6, p<.05$). The advice ego-networks came second last (.02 in 2010 and .17 in 2012), and the co-authorship ego-networks are ranked the lowest in both 2010 (.01) and 2012 (.03).

Table 4.6: A comparison of network density measures at 2010 and 2012

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Density (StDev)</th>
<th>2010</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Email</td>
<td></td>
<td>.35(.04)</td>
<td>.38(.07)</td>
</tr>
<tr>
<td>Face-to-face</td>
<td></td>
<td>.28(.03)</td>
<td>.31(.04)</td>
</tr>
<tr>
<td>Acquaintance*</td>
<td></td>
<td>.11(.02)</td>
<td>.19(.05)</td>
</tr>
<tr>
<td>Advice</td>
<td></td>
<td>.03(.01)</td>
<td>.17(.03)</td>
</tr>
<tr>
<td>Co-author</td>
<td></td>
<td>.01(.01)</td>
<td>.03(.01)</td>
</tr>
</tbody>
</table>

*Statistically significant difference between 2010 and 2012 densities (P <.05)

More interestingly, as seen in Figure 4.5, the ego-network that underwent the biggest change in its centrality measure is the advice ego-network (an increase of .14). This means that the ego-networks are denser now; more researchers that did not exchange advice with one another in 2010 are doing so in 2012. We can see that the second largest change was in the acquaintanceship ego-networks (an increase of .08). The third largest change in the density of was in the email and face-to-face communication ego-networks (both underwent an increase of .03). Lastly, the co-authorship ego-networks underwent the smallest change (an increase of .02).
4.3.2 Centrality Measures Changes

Table 4.7 presents the centrality measures of each of the five networks in 2010 and 2012. Email ego-networks has the highest degree centrality in both (.32 in 2010 and .30 in 2012), betweenness centrality in both (.28 in 2010 and .24 in 2012), and the highest eigenvector centrality in both (.29 in 2010 and .26 in 2012). Co-authorship ego-networks has the lowest degree centrality in both (.01 in 2010 and .02 in 2012), betweenness centrality in both (.02 in 2010 and .02 in 2012), and the lowest eigenvector centrality in both (.02 in 2010 and .02 in 2012). None of these changes were significant.

![Figure 4.5: Changes in network density measures at 2010 and 2012](image)

Figure 4.5 shows that the acquaintanceship, advice, and co-authorship ego-networks underwent mainly a positive change in their centrality measure. More specifically, the acquaintanceship ego-networks degree centrality has increased by .02, betweenness centrality has decreased by .02, and eigenvector centrality has increased by .03. The advice ego-networks degree centrality has increased by .11, betweenness centrality has decreased by .04, and eigenvector centrality has increased by .02. Lastly, the co-authorship ego-networks degree centrality has remained unchanged, betweenness centrality has decreased by .01, and eigenvector centrality has increased by .01.
the co-authorship ego-networks degree centrality has increased by .01 while the betweenness centrality and eigenvector centrality both remained unchanged.

At the same time, we can see in Figure 4.7 that both the email and face-to-face communication ego-networks mainly underwent a negative change. More specifically, we can see that email ego-networks degree centrality has decreased by .02, betweenness centrality has decreased by .04, and eigenvector centrality has decreased by .03. The face-to-face ego-networks degree centrality and eigenvector centrality have both decreased by .03 while the betweenness centrality remained unchanged. None of these changes were significant.
Figure 4.6: Changes in acquaintance, advice and co-authorship networks centrality measures 2010-2012

Figure 4.7: Changes in email and face-to-face networks centrality measures 2010-2012
### 4.3.3 Heterogeneity Changes

Table 4.8 presents the heterogeneity measures of each of the five networks in 2010 and 2012. Email ego-networks has the highest heterogeneity in both (.21 in 2010 and .12 in 2012) followed by face-to-face (.16 in 2010 and .09 in 2012). The acquaintanceship ego-networks come next (.08 in 2010 and .07 in 2012), followed by advice ego-networks (.02 in 2010 and .03 in 2012). Lastly, the co-authorship ego-networks are ranked the lowest in both 2010 (.005) and 2012 (.01).

**Table 4.8: A comparison of network heterogeneity measures at 2010 and 2012**

<table>
<thead>
<tr>
<th>Relationships</th>
<th>Heterogeneity (StDev)</th>
<th>2010</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Email</td>
<td></td>
<td>.21 (.03)</td>
<td>.12(.01)</td>
</tr>
<tr>
<td>Face-to-face</td>
<td></td>
<td>.16 (.04)</td>
<td>.09(.02)</td>
</tr>
<tr>
<td>Acquaintance</td>
<td></td>
<td>.08 (.02)</td>
<td>.07 (.01)</td>
</tr>
<tr>
<td>Advice*</td>
<td></td>
<td>.02 (.01)</td>
<td>.03 (.01)</td>
</tr>
<tr>
<td>Co-author</td>
<td></td>
<td>.005 (.001)</td>
<td>.01 (.001)</td>
</tr>
</tbody>
</table>

*Statistically significant difference between 2010 and 2012 heterogeneity (P < .05)

When looking more closely at these changes, we can see in Figure 4.8 that while the email, face-to-face, and acquaintance ego-networks underwent a decrease in their heterogeneity (.09, .07, and .01 respectively); the advice and co-authorship ego-networks underwent an increase in their heterogeneity (.01, and .005 respectively); this was the only difference that was significant ($\tau(99)=3.2, p<.05$).
4.3.4 Effective Size Changes

Table 4.9 presents the effective size changes of each of the five networks at 2010 and 2012. Email ego-networks has the highest effective size in both (.12 in 2010 and .13 in 2012), followed by face-to-face (.09 in 2010 and .07 in 2012). The acquaintanceship ego-networks come next (.07 in 2010 and .04 in 2012), followed by advice ego-networks (.03 in 2010 and .03 in 2012). Lastly, the co-authorship ego-networks are ranked the lowest in both (.01 in 2010 and .005 in 2012).

When looking more closely at these changes, we can see in Figure 4.9 that while the email ego-networks underwent an increase in their effective size (.01), the face-to-face, acquaintance and co-authorship ego-networks undergone a decrease in their effective size (.02, .03, and .005 respectively); the advice ego-network remained unchanged. None of these changes were significant.
4.3.5 Summary

By adopting social network analysis (SNA), I investigated emerging social structures of co-authorship, advice, communication (e-mail and face-to-face) and advice exchange that helped to create collaborative patterns among GRAND researchers. As discussed in the opening of this section, due to the small sample size used for this analysis discussed both significant and not significant results (as having small sample size often precludes achieving significance). It is also important to note that within the context of research networks, SNA is mainly helpful for comparing different manifestations of interactions among the involved researchers (e.g., co-authorship, advice, communication, and advice exchange, in the case of this study) (Klenk, Hickey, & MacLellan, 2010). Thus my analysis was framed in a way that enabled this comparison. Furthermore, SNA are useful for evaluating the changes in the network structure over time. In this section I have tried presented these changes and now I offer my interpretation for these changes.

The biggest change in density was an increase in the density of the advice exchange and acquaintance ego-networks. This implies that GRAND indeed promoted more advice exchange among GRAND researchers and helped more researchers within the network to know each other. Looking at the centrality measures we can see that the communication ego-networks (both email and face-to-face) have decreased in their centrality. This can be explained when considering that when GRAND was launched in 2010, it consisted of 144 researchers while in 2013 it consisted of 208 researchers. The majority of the new researchers that have joined GRAND did not have an established communication (email
and face-to-face) network with GRAND researchers that were part of network since it was launched (Hayat and Mo, forthcoming).

At the same time, the biggest change in the centrality measures was for the advice network. This finding indicates that there was an increase in number of ties, among GRAND researchers that were used for advice exchange, thus providing additional support to the increase in advice exchange within GRAND. The key changes when looking at the heterogeneity measure was a decrease in both email and face-to-face communication. This pattern implies that GRAND researchers increased in communication with researchers from their own discipline and decreased in communication with researchers from other disciplines. This finding is in line with previous studies indicating that researchers usually prefer to work in disciplinary homogeneous teams (Olson et al., 2008b). This is explained, in part, due to the fact that it is easier to find common language and common ground with researchers coming from similar disciplinary background. This finding suggests that it is not enough to bring researchers from different disciplines together (as GRAND did) and assume that they will communicate and interact with one another.

Lastly, the key changes when looking at the effective size measures indicate that the acquaintance and face-to-face communication have become more “redundant” (and thus having lower effective size). The effective network of a researcher is the number of peers that s/he has, minus the average number of ties that each of these peers has with one another. Redundancy or effective network size is an important factor for communication advice exchange (Lazega, Mounier, Snijders, & Tubaro, 2012). Researchers in redundant networks are more connected with their peers. In this case, both acquaintance and face-to-face communication networks are more connected and thus offer more opportunities to communicate face-to-face or to exchange advice with one another.

In this section, I have looked at the changes in examined networks as demonstrated through the changes in the density, centrality measures, heterogeneity and effective size. In the following section, I examine how these changes interplay with the research outcomes of the GRAND researchers.
4.4 Findings Concerning Research Outcomes: Research Question 3

This section highlights the results of the regression analysis, showing the relationships between the change measures presented in the previous section and the research outcomes of GRAND researchers. I used ordinary least squares regression to examine the simultaneous effects of the changes variables (discussed in the previous section); it the regression analyses statistically control for the geographical location of the institute to which the researcher is affiliated, gender (men and women); academic status (Assistant Professor, Associate Professor, Professor, and not relevant); position within GRAND (CNI, PNI); age; and disciplinary background of each researcher (computer science, information science, arts and technology, social science, humanities, professional program, engineering, and medicine). By doing so, I was able to address the third research question, restated here:

RQ 3: How do the structural features of the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers, and the change of these features over time interplay with the researchers’ research outcomes?

Table 4.10 (Model 1) shows the results from regression analyses of the interplay between the change variables and knowledge outcomes. Before examining the findings I conducted a multicollinearity test, the variance inflation factor (VIF). The VIF was calculated for each of the variables entered into the regression models. VIF estimates how much the variance of a coefficient is “inflated” because of linear dependence with other predictors (O’Brien, 2007). Thus, a VIF of 1.8 tells us that the variance of a particular coefficient is 80% larger than it would be if that predictor was completely uncorrelated with all the other predictors. O’Brien (2007) further indicated that when a VIF is greater than 2.50 (which corresponds to an $R^2$ of .60 with the other variables), this constitutes a problem. All of the VIF measures in my analysis were lower than 1.85, thus VIF was not found to pose a problem for the analysis presented below.

The strongest statistical correlations are derived from the density of the co-authorship ego-network $\beta = .40$, $t(90)=3.82$, $p < .01$. The second strongest statistical effects are derived from the betweenness centrality of the advice ego-network $\beta = .35$, $t(90)=3.5$, $p < .01$. Heterogeneity of advice ego-network accounted for the next strongest statistical
effect $\beta= .24$, $t(90)=2.6$, $p < .05$. Following which, the effective size of the advice ego-networks also had also a statistical effect $\beta= .08$, $t(90)=2.9$, $p < .05$. Lastly, the degree centrality of the co-authorship ego-networks was the only variable that was found to have a negative statistical effect $\beta= -.04$, $t(90)=2.47$, $p < .01$.

Table 4.10 (Model 2) shows the results from regression analyses of the interplay between the change variables and training outcomes. The strongest statistical effects are derived from the advice ego-network $\beta= .42$, $t(90)=4.9$, $p < .001$. The second strongest statistical effects are derived from the density of the communication ego-network $\beta= .39$, $t(90)=3$, $p < .05$. The degree centrality of the advice ego-network accounted for the next strongest statistical effect $\beta= .24$, $t(90)=2.8$, $p < .01$. Lastly, the effective size co-authorship ego-network was found to have a negative statistical effect $\beta= -.19$, $t(85)=4.27$, $p < .01$.

Table 4.10 (Model 3) shows the results from regression analyses of the interplay between the change variables and outreach outcomes. The strongest statistical effects are derived from the effective size of the acquaintanceship ego-network $\beta= .38$, $t(85)=3.95$, $p < .01$. The second strongest statistical effects are derived from the effective size of the advice ego-network $\beta= .31$, $t(90)=3.13$, $p < .01$. The degree centrality of co-authorship ego-network accounted for the next strongest statistical effect $\beta= .24$, $t(90)=3.9$, $p < .01$. Lastly, the eigenvector centrality of co-authorship ego-network had the weakest statistical effect $\beta= .19$, $t(85)=2.07$, $p < .05$.

Table 4.10 (Model 4) shows the results from regression analyses of the interplay between the change variables and collaboration outcomes. The strongest statistical effects are derived from the degree centrality of advice ego-network $\beta= .26$, $t(85)=3.4$, $p < .01$. The second strongest statistical effects are derived from the degree centrality of co-authorship ego-network $\beta= .25$, $t(85)=2.833$, $p < .01$. Lastly, the density co-authorship ego-network had the weakest statistical effect $\beta= .13$, $t(90)=3.13$, $p < .05$.

This part of my analysis examined the correlation between the structure and change of the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers, along with the GRAND researchers' research outcomes. I explored this interaction through four ordinary least squares regression tests. In Chapter 6, I will discuss the interpretation of these results and frame them within the context of related
literature. This interpretation will be largely based on the insight I gained through the semi-structured interviews I conducted with GRAND researchers.
Table 4.10: Regression analyses testing the interplay between the network change measures, and research outcomes.

<table>
<thead>
<tr>
<th>Model 1: Knowledge Outcomes</th>
<th>Model 2: Training Outcomes</th>
<th>Model 3: Outreach Outcomes</th>
<th>Model 4: Collaboration Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density of co-authorship ego-network</td>
<td>Degree centrality of advice ego-network</td>
<td>Effective Size of Acquaintance ego-network</td>
<td>Degree centrality of advice Ego-network</td>
</tr>
<tr>
<td>.40**</td>
<td>.24**</td>
<td>.38*</td>
<td>.26**</td>
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<tr>
<td>Betweenness centrality of advice ego-network</td>
<td>Effective size of co-authorship ego-network</td>
<td>Effective Size of advice ego-network</td>
<td>Degree centrality of co-authorship ego-network</td>
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<td>.35**</td>
<td>-.19**</td>
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<td>Degree centrality of co-authorship ego-network</td>
<td>Density of advice ego-network</td>
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<td>-.04**</td>
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<tr>
<td>Heterogeneity of advice ego-network</td>
<td>Density of communication ego-network</td>
<td>Eigenvector centrality of co-authorship ego-network</td>
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<td>Effective Size of advice ego-network</td>
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<td>R square: .47</td>
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<td>R square: .47</td>
<td>R square: .33</td>
</tr>
</tbody>
</table>

Note: Values in table are beta coefficients. Statistical significance is indicated by:
* $p < .05$; **$p < .01$.
A positive beta indicates that the predictor is associated with more outcomes in each category shown. A negative beta indicates that the predictor is associated with fewer outcomes in each category shown.

As addressed in my literature review, an ongoing debate occurs within the social networks analysis literature regarding the potential effect of network structure on the
research outcomes of researchers. The findings presented in this section present the four exploratory regression models I have used to test these interplays. In the next chapter, I will use the social capital literature in order to provide a more nuanced analysis of the change of co-authorship, communication, acquaintanceship, and advice exchange networks and their interplay with GRAND researchers’ research work. I will then distill and interpret these results and framed them within the context of related literature.
Chapter 5: Findings Concerning Research Outcomes, the Interplay between Network Structures and Researchers Social Capital

This chapter focuses on the qualitative analyses of the GRAND research network wherein the results of the qualitative analysis of semi-structured interviews is used to help understand how can the social capital literature be used to interpret the interplay between research outcomes and the structural features of the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers, as well as the changes of these features over time? (RQ4). This analysis enriches my social network analysis findings with insights from research in the field of social capital.

Findings will be presented and elaborated on in a descriptive manner, in the form of paraphrases and direct quotations. In addition to presenting the research study’s findings in this chapter, key discussion points will be included and intertwined in an attempt to interpret findings, draw conclusions and connect the findings back to the literature review included in Chapter 2. Before moving on to the findings, Figure 5.1 illustrates how I gathered, recorded and organized the data in NVivo 9 as it relates to the dimensions of social capital.
Figure 5.1: NVivo – dimensions of social capital.

After collecting data regarding the dimensions of social capital through semi-structured interviews, I thematically organized the data utilizing NVivo 9. In the hierarchical node structure in Figure 5.1, the primary parent node is social capital dimensions. Under that parent node, there are child nodes for the different dimensions: the structural dimension of social capital (discussed in section 5.1); the relational dimension of social capital (discussed in section 5.2); and the cognitive dimension of social capital (discussed in section 5.3). Finally, within each of these nodes, additional nodes exist for specific themes that emerged through an examination of the analyzed data. Through this process, I inductively analyzed and thematically organized the data and findings. For the purposes of answering research question 4, all the answers given by the interviewees when discussing their work within GRAND were identified and included in one of the nodes presented in Table 5.1.
As discussed in section 3.4, the qualitative data analysis is both deductive and inductive. This process affects the structure of this chapter and sections 5.1-5.3 are a result of the deductive phase. Deductive analysis is the act of organizing data based on predetermined themes, concepts, and theories derived from the literature review. In my review, I have proposed to look at social capital as resources and benefits which individuals can derive based on their embeddedness in a social network (Bourdieu, 1986). Social capital can be defined as “resources embedded in social networks accessed and used by actors for action” (Lin, 2001, p. 25). Nahapiet & Ghoshal (1998) proposed three main dimensions for the study of embeddedness: structural, relational, and cognitive. This widely used conceptualization serves for defining the broad themes discussed in sections 5.1, 5.2, and 5.3.

The subsections of these sections (5.1.1-5.1.4; 5.2.1-5.2.3; and 5.3.1-5.3.2) as well as section 5.4 are results of my inductive analysis (i.e., the act of coding the data based on new themes generated through an examination of the analyzed data). This process of inductive analysis enabled me to identify new insights not included in the literature; it also allowed me to take into account ideas that may not have been initially considered (e.g., the notion of levels of collaboration discussed in section 5.4). Furthermore, as current studies of research networks have been unclear, and in some cases even contradictory, when regarding which network structures foster social capital among researchers, the inductive analysis enabled me to identify narratives that can help explain the interplay between network structures and researchers social capital.

5.1 The Structural Dimension of Social Capital

The structural dimension captures the overall patterns of ties among the actors (i.e., the network structure); it reflects the ‘who knows whom’ as a potential resource available to the actors (Nahapiet & Ghoshal, 1998). The fundamental proposition of social capital theory is that network ties provide access to resources. This perception can be observed in the following quote by John.

*The list of researchers who are involved in GRAND looks like the Who's Who list of the Canadian graphic design [field]. Being connected to such a group of people can open a lot of opportunities.*
One of the central themes observed in the interviews was that social capital constitutes a valuable source of information benefits (i.e., "who you know" affects "what you know"). This finding is in line with Coleman (1988) who noted that information is important in providing a basis for action but is costly to gather; however, social relations, often established for other purposes (e.g., friendship, and acquaintanceship), constitute information channels that reduce the amount of time and investment required to gather information. The following quotes demonstrate this notion:

Matt: Prior to joining GRAND I didn’t really have a chance to talk to Jeff, I just knew broadly what he was working on. After our first conversation [in the first GRAND annual conference] in Ottawa I realized that Dan [Matt’s PhD student] can really use his [Jeff’s] dataset.

Suzanne: Keith was my supervisor, and he told me about his plans for this project before he started working on the proposal. As soon as he told me about it I decided that I wanted to be a part of it.

James: It’s not just that the PNI was constantly putting us in touch with industry partners; he also made sure that we would meet them face-to-face [during the GRAND conference meeting].

It is also important to differentiate between the different forms of information benefits: access, timing, and referrals. Matt’s quote highlighted the notion of information “access” by referring to receiving a valuable piece of information, knowing who can use it, and identifying the role of GRAND in providing an efficient information screening and distribution process for its researchers. Thus, network ties influence access to other members of the network, and this can potentially affect the collaboration among the network members. Suzanne’s quote highlights the notion of “timing” by referring to the ability of personal contacts to provide information sooner than it becomes available to people without such contacts. Lastly, James touches upon the notion of information “Referrals” which provide information on available opportunities to GRAND researchers.
The referred researchers can enjoy more opportunities to form partnership with additional researchers, industry partners, and governmental and not-for-profit agencies (Bozeman & Corley, 2004).

Five attributes of social structure that the interviewees used to characterize the structural dimension of social capital are brokerage and structural holes; heterogeneous; closure; ties to well connected researchers; and large network focus. These attributes are discussed below.

5.1.1 Brokerage and Structural Holes in Research Network

The benefits of embeddedness in social network structures have been conceptualized by Burt (1995), who proposed the theory of structural holes. According to this theory, an individual might be motivated to establish a broker position between dense regions of relationships that have only sparse connections between them; in other words, in regions where there is a structural hole. Researchers in one of these dense regions are not linked directly to researchers in the other and depend on the broker as their connector. In the interviews, the notion of a brokerage mechanism came up, especially through emphasizing the importance of relationships that bridge gaps between disconnected GRAND researchers. When discussing how interdisciplinary her project came to be, Carol, a PNI, indicated that:

That’s a new collaboration that came out of some work I was doing with some collaborators at my university, which was to be delivered to another group. I got to – I was working with Jeremy, who’s a member of GRAND, and Jeremy is good colleagues with – with Debora, Matt is my colleague, Matt works with Debora, and we realized we were all interested in [the same idea] as a possible application for one of these other projects. So that was a GRAND member and my own colleague networking.

These structural holes are not just a result of disciplinary divisions, they exist because individuals are differentiated according to their positions in the organization’s structure (Blau, 1963). In a previous analysis of GRAND (Hayat et al., 2012), it was found that geographical location plays a big role in the creation of structural holes, as
there is small connection between groups of researchers in different geographical locations. Alexandra alluded to that in the following quote:

Alexandra: *since I moved to [my current university] I’ve mainly been working with other researchers in my faculty. I haven’t been working with people from other departments at [my university], let alone with people from other universities.*

The interviewees indicated that in cases where their networks are more sparse—that is, characterized by more structural holes—they had access to more and better information and referrals as well as a greater opportunity to benefit from them. Amber, a computer scientist, when discussing her project members indicated one of its unique advantages is the bringing together of previously unconnected researchers from different disciplinary backgrounds:

*None of them are in Computer Science or even...I guess they're...they're not even NSERC [the Natural Sciences and Engineering Research Council of Canada] researchers for the most part. They’re CIHR [Canadian Institutes of Health Research] researchers so it's...it's quite unique the types of collaborations that are going on within that project.*

James also referred to this point and indicated the GRAND annual conference offers a unique opportunity to introduce his graduate students to other researchers:

*They’ve all got posters upstairs [James’s PhD students]. We’ve got two posters and they brought a demo too, in front of the poster. That’s why I’m itching to get up there [to the poster session] because I want to introduce them to people.*

Jeff (a researcher studying mobile computing), referred to the same point by stressing the importance of bridging disciplinary divisions:

*During our flight here [to the GRAND annual conference] I told my students that they need to be able to communicate their research work to people from other fields.*
This supports the structural holes theory which argues that social capital derives from bridging structural holes or gaps between different actors in a social network (Burt, 1992). As a result, a GRAND researcher who develops ties with disconnected groups gains access to a broader array of opportunities than those who are restricted to a single one (Granovetter, 1973). The interviewees have discussed the benefits of a brokerage position within the context of communication, knowing other people (i.e., acquaintances) and within the context of advice exchange. Yet, it is interesting to note that brokerage position within a co-authorship network was not discussed as a benefit. This can be partially explained in light of the fact that many of the benefits associated with a brokerage position can be attained without necessarily co-authoring a paper.

Kevin, for instance, indicates that you can still get advice and help from other GRAND members even when you are not co-authoring a paper:

_We [the project members] just had, for example, a lunch today, and all of the major players came, from – and we’re from four different universities. And I know them through the [project name] group and we, um, I don’t know that I’ve worked with them so much but I have – I know I have called on them for this or that, an academic question._

Mary provided another example for this notion of helping other people without co-authoring a paper:

_Other people have contacted me about physiological sensors and saying you know, “which ones should I use to evaluate this particular thing that I'm interested in?”_. And so then I give them an answer and we…and they go off and they do their thing…

_But I’m not really working with any of them._

As Kevin and Mary put it, you can still consult and get feedback from your colleagues without working with them. Additionally, it is very time consuming to maintain co-authorship collaborations:
James: *I mean we have to start off with a large literature review of history and figure out within that which research questions have been asked. And then figure out what’s a good research question and then get close to the technology and experience it to figure out what’s interesting about working with it. I mean, it takes a long time!*

At the same time, the interviewees indicated that there is importance in holding a brokerage position in co-authorship networks. For example, John, according to my pre-interview file, serves as a brokerage in his co-authorship ego-network, indicates that while advice and acquaintanceship ties are importance, when he faces significant research challenges, he solves them with his co-authors:

*When we got to a dead end in our work, we meet for half a day [just the researchers working on the paper]. It was just us and our students. None of the others [other GRAND researchers to which John is connected] was involved in that. When it comes down to it that’s how it always work.*

John echoed Hansen’s (1996) research that found that a weak tie (such as advice and acquaintanceship) facilitates the search for relevant information but impedes knowledge transfer, especially when knowledge is not codified. Thus, whereas networks having little redundancy may be both effective and efficient for the transfer of information whose meaning is relatively unproblematic, much richer patterns of relationship and interaction are important where the meaning of information is uncertain and ambiguous or where parties to an exchange differ in their prior knowledge. This point came up especially within the context of graduate student training.

Mike: *I only want them [his PhD students] to work with other students if it is right up their alley. They have enough time to collaborate in the future, now they need to establish their expertise.*

Allan: *I found some of the comments that my students got during the Rnote session were really un-constructive. Some of the questions were so out of context that I didn’t see what they had to do with the presentation.*
Nonetheless, the general point remains that a brokerage position can have an important influence on accessibility to information resources within GRAND, although the influence is contingent on the degree to which the parties share a common knowledge base and the complexity of the problem at hand.

5.1.2 Heterogeneous Research Networks

Burt (1992) argued that network positions are especially beneficial if the linked regions have a high level of diversity. Jacobs (1961) and Granovetter (1973) have made similar arguments, identifying the role of "hop-and-skip" links and "loose ties" in information diffusion. Mark addressed that when referring to a cognitive psychologist joining his project that was comprised mainly of computer scientists.

Mark: *Sam [a CNI in Mark’s project] is great, he introduced us to Jenna’s [a social scientist] work, following which Jenna joined our project…Other than Sam, none of us had really worked with social scientists in the past.*

This aspect of diversity is very important, because it is well established that significant progress in the creation of knowledge often occurs by bringing together knowledge from disparate sources and disciplines (Contractor, 2009). Networks, and thus network structures, represent facets of social capital that influence the range of information that may be accessed and becomes available to individuals. As such, these structures constitute a valuable resource as channels or conduits for knowledge diffusion and transfer. This aspect of knowledge diffusion came up while referring to researchers outcomes. While addressing his “highly productive project,” Tom attributed its success to the diversity of the project members.

*I hire designers and artists who have different skill sets – right? – methodologically, at least, and coders – people that write code – computer programmers. And we add the social science to it for testing. We didn’t start seeing results until the second year, but that year we published over 10 papers.*

John (a computer scientist) also indicated that:
One of my most cited papers was a result of advice I got after giving a guest talk at a Kinesiology lab.

Thus, the interviewees addressed this notion by indicating that diversity of knowledge is useful for idea generation and leads to higher performance in terms of publications. This finding echoes those of past studies (Milliken, Bartel, & Kurtzberg, 2003; Taylor & Greve, 2006; Tziner & Eden, 1985) showing increased diversity within an ego network, implying a mix of researchers from different backgrounds having different skills, abilities, information, and knowledge. When cross-disciplinary interactions exist among collaborators, knowledge is transferred. Consequently, social capital brought about by cross-boundary practices leads to the increase of research productivity.

5.1.3 Closure in Research Networks

Although there is consensus that larger networks of non-redundant contacts provide advantages for accessing information and other resources, there are also compelling arguments in favor of closure (Coleman, 1988, 1990: 275–278, 318–320). Whereas structural hole theory focuses on the benefits of one’s ability to exploit unconstrained network positions, the closure argument emphasizes the benefits of that very constraint. Thus, in this section I focus on interviewees that demonstrated high degree of closure in their network.

Closure, Coleman argues, introduces useful constraints in the form of exchange-inducing social norms supporting sanctions (Coleman, 1990: 116). These constraints engender a high degree of mutual obligation, to the point where favors are done freely, naturally, and without any accounting. One example for this can be seen in the following quote:

Ben: Well, after we talked to them [researchers from another project within GRAND] we open sourced all of our code, and shared it with the other projects [within GRAND]…. I’m sure that they would have done the same.

According to Coleman’s social closure theory, if Ben had decided not to share his code after being requested to do so, he would not be able to incur any social capital
benefits from this relationship in the future. As researchers within GRAND have the capacity to help each other, the most beneficial course of action for Ben to take was to volunteer his expert knowledge and share it with other researchers within GRAND.

Such effects, Coleman argues, ensure the ‘opposite of free riding,’ not only through more efficient cheater detection and sanctions, but also via the generation of ‘excessively zealous activity,’ as a group identity is formed and cooperative routines are solidified (Coleman, 1990: 277). The following quotes demonstrate this point.

Albert: *we also have been having routine meetings. I don’t think it’s every month, but we do. And it’s not just sort of, hey, what’s going on? It’s, you know, people come and they deliver something. Without this kind of routine it’s very easy to neglect your project responsibilities. After all we are all very very busy.*

Carl: *We have weekly meetings and the way we’ve learned to work best is that we have a weekly work day. And so sometimes people can only stay for four hours but we start off with a catch-up meeting, timelines and then we work together. Beforehand [i.e., before they started doing the weekly meetings] things were kind of stuck. We just didn’t know what they are doing.*

Dirk: *It’s not just that he’s working with me, he’s also working with my [former] supervisor, and with two other good colleagues of mine… so he has just as much as me to lose if anything goes wrong…*

In line with the work of Nicolaou and Birley (2003), it is also important to note the importance of trust within research networks that are characterized by a higher tendency toward innovation and the creation of new knowledge (Cummings, 1997). Steve’s quote can serve as an example for what happens when trust is missing:

*We [Steve’s lab] shared with them knowledge, we shared methods. I don’t know to what extent they’ve taken them up, I haven’t heard anything from them. I haven’t spoken with them since last year [at the GRAND annual conference], and we haven’t*
done anything together... It’s been a very bad experience for me, I simply can’t trust them.

Another important point that the interviewees touched upon was that formation of a group identity and shared contextual understanding is likely to facilitate the transfer of less tangible resources and tacit knowledge.

Sam: And so Simon’s been doing that with his group, and then I’ve got Mike who’s been doing that with his group. So, yeah, I don’t wanna hold the rein too tightly but in terms of, sort of, you know, we have regular meetings, and that’s where we sort of vet – you know, I vet that, okay, this is a good direction.

This point echoes Hansen’s (1996) findings indicating that that dense, intertwined networks improve the actual transfer of (as opposed to simply the search for) rich, non-codified information. Thus, cohesion created by closure not only increases the extent and speed of information transfer among group members, but it also gives them additional assurances on how such information will be used. As others have suggested (Portes, 1998) and this dissertation aims to show, it is important to distinguish the structural mechanisms at play from the relational (interpersonal) ones. In this section, I have focused on researchers with structural closure, and the potential benefits of such a network structure. The group-induced advantages of closed networks—provided through the formation of exchange norms, routines, sanctions, and even a common cognitive context was mentioned, but it will be elaborated on separately from the strictly structural factors in section 5.2.

5.1.3 Ties to Well-Connected Researchers

Collaboration with well-connected peers is considered a valuable resource for career development (Agneessens & Wittek, 2012). Specifically, the interviewees indicated that well-connected researchers have access to resources and opportunities that otherwise could remain inaccessible.
Oliver: *He [a project member] just knows everyone within GRAND…he established strong collaboration with two champions [i.e., industry partners] and secured additional funding for a retreat [for the project].*

Jim: *One of the things we said was that they are the [experts in their field] – we’re not the experts, right?…Matt doesn’t just know many people in GRAND he also knows what they do. He suggested that we work with them in the first place.*

As discussed above, GRAND imposes hierarchical differentiation on researchers by assigning a project leader (i.e., PNI). PNIs have direct responsibility for completion of the project, directing the research and reporting directly to the GRAND board of directors. The PNIs are typically the ones who either conceived of the investigation or were selected by a team to obtain the best strategic advantage for the project (Atkinson-Grosjean, 2006). Furthermore, every PNI in GRAND must be involved in three or more projects, thus expanding the PNI’s ties with GRAND researchers. Thus, PNIs have larger advice and communication networks because of the nature of their role in GRAND (Hayat & Mo, forthcoming).

PNIs also enjoy a more central role within the advice and communication networks of GRAND (Hayat & Mo, forthcoming). In addition to being central, the PNI represents access to power and resources at the higher levels of the organization and knowledge of the organization’s formal goals (Etzioni, 1965). The discussion of PNIs’ access to power intertwines both their hierarchical position and their centrality within GRAND. Matt demonstrates that when referring to the notion of keeping informed about what is happening in GRAND.

*I don’t really visit the GRAND website or the forum. Bill [the project PNI] is the main source from which I learn about what is happening in GRAND. I know that he [Bill] is in touch with the GRAND academic director and with the theme leader, and I trust him completely.*
Because of their central network position in GRAND, PNIs have access to power and have the ability to facilitate change and to provide necessary resources and critical assistance.

Boris: [the project PNI] was the one who defined the scope of the project. He was also able to secure budget for two lab visits that really helped us get started.

GRAND projects, like in other NCEs, can become segmented into subgroups based on the different interests and needs of its members (Hayat, 2012), as is the case within GRAND (Wellman et al., 2014). A researcher’s ability to connect various sub-project groups can determine the overall effectiveness of his/her work, as he can gain timely access to relevant information.

Pat: The last time I spoke to the others [i.e., other project members] was last year [in the GRAND annual conference]. I have no clue what they have done since; I know that I’ve done nothing.

Christophe: [the project PNI] have been great in making sure that we are all on the same page. I’ve just realised that Mark [another project member] is working on a very similar problem. So because we both share this intense interest in understanding this set of problems, we’ve discovered a lot, we’ve had a lot of really good joint papers and our proposals got excellent reviews, it’s been a big success.

The PNI is required to maintain ties with these sub-project groups as part of his/her job. Thus, an efficient way for a researcher to quickly access information and resources in the various subgroups within the project is to either establish ties with at least one person in each subgroup (Brass & Krackhardt, 1999) or to maintain a strong connection with their PNI. It is unlikely that a researcher will have a strong relationship with every member of a project (Graen & Uhlbien, 1995); therefore, his/her ability to maintain a strong relationship with the PNI can enhance his/her social capital.
5.1.4 Large Network Focus

Previous research by Hall and Graham (2004) has found that smaller groups of researchers are better able to support genuine collaboration and new knowledge creation. McFadyen and Cannella’s (2004) research also shows diminishing returns on knowledge creation as the number of relations in a researcher’s social network increases. The interviewees expressed similar experiences as part of their work within GRAND. Karen was addressing this point when she was explaining why it is difficult to maintain co-authorship ties with other researchers in her project (some of them are based in the same university as Karen and some in other universities):

*If you're working jointly on something then there's kind of a lot of back and forth but as I collaborate with Nick, for example, we published a paper together recently and you know, but for the paper deadline we were meeting fairly often over Skype. Before that it was mostly by email every once and a while kind of thing with some phone meetings here and there so it would just be too hard to maintain these types [i.e., co-authorship] of relationships with all the group [i.e., her GRAND project] members; it would be more effective to just do the work with my students you know.*

In the university research environment, researchers must reach a balance between using their own personal resources to maintain relationships within their social networks and putting those resources towards their actual research. John was also referring to this point when discussing his schedule during the GRAND annual conference:

*Every one of my breakfasts and lunches is taken up by project meetings this year and it's so difficult because there's no other time. I mean that's the time when you actually...I am so busy at these, like, this demo session tonight or this reception tonight, I'm going to be so busy because I have to keep an eye on my own students who are presenting their posters and I have a whole bunch of them but I also...I'm going to be bumping into lots of people [i.e., other researchers in his project] who have been waiting for this opportunity to talk because it's so much easier to just do it face-to-face...but I just won’t have time to talk to all of them and I know that it means that some things will be put on the back burner.*
This notion is further supported by Hall and Graham’s (2004) study showing that although larger groups provide increased opportunities for individual learning, smaller groups have a higher tendency for the emergence of actual new knowledge (knowledge outcomes in the case of GRAND). Moreover, the interviewees indicated that smaller co-authorship networks were more constructive to their work. When referring to the fact that he finds it more constructive to co-author papers with GRAND members he already co-authored with in the past, Carl indicated that:

*It’s is just too time consuming to work with so many people [i.e., other researcher in his project]…It is really hard to assess if working with other project members will indeed prove to be a good match. There is just so much that can potentially go wrong, that I usually prefer working with people I have already worked with in the past.*

While small co-authorship networks were discussed as more constructive for knowledge outcomes, some interviewees pointed out that knowing more people and exchanging advice with them is constructive for the formation of new partnerships and relationships.

Albert: *The poster session [during the GRAND annual meeting] is great for branching out. In at least two cases, my students and I exchanged datasets with other people [i.e., GRAND members] we had met during these sessions.*

Mark: *I make a point of getting to know other people [i.e., GRAND researchers], that’s why the informal events are so important. That’s where I actually get to meet new people whose studies I have heard about and tell them about mine. Just last year [following the GRAND annual conference] I invited Jim [a post-doctoral fellow who I had met at the annual conference] to come and give a talk in our lab.*

David: *I won't bump into people, you know, the same way you do at a reception. You know, at a reception you move around and you bump into people and it's opportunistic and it's serendipitous and more of that...more of that.*
This seemingly contradictory finding (i.e., benefiting from large acquaintanceship and advice networks and from smaller co-authorship networks) was explained by the interviewees in their discussions of the cost of maintaining a relationship with a fellow researcher. Maintaining a co-authorship tie is more costly—both in terms of time and effort—when compared to maintaining an advice tie. Thus, although maintaining a large co-authorship network can diminish the resources a researcher can dedicate to his/her actual research work, the benefits of having such an advice network outweigh the time and effort required to maintain it. Furthermore, current literature indicates that when forming new teams, people prefer to work with previous partners to reduce uncertainty in their collaboration (Wholey, Padman, Hamer, & Schwartz, 2000). Kent referred to this point when he explained why he would prefer to continue collaborating with an author he has been co-authoring with for over 20 years, as opposed to work with new collaborators:

“When we write, the writing style is the same, the focus is the same. We can write two halves of a review article and put them together and they fit because we like to look at things in the same way. It’s quite unusual.

I have not had that experience before where the writing style and the focus was never an issue.

This notion is in line with prior research on team collaboration whereby previously working on a team helps overcome geographic and disciplinary hurdles to future team assembly and influences subsequent collaboration. Together, these findings suggest that, in the context of research collaboration, researchers who have collaborated in the past are more likely to collaborate in the future. Therefore, it is not surprising that the interviewees indicated that when selecting team members, they are biased toward selecting collaborators with whom they have already developed either strong (co-authorship) or weak (advice) working relationships within GRAND. Thus, these prior ties can lead to greater collaboration outcomes.
5.2 The Relational Dimension of Social Capital

While the structural dimension determines the extent and range of resources that are within a researcher’s reach, the relational dimension establishes how much of this potential will be realized. In other words, the quality of social relations influences which of those resources that are within reach will be accessed and to what extent. Although a researcher may have access to several other researchers who are potentially critical sources of information, personal experience and the quality of past interactions will often influence who s/he is likely to approach and engage.

Three attributes of social relations that the interviewees used to characterize the relational dimensions of social capital are closeness, trust, and norms. These represent progressively deeper degrees of relational quality: from inclination to provide resources, to personal familiarity (relational closeness), and to a deep sense of the researcher’s reliability and faithfulness in resource exchange (interpersonal trust).

5.2.1 Closeness in Research Networks

Relational closeness refers to the extent of personal familiarity in a relationship. Bourdieu’s original designation of social capital emphasizes that the usefulness of social capital rises from ‘lasting’ and ‘durable’ social relations which require the expenditure of significant ‘time and energy’ (Bourdieu, 1986: 249–250), implying relations that have a considerable degree of familiarity and mutual regard. Mary offers an example for such commitment:

Mary: *this [GRAND annual conference] is going to be very very busy and it’s disappointing to me that there’s...that there’s so little time at this session to actually get done what needs to get done for me which is connecting up with the other researchers. I have known these people for such a long time, they are like my second family and I wont have enough time to talk to them.*

Whereas the existence of a tie provides the potential for either researcher to access the resources available to the other, relational closeness shapes the willingness of either party to actually provide those resources; he or she is more likely to offer information, know-how, or aid to others who are close, than to those more distant. Max provides an example for how such closeness can foster the willingness to share resources:
Max: We have known each other really well for ages, and we've been meaning to talk about it and last year we were all in the same reception and I bumped into one person, we talked about it. And then I bumped into someone else and we talked about it and we said, "okay let's do this," the following day we already exchanged our datasets.

Granovetter appears to concur; he argues that weak ties provide people with access to information and resources beyond those available in their own social circle, but strong ties have greater motivation to be of assistance and are typically more easily available. (Granovetter, 1985: 209). Jeremy offers an example of how strong ties can be motivators for providing assistance in the following quote:

Jeremy: I wouldn’t have done it [joined an additional project] for anyone else. But after all he did for me I just wasn’t able to say no when he asked.

Podolny further emphasized the point that “controlling for the extent to which a tie serves as a bridge to distinctive sources of information, stronger ties are actually more beneficial than weak ties since they allow a greater volume of resources to move between actors” (Podolny, 2001 p: 34). It follows that once we have controlled for the bridging effect of weak ties (i.e., Burt’s structural holes reinterpretation of weak ties), then greater relational closeness is likely to increase the transfer of resources, in general, and the transfer of tacit and complex knowledge, in particular, as close contacts are generally more willing to take the time to carefully explain, detail, or listen to novel or complex ideas (Granovetter, 1985). Wendy addresses this point when talking about working with GRAND researchers who she has been referring to as my ‘close friends’:

You know how in some meeting you can doze off or do other stuff? With them I will never do that. I make sure that I am caught up and informed, and that notes are taken, and we’re keeping track.
5.2.2 Trust in Research Networks

Trust is an essential prerequisite for most forms of interdependent relationships. It establishes some form of assurance that a researcher can rely on the intentions and behaviour of others in order to make decisions and act (March & Simon, 1958). David offers an example for collaboration that can only be achieved when trust exists:

David: So people are doing their own thing in the project and when we have a project with milestones, there will be more than one researcher contributing to a milestone. So it is not like it is an explicit collaboration that results in joint authorship...publications. But it is collaboration in that we’re making kind of parallel progress towards one single goal. There is no way that would have worked if we didn’t completely trust each other.

Implicit in the notion of social capital is that people often require resources that are controlled by others, and, as a result, some degree of uncertainty and reliance upon others is required. Indeed, Coleman’s view of social capital is particularly sensitive to uncertainty and emphasizes the role of trust in facilitating exchange (Coleman, 1990: 306–308). Trust can be viewed as the basic active ingredient of social capital, the condition that allows an actor to reliably expect to obtain and use the resources made available through one’s contacts (Nahapiet and Ghoshal, 1998). An example for such trust within the context of GRAND can be seen in the words of Adam when he compared his GRAND project with another NCE project in which he was involved:

Adam: In my previous project I didn’t feel confident, because people had been sort of in parallel, working towards the same thing and not sharing it with each other...in my current project I feel that we’re leveraging each other.

He further indicates that:

We [his collaborators within GRAND] would be discussing probable publications so...where we’re at on a specific thing that we might be working on jointly; where we’re going; outlining potential projects, ideas; iterating on milestones, thinking of
like, becoming involved with a new project submission so...you know that's a pretty different process than these older projects.

As the above indicates, such expectations are vital for the initiation of exchange, enabling a researcher to engage (trust) others when judging ideas, tackling problems, seeking perspective or feedback, and so on. More generally, where there is high relational trust, more interactive and adaptive exchanges may result, permitting, for example, the discovery of greater novelty (Moran & Ghoshal, 1999); this is the difference between a short conversation about a new idea, and active and open brainstorming and tweaking of a new initiative. An example for the former can be seen in when by Brown recalls an example for an interaction that was limited to presentation and some feedback and didn’t mature into actual discussion or a development of new ideas:

Brown: The grad students have made five recommendations for possible solutions at the [GRAND annual conference] meeting. They got some feedback, but only we followed up on that.

Harris, on the other hand, provide an example for intensive discussions and explicitly titled them as “brainstorm”:

Harris: They [the other project members] say, I’m going to present one of our most recent experiments and this is what we’ve discovered. And we’ll talk on it and give them feedback and see how it fits with what we’re doing. It’s a brainstorm.

Trust stimulates those exchanges that may serve to reinforce and build social capital (Coleman, 1990). As Nahapiet and Ghoshal (1998: 251) argue, trust creates anticipation of value through social interaction with others and thus motivates actors to deepen relations and pursue interactions. When discussing why he chose to start working with researchers affiliated in another GRAND project, Murphy explicitly indicated that they are trustworthy, he elaborated and said that:

Murphy: They [a group of researchers in another GRAND project] have a couple of interfaces that they’ve designed that are visual interfaces for coding, and um, those have been made available online. They gave us full credit for our input, and
we now use their code. We’re already discussing how to work together in a more formal way.

5.2.3 Norms in Research Networks

According to Coleman (1990), a norm exists when the socially defined right to control an action is held not by the actor but by others. Thus, it represents a degree of consensus in the social system. Coleman suggests that “where a norm exists and is effective, it constitutes a powerful though sometimes fragile form of social capital” (1988: 104). This notion came up repeatedly when the interviewees addressed how the collaborative norms within GRAND affected their work. For instance, Dana indicated that there is an “administrative encouraged norm” for connecting with other GRAND researchers who are working on similar problems. She provided an example for how it affects her involvement in GRAND:

Dana: So I’m meeting with some people who have contacted me, you know, lately to say they're working on similar projects or looking for a way to collaborate within my project, and they're not on my project. I'm going to meet with them and see how we can make this work.

Lisa, when discussing why she thinks her GRAND project is more successful than past collaborative projects in which she was involved, highlighted the norms developed within her project for meeting in face-to-face more than once a year:

Lisa: So the face-to-face thing I think is what keeps things happening so we tend to meet up at conferences or if I'm visiting a particular city. So I meet with people a couple times a year, I would say.

Norms of cooperation can establish a strong foundation for the creation of research outcomes. Becoming, in effect, "expectations that bind" (Kramer & Goldman, 1995), such norms may be a significant influence on collaboration processes, opening up access to researchers for the exchange of knowledge. Lora explicitly addresses this notion when discussing the collaborative nature of GRAND, explaining how it affected her interactions with other researchers.
Lora: Jim [a researcher from another GRAND project] contacted me because he’s doing some work and he wanted to measure the cost of task switching. He...and he knows that I have expertise in EEG, so he wanted to ask me some questions about that which I think actually is going to lead to us to working together on a project.

Ella also addressed this point by indicating that:

*I know that Mary is leaving...leaving her family to come [to the GRAND annual conference] and she has a two year old and an eight month old. So obviously I feel like it's important that I come prepared to the meeting.*

On the other hand, we can also see how other types of norms (e.g., norms about updating your project members about your work progress) can actually discourage interactions and potential collaboration among GRAND researchers. For instance, Jack discussed how the lack of norms regarding when and how project members need to update each other on their work prevented potential collaboration.

Jack: *I think sometimes...when we find out what everyone else is working on, it’s a little too late to...to use that.*

Another example was discussed by Emma, who explicitly indicated that her project is missing collaborative norms. She also indicated that it affected the nature of the work within the her project:

Emma: *I’m not really collaborating with my other researcher in the project… I think people are kind of doing their own thing.*

These findings are consistent with previous studies (Leonard-Barton, 1995). In these studies, it has been found that the potential for enhancing the tendency towards collaborative work that may emerge in strong, convergent groups and that represents high levels of social capital, may be a real enabler for the development of new knowledge and new ties with peers (Janis, 1982). Rebecca nicely summarizes this point:

*Research is funded individually and so there’s so much autonomy as a researcher of what you're doing that I'm not sure there's that much explicit coordination happening with...in a project. What works great in GRAND is that we have a great group of*
dedicated people, and there is this collaborative attitude so new projects are formed and new CNIs are joining existing projects.

The interviewees echoed Starbuck’s (1992) findings on the importance of social norms of openness and teamwork as key features of knowledge intensive work; they highlighted the significance of the emphasis on cooperation, on open disclosure of information, and on a sense of obligation to the project as significant underpinnings of the success of their research work and of the success of GRAND.

5.3 The Cognitive Dimension of Social Capital

The cognitive dimension refers to those resources providing shared representations, interpretations, and attention among parties (Cicourel, 1992). Following Nahapiet and Ghoshal (1998), I have identified this dimension separately from the structural and relational because I believe it represents an important set of assets not yet discussed in the mainstream literature on social capital within the context of research collaboration.

5.3.1 Shared Language

Research collaborators like to work with people from the same cultural and disciplinary background. In their study on the Canadian Water Network NCE, a study that looked at a network of researchers and practitioners in the area of water and the ways they work together, Dimitrova and Koku (2010) found that although researchers are collaborating with peers from different disciplines, they have a cultural and disciplinary homogeneous network of researchers with whom they exchange ideas. In other words, the researchers collaborate across disciplines, but they are still more comfortable discussing ideas with members in their own fields. Tracy, a communication researcher, addressed this point when talking about why she worked with two other social scientists involved in her project and not with the other computer scientists involved in her project:

Tracy: During the project meeting, I got the sense that my [qualitative] research approach was perceived as lacking methodological rigor. None of the present computer scientists stayed after the meeting to further discuss the potential contribution of my study to their work.
John, a computer scientist, provides additional support for this notion when discussing why he only works with the computer scientists involved in his project; and why he is not involved in the qualitative studies done by other researchers in his project:

_To be honest, I don’t know how much we can rely on studies that are based on the examination of 10-15 users. It might be that I just didn’t get the point they [his qualitatively oriented project members] were making._

As we can learn from both Tracy and John, some GRAND researchers are frustrated by the misunderstandings resulting from differences in background or expertise. Monteiro and Keating (2009) had similar findings and they identified various types of misunderstandings among multidisciplinary collaborators. They further emphasized the importance of researchers having a shared language.

There are several ways in which a shared language can affect research collaboration. First, language has a direct and important function in social relations, for it is the means by which people discuss and exchange information, ask questions, and conduct business in society. To the extent that people share a common language, this facilitates their ability to gain access to people and their information. To the extent that their language and codes are different, this keeps people apart and restricts their access. Shelly, a sociologist, addressed this point when talking about her ethnographic work:

_Computer scientists don’t value its [i.e., ethnography] results, because it’s a relatively unfamiliar field for them. Without the computer scientists knowing what I can do, what insights I can gain, they don’t give me any feedback on what they would like me to look at... They simply don’t know what I can do._

Stephanie, a computer scientist, was also aware of that issue and explained how she tries to deal with it:

_When I have a meeting with the government people, I’ll make sure I understand what they say. Also, I will try my best to convince them and explain to them in layman terms so that they fully understand what I mean._
Language also influences our perception (Berger & Luckmann, 1991; Pondy & Mitroff, 1979). Codes organize sensory data into perceptual categories and provide a frame of reference for observing and interpreting our environment. Thus, language filters out awareness of the events for which terms do not exist in the researcher terminology and filters in the activities for which terms do exist. Jessica, a researcher looking at usability issues alluded to this point:

*I wasn’t involved in the early days of the project, so initially they [the other project members] didn’t even think to look at usability issues, which is surprising given all the usability experts you can find here [in GRAND].*

Collaborative research advances through developing new concepts and narrative forms (Sonnenwald, 2007). However, to develop such concepts and to combine the information gained through research collaboration, the different parties must have some overlap in knowledge. Boland and Tenkasi (1995) identify the importance of both perspective taking and perspective making in knowledge creation, and they demonstrate how the existence of a shared vocabulary enables the combining of information. The interviewees suggested that researchers increasingly recognize group-specific communication codes as a crucial foundation for collaborative research projects.

### 5.3.2 Attention and Time

It is important that researchers have time and resources to commit to a collaborative project. In research work, it is common to have multiple projects going at the same time. A researcher proposes different research plans to a number of funding agencies and with some probability each gets funded. It is possible, therefore, to have too many commitments to spend sufficient time on one or more of them in order to succeed. Tatiana addressed her discomfort resulting from this lack of time:

*I’m now involved in four projects, and I’m just swamped. I know that I’m going to drop the ball [i.e., not working as much as needed on one of the projects].*

On the other hand, Tom addressed his frustration with one of his project members who is “over committed” and does not get things done on time:
I know that he is involved in two other projects, one in GRAND and in another NCE… We just can’t count on his work. More than twice he promised to finish his analysis by a given date, and both times he didn’t come through. In one of these cases it also caused a delay in my work.

Another issue that came up from the interviewees when they were discussing the notion of time and attention was the challenges of coordinating remote collaboration. Research has shown that when working on multiple projects, some with people who are co-located and others with people who are remote, the co-located people get time and attention, even though the projects are of equal importance (Bos et al. 2004). Several interviewees alluded to this point. Steve indicated that all the other researchers in his project are based in two other institutes.

In many cases I feel out of the loop. Even though I Skype in to their lab meetings it’s just not the same... You know how always the best discussions come up when you go to lunch or over coffee, right? So I’m just not a part of that.

In projects that span many time zones, it is also more difficult to find times in the normal working day when real-time conversations can take place. GRAND researchers indicated that in such cases they try to schedule their meetings during the workday overlap. David, for instance, indicated this when collaborating with two of his remotely located collaborators:

We [the project researchers] had very few opportunities to clarify information, align our goals, and so on. It was especially problematic at the beginning of a project, before things have a chance of becoming less ambiguous and more routine.

A key feature of research work is that it is rarely routine. In addition, when participants are working in different time zones, their “body clocks” are set locally (Olson et al., 2008b). When conversations exclude any clues as to the real time of day in the remote location, misunderstandings can occur. Mark, a computer scientist based in Halifax, touches on this:
We were talking with our colleagues in Vancouver on Friday late afternoon, and they carried on the conversation for too long. I saw that my graduate students were starting to get distracted as they were being kept from going home.

When people are remote and isolated, they are often ignored. Several interviewees indicated that having a critical mass of people at each location can amend some of this. When people feel isolated, they feel less motivated to contribute, not owning the problem and not being asked to contribute in any way as frequently as those who are visible to each other and “at hand.” Some of the interviewees indicated that the projects should consider designating a point person at each location who will be responsible for making sure that all participants there are informed and contributing.

5.4 Research Outcomes: The Interplay between Network Structures and Researchers’ Social Capital: Research Question 4

As addressed in my literature review, an ongoing debate occurs in the literature about social capital and social networks regarding the potential effect of network structure on the research outcomes of researchers. Thus, in the fourth part of my analysis, using the literature on social capital, I provided a more nuanced analysis of the change of co-authorship, communication, acquaintanceship, and advice exchange networks and their interplay with GRAND researchers’ research work. I then distilled and interpreted these results and framed them within the context of related literature. This interpretation is based on the insight I gained through the semi-structured interviews I conducted with GRAND researchers. Even though the interviewees did not always discussed explicitly how the different dimensions of social capital (structural, relational, and cognitive) interplay with their research outcomes, they elaborated on how these dimensions interplay with their research work. Thus enabling me to interpret how network structures interplay with research outcomes.

As illustrated below, a full interpretation of my social network analysis results, and its interplay with researchers’ research outcomes, cannot be addressed merely by examining patterns of connection independent of social meaning, or, as discussed in my literature review, by looking at the social structure without addressing the social content. In order to address this aspect, I discuss the joint effects of social networks and social
capital on research outcomes. My findings are addressed below, divided into the four types of research outcomes examined.

5.4.1 Knowledge Outcomes

My statistical analysis showed that knowledge outcomes (i.e., gains in new knowledge) have positive correlation with the density change of co-authorship ego networks. This means that the denser the co-authorship ego networks become, the greater the knowledge outcomes become. Building on the interview findings, I argue that this finding can be explained through Coleman’s social closure theory, which proposes that networks that are more cohesive can generate social capital benefits. The interviewees also echoed Pescosolido and Georgianna’s (1989) notion that denser networks (e.g., with a high percentage of connectedness among co-authors) can provide greater social capital through facilitating trust and social support among co-authors. In line with the work of Birley and Nicolaou (2003), the interview findings also highlighted the importance of trust within research networks that are characterized by a higher tendency toward innovation and the creation of new knowledge (Cummings, 1997).

My statistical analysis also showed that knowledge outcomes have positive correlation with the change of the betweenness centrality in the advice ego network. In essence, betweenness centrality measures to what extent an ego is the go-between for pairs of other actors. This means that the more times a researcher falls along the shortest path between two other researchers, the more knowledge outcomes s/he produces. One explanation for this finding that came from the interviews is that researchers with high betweenness centrality are likely to be exposed to more information. This notion was explicitly discussed in the interviews as a product of the researcher’s central position within the GRAND advice network. More specifically, as one of interviewees puts it, being positioned in this way is perceived as being “on the knowledge paths” of a number of other researchers. Such a position makes the researcher more visible, or known, to others. This position also enables easier access to information when needed, which, in turn, is helpful for the generation of knowledge outcomes.

At the same time, knowledge outcomes are negatively correlated with the change in degree centrality in the co-authorship ego network. This means that researchers who are connected to more co-authors have fewer knowledge outcomes. One explanation for this
finding that came from the interviews may be the fact that researchers must reach a balance between using their own personal resources to maintain relationships with their co-authors and putting those resources towards their actual research. This is also supported by findings in the literature which demonstrate that smaller groups of collaborators are better able to support genuine collaboration and new knowledge creation (Hall & Graham, 2004). Hall and Graham (2004) show that while larger groups provide increased opportunities for individual learning, smaller groups have a higher tendency toward the generation of new knowledge. This notion came up repeatedly among the interviewees when addressing their experiences working with their co-authors within GRAND.

The results of my analysis also showed that knowledge outcomes are positively correlated with the change in diversity within researchers’ advice ego networks. This means that the number of knowledge outcomes increase when researchers exchange advice with peers from more diverse disciplines. One explanation for this finding that came from the interviews might be the fact that diversity of knowledge is useful for idea generation and leads to higher performance. This finding is also consistent with Florida’s (2004) findings indicating that diversity is associated with the increase of innovative outcomes. Florida further showed that increased diversity within an ego network implied a mix of researchers from different backgrounds having different skills, abilities, information, and knowledge. Within such an environment, researchers are more likely to search for solutions that recombine heretofore disconnected ideas to generate innovation (Guimera, Uzzi, Spiro, & Amaral, 2005). As my interviews analysis indicates, in the case of GRAND, knowledge and expertise are the resources that flow along networks within and across projects. When cross-disciplinary interactions exist among collaborators, knowledge is transferred. Consequently, social capital brought about by cross-boundary practices leads to the increase of research productivity (the interviewees mainly referred to publications when addressing this aspect).

Finally, the results of my analysis also showed that knowledge outcomes are positively correlated with the change of the effective size of researchers’ advice ego networks. This means that the number of knowledge outcomes is higher for researchers with less redundant advice networks. A potential explanation for this finding that came
from the interviews was that researchers with sparse advice networks, that is, characterized by more structural holes, have access to more and better information and resources, as well as greater opportunities to benefit from them (the majority of the examples provided within this context referred to publications). This finding is also supported by the structural holes theory which argues that social capital derives from bridging structural holes or gaps between different actors in a social network (Burt 1992). The interviewees echoed Burt’s (1992) notion indicating that boundary spanning generates "new perspectives" because information tends to be relatively redundant within a given group (Burt 1992, p. 13-16). As a result, a GRAND researcher who develops advice ties with disconnected groups gains access to a broader array of opportunities than those who are restricted to a single group. The main assumption is that social capital theory, which is based on structural holes, stresses the opportunity side of networks. The structural holes theory argues that researchers have high levels of social capital because they are not part of cohesive, embedded advice networks (i.e., closure within the advice network may not help, but rather hinders researchers’ knowledge outcomes).

The co-authorship ego network’s smaller size and denser connections correlated with higher knowledge outcomes, whereas the advice ego network’s more sparse and diverse structures were found to be correlated with higher knowledge outcomes. This seemingly contradictory finding was explained by the interviewees in their discussions of the cost of maintaining a relationship with a fellow researcher. Maintaining a co-authorship tie is more costly in terms of time and effort when compared to maintaining an advice tie. Thus, although maintaining a large and dispersed co-authorship network can diminish the resources a researcher can dedicate to his/her actual research work, the benefits of having such an advice network outweigh the time and effort required to maintain it.

5.4.2 Training Outcomes

Training outcomes (i.e., training of students and post-docs) are positively correlated with the size change of the advice ego networks. This means that the number of training outcomes is higher for researchers with more ties in their advice networks. As previously discussed, the interview findings suggest that smaller groups of collaborators are better able to support genuine collaboration and new knowledge creation. The interviewees specifically indicated that this is the case for “true collaboration,” but when “minimal
collaboration” or “consultation” is required, the size of the network can offer an advantage. Again, according to the interviewees, this seemingly contradictory preference is due to the effort required to maintain the network, i.e., maintaining consultation ties is less costly than maintaining true collaboration. Thus, the advantage of large consultation networks outweighs the costs of maintaining such a network. As Hall and Graham (2004) argue, larger groups provide increased prospects for individual learning and for being exposed to different opportunities. This notion came up repeatedly in the interviews, specifically when the interviewees addressed how the breadth of their advice network was helpful in supporting their graduate students in finishing theses or dissertations or in searching for (and then accepting) academic jobs.

Training outcomes are negatively correlated with the change of the effective size of researchers’ co-authorship ego networks. This means that the number of training outcomes is higher for researchers with redundant advice networks. While conventional wisdom, based on the research collaboration literature, suggests that novel ideas come from non-redundant ties (Ahuja, 2000), my findings showed that the opposite is true in the case of training outcomes. This is further supported by the interview findings indicating that training outcomes are positively correlated with the density change of both the advice and communication ego networks (i.e., the denser the co-authorship ego networks become, the greater the knowledge outcomes become). Thus, my findings indicate that dense, redundant networks are more constructive for training outcomes.

My interview analysis offered a possible explanation for this pattern: network closure can help build the intellectual coherence that is crucial for fostering supportive training environments. Previous studies have shown that researchers who share many of their collaborators are more likely to trust each other (Burt & Knez, 1995). To some extent, this trust is a product of the dense social structures that help in facilitating sanctions, which, in turn, make it less risky for people in the network to trust one another (Coleman 1988). Furthermore, we know that trust plays an important role in enabling the discussion of unformed creative ideas (Abrams, Cross, Lesser, & Levin, 2003). Such unformed creative ideas are the hallmark of students’ work. The interviewees further echoed the work of Abrams et al. (2003) by indicating that a trusting environment is helpful in encouraging the articulation of early stage, unformed creative ideas. Such environments
can potentially offer support for helping graduate students finish theses or dissertations and training of undergraduate and graduate students.

5.4.3 Outreach Outcomes

Outreach outcomes (i.e., the formation of new partnerships/relationships) are positively correlated with the growth of the effective size in both the acquaintanceship and communication ego networks. This means that the number of outreach outcomes is higher for researchers with less redundant acquaintanceship and communication ego networks. My interviews analysis offered a possible explanation for this pattern by echoing the findings of Seibert et al. (2001), indicating that dense networks are redundant in that they convey similar information and resources among researchers. Researchers in a dense network are likely to be strongly tied to each other and thus exposed to the same set of opportunities (Seibert et al. 2001). At the same time, diverse communication and acquaintanceship ties can expose researchers to more diverse partnership opportunities. This finding is further supported by the work of Constant, Sproull, and Kiesler (1996), indicating that people share different opportunities with other members in their organization even when they do not directly work with them.

Outreach outcomes are positively correlated with the size change of co-authorship ego networks. This means that the number of outreach outcomes is higher for researchers with more co-authors. Building on the interview findings, I argue that being connected to diverse collaborators provides opportunities for productive interactions. More specifically, these ties expand the spectrum of opportunities to form partnerships with additional researchers and industry partners, as well as with governmental and non-profit agencies. My interview findings further indicate that while researchers are likely to share information about different opportunities with their GRAND peers, they usually actively endorse people for new partnerships/relationships only after they have worked together (i.e., they know the quality of their work). Thus, while advice ties can expose researchers to different opportunities, co-authorship ties can lead to actual endorsement for receiving these opportunities.

Finally, my statistical analysis also revealed that outreach outcomes have positive correlation with the eigenvector centrality change of co-authorship ego networks (recall researchers have high eigenvector scores when they are connected to well-connected
researchers). This means that the number of outreach outcomes is higher for researchers who are co-authoring with highly connected peers. Collaboration with well-connected peers is considered a valuable resource for career development (Agneessens & Wittek 2011; Cross & Parker 2004). Specifically, my interviews findings indicates that well-connected researchers have greater access to resources and opportunities, and they are likely to spot career-related opportunities and to connect less-connected researchers to those opportunities. Thus, being connected to such researchers enhances one’s chances of becoming involved in opportunities that can increase one’s research outreach.

5.4.4 Collaboration Outcomes

Collaboration outcomes (i.e., collaboration that has begun and will continue beyond the scope of GRAND) are positively correlated with the size, change of advice, and co-authorship ego networks. This means that the number of collaboration outcomes is higher for researchers with more advice and co-authorship ties. This finding is consistent with the current literature, which indicates that when forming new teams, people prefer to work with previous partners to reduce uncertainty in their collaboration (Whooley et al., 2000). The positive correlation of co-authorship and advice relationships with collaboration outcomes is in line with prior research on collaboration in teams, wherein low turnover improves the efficiency and performance of a team in particular situations (Cummings & Kiesler, 2007).

In the context of research collaboration, prior studies have shown that previous collaboration in knowledge creation increases the likelihood of future collaboration. Furthermore, previously working on a team helps overcome geographic and disciplinary hurdles to future team assembly and influences subsequent collaboration. Together, these findings suggest that, in the context of research collaboration, researchers who collaborated in the past are more likely to collaborate in the future. Therefore, it is not surprising that larger advice and co-authorship networks are positively correlated with collaboration outcomes. As my interviews analysis indicates, when selecting team members, GRAND researchers are biased toward selecting collaborators with whom they have already developed either strong (co-authorship) or weak (advice) working relationships. Thus, these prior ties within GRAND lead to a greater likelihood of future collaboration.
Collaboration outcomes are positively correlated with the change in the density of co-authorship ego networks. Thus, my findings indicate that dense, redundant co-authorship ego-networks are more constructive for collaboration outcomes (as compared with other types of ties). As indicated above, my interviews analysis suggests that network closure can help build an intellectual coherence that is crucial for fostering supportive research working environments.

Previous studies have shown that researchers who share many of their collaborators are more likely to trust each other (Burt & Knez, 1995). To some extent, this trust is a product of the dense social structures that help facilitate sanctions, which in turn make it less risky for people in the network to trust one another (Coleman, 1988). Previous studies have also found that trust plays a crucial role when researchers decide with whom they want to work (Olson et al., 2008b). Thus, the density of the co-authorship network can enhances the trust among GRAND researchers, which in turn makes it more likely that they will work together again in the future.

While my main purpose in this chapter was to look at how the social capital literature can help better understand the interplay between social networks and research outcomes, during the interviews an additional theme emerged: levels of collaboration.

5.5 Levels of Collaboration

A broad theme that came up in the interviews was that collaboration manifests itself in different forms among GRAND researchers. From my analysis of interview data, a typology of collaboration emerged. GRAND researchers discussed collaboration as a continuum of different types or levels of teamwork, ranging from complementary to integrative.

Turner, one of my interviewees, suggested that the collaboration that exists at the top to the middle part of the continuum is called to use his words, “minimal collaboration” or “consultation,” and the one at the lower part of the collaboration continuum is called a “true collaboration.” He clarified what he meant by consultation:

*[When] somebody needs something from me they approach me and see if I can provide that. That’s more of a consultation than collaboration—whatever you want*
to call it. But that happens all the time, it doesn’t require much from me, I’m still going to do my own work, but what I produce will be useful to somebody else.

The interviewees further indicated that this type of collaboration implies the need for both an awareness of the other participant’s distinctive knowledge/skills and the complementary fit of those knowledge/skills with the ongoing aspect of research. This type of collaboration requires awareness and complementarities rather than personality compatibilities; thus, it can be easier to establish. Much of the collaboration discussed by the interviewees falls into this category.

Walsh and Bayma (1996) found a similar trend in their study of research collaboration. Their findings indicate that collaborating researchers are looking for a complementary or sequential fit with their research; they may work on the same project, but not necessarily work closely with each other. They are responsible for their own pieces of the research process, contributing to the project by providing their particular inputs. The whole, or end result, is bigger than what any members could accomplish by themselves. For example, Oliver explained the details of a collaborative project with Pat (who works at a different location) that shows this complementary division of work:

*Pat’s group have provided us with the results of the MRI tests they have conducted. We then were able to test if the findings of these tests are indeed consistent with what we were expecting to find.*

This quote indicates that this project could not be accomplished without each researcher’s knowledge and contributions. Pat’s research group conducted the MRI tests, which they provided to Oliver’s group, and then, Oliver’s group analyzed these tests. Thompson (1967) refers to this kind of working relationship as sequential interdependence. In this situation, both parties have very complementary expertise. Additionally, this type of collaboration appears less likely to lead to conflicts over responsibility and contribution. As Oliver puts it:

*It was very clear who does what; even though both my students and Pat’s students were involved in the process, no coordination was needed. Everything went really smoothly.*
Integrative collaboration, on the other end, requires individuals to work closely together throughout the research process in order to develop ideas, and challenge each other’s assumptions while respecting and trusting each other on both personal and professional levels. Mike described his experience within an integrative collaboration as follows:

_The most amazing thing about Kent and I is that if you ask either one of us independently about our current project, what makes this interesting or important, we’ll probably come up with the same answer._

When talking about his work with his other project members Jack indicated:

_We are doing a fully shared project; it will be very difficult for me to tell you exactly who did what. Our artefacts are truly collaboratively generated._

The interviewees indicated that in this type of collaboration, both parties are involved in developing research problems, refining ideas, and analyzing results through reporting the results. They fully participate in the whole process together and share responsibilities in all the components.

5.6 Summary

My main argument in this section has been that the social capital literature can help better understand how the structur and change of GRAND researchers’ ego-networks interplay with their research outcomes. The statistical regression models discussed in section 4.4 were used to study the interplay between the networks (structure and change), and the research outcomes. The interviews analysis discussed in sections 5.1, 5.2, and 5.3 were then used to explain these interplays. I pulled the strands of my analysis together by proposing that it is the interaction between social capital and network structure that underpins the interplay between networks structure and research outcomes.

My results provide a framework that is grounded in an emerging research collaboration network involving the multidisciplinary interaction of researchers who are spread across Canada. This framework articulates various aspects of collaboration among researchers and identifies factors that influence collaboration. These factors include the structural, relational, and cognitive dimension of social capital. I found ample examples
for how these dimensions can help interpret interaction between types of collaboration and research outcomes.

Probably the main reason for the existence of GRAND (and similar research networks) is to enhance collaboration among the members as a means of achieving a level of research output that is greater than would have been achieved by working alone. As mentioned earlier, the research community increasingly celebrates collaboration (Sonnenwald, 2007), yet successful collaboration is not easily found.
Chapter 6: Discussion

This chapter discusses the results and interpretation of the findings in terms of how they address my research questions and their fit with the theories presented in the literature review chapter. Specifically, I discuss how I used the framework of social network analysis (SNA) to understand the structure of the GRAND collaborative research network, as well as how it changes over time. I discuss how I looked at the structure and change of network characteristics and their interplay with researchers’ outcomes before finally, I explain this interplay through discussing these structure and change as conditions that interplay with researchers’ social capital and that can, in turn, affect researchers’ outcomes.

As indicated in my literature review section, different network structures have been proposed as being constructive for fostering high social capital for individual researchers. Yet, current studies of research networks have been unclear, and in some cases even contradictory, when regarding: (a) which network structures indeed foster social capital among researchers and (b) whether researchers’ social capital enables productive benefits, or rather, causes negative outcomes. Thus, when discussing my results, I elaborate on why, how, and when different network structures (and their change) interplay with research outcomes.

6.1 Key Research Findings:

This dissertation offers a study of collaboration in Graphic Animation and New Media (GRAND), a research network funded by NCE. GRAND’s objective is to address complex issues in digital media and was created to explore the use and application of digital media in a variety of settings. GRAND is a modern, multidisciplinary, distributed research network. In order to capture GRAND researchers’ epistemic and social ties, I have examined the collaboration patterns of GRAND researchers in terms of four networks of interaction: co-authorship, communication, advice exchange, and acquaintanceship. This study of GRAND is based on data collected through both quantitative (i.e., two online surveys of GRAND researchers; an outcome survey; data collected from the GRAND forum) and qualitative data (gathered through semi-structured interviews).
6.1.1 Key Findings Concerning Network Topology: Research Question 1

The first part of my analysis looked at the ego network structure of GRAND researchers. The structure of these networks was described by size/degree, betweenness and eigenvector centrality, as well as through heterogeneity, effective size and density measures. By themselves, these measures are not very insightful, but when compared and constrained, we can see that in its early stage, the most numerous ties that hold the GRAND network together are email and face-to-face communication, followed by acquaintanceship ties, advice exchange ties and co-authorship (as can be learned from both the density and degree centrality measures). The preponderance of these types of ties is consistent with the recruitment practices and with the goals of the network, i.e., the people who were recruited knew each other to some extent (which explains the high email, face-to-face acquaintanceship ties); although, we can see that they have not been exchanging much advice in this stage. They also co-authored fairly little with one another.

6.1.2 Key Findings Concerning Network Change: Research Question 2

The second part of my analysis focused on the change of the GRAND researchers’ ego network (i.e., changes in the network over a four-year period). In this portion of research, I examined the research collaboration dynamics that take place among GRAND researchers. Whether naturally emerging in the course of professional interaction or deliberately designed, networks are in constant flux. Ongoing interactions among members potentially give rise to new relationships, dissolve old ones, or alter the structure of ties. The changes in GRAND researchers’ ego networks (as measured by the changes in the network measures calculated based on the results of the first survey compared to the network measures calculated based on the results of the second survey).

The biggest change in the density network was an increase in the density of the advice exchange and acquaintance ego-networks, implying that GRAND indeed promoted more advice exchange among GRAND researchers, as well as helped more researchers within the network to know each other. The communication ego-networks (both email and face-to-face) have decreased in their centrality, likely due to the inclusion of new (and not connected) researchers in GRAND. At the same time, the biggest change in the centrality measures was for the advice network, proving an additional indicator for
the increase in advice exchange within GRAND. The key changes when looking at the heterogeneity measure was a decreased heterogeneity in both email and face-to-face communication. This pattern implies that GRAND researchers moved to communicate more with researchers from their own discipline and less with researchers from other disciplines. Lastly, the key changes when looking at the effective size measures indicates that the acquaintance and face-to-face communication have become more redundant. This implies that there are more connected clusters of researchers within GRAND who communicate face-to-face or exchange advice with one another.

6.1.3 Key Findings Concerning Network Change and Research Outcomes: Research Question 3

The third part of my analysis examined the correlation between the structure and change of the co-authorship, communication, acquaintanceship, and advice exchange networks of GRAND researchers and their outcomes. As summarized in Table 6.1, I explored this interaction through four ordinary least squares regression tests and have identified that: (1) Knowledge outcomes are positively correlated with the density of the co-authorship ego network, and with the betweenness centrality, heterogeneity and effective size of the advice ego network; knowledge outcomes are also negatively correlated with the size of the co-authorship ego network; (2) Training outcomes are positively correlated with the size and density of the advice ego network, and with the density of the communication ego network; training outcomes are also negatively correlated with the effective size of the co-authorship ego network; (3) Outreach outcomes are positively correlated with the effective size of both the acquaintanceship and advice ego networks, as well as with the size and eigenvector centrality of the co-authorship ego network; (4) Collaboration outcomes are positively correlated with the size of the advice ego network as well as with the size and density of the co-authorship network. The significance of these findings is discussed below in section 6.2.3.
Table 6.1: Regression analyses testing the interplay between changes in network measures, and research outcomes.

<table>
<thead>
<tr>
<th>Model 1: Knowledge Outcomes</th>
<th>Model 2: Training Outcomes</th>
<th>Model 3: Outreach Outcomes</th>
<th>Model 4: Collaboration Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density of co-authorship ego-network</td>
<td>.40**</td>
<td>Degree centrality of advice ego-network</td>
<td>.24**</td>
</tr>
<tr>
<td>Betweenness centrality of advice ego-network</td>
<td>.35**</td>
<td>Effective size of co-authorship ego-network</td>
<td>-.19**</td>
</tr>
<tr>
<td>Degree centrality of co-authorship ego-network</td>
<td>-.04**</td>
<td>Density of advice ego-network</td>
<td>.42**</td>
</tr>
<tr>
<td>Heterogeneity of advice ego-network</td>
<td>.24*</td>
<td>Density of communication ego-network</td>
<td>.39*</td>
</tr>
<tr>
<td>Effective Size of advice ego-network</td>
<td>.08*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R square: .47</td>
<td>R square: .38</td>
<td>R square: .47</td>
<td>R square: .33</td>
</tr>
</tbody>
</table>
6.1.4 Key Findings Concerning Research Outcomes: The Interplay between Network Structures and Researchers Social Capital: Research Question 4

As addressed in my literature review, an ongoing debate occurs within the literature about social capital and social networks regarding the potential effect of network structure on the research outcomes of researchers. Thus, in the fourth part of my analysis, using the literature on social capital, I provide a more nuanced analysis of the change of co-authorship, communication, acquaintanceship, and advice exchange networks and their interplay with GRAND researchers’ research work. I, then, distill and interpret these results and frame them within the context of related literature.

The data analysis and findings of this section study are vast and informative and equate to an elaborate reporting in Chapter 5. The type of qualitative research conducted, as well as the rich data obtained through the semi-structured interviews, lends itself to an example-heavy, narrative report and discussion of the research study’s findings. In order to balance the breadth of the findings contained in Chapter 5 with a briefer account of the results of this chapter, the following key findings sections concisely highlight and summarize the key findings presented in Chapter 5, as related to research question 4.

Sections 5.1-5.3 are a result of the deductive coding phase. Deductive analysis is the act of organizing data based on predetermined themes, concepts, and theories derived from the literature review. In my review, I have proposed to look at social capital as resources and benefits which individuals can derive based on their embeddedness in a social network (Bourdieu, 1986). Social capital can be defined as ‘resources embedded in social networks accessed and used by actors for action’ (Lin, 2001, p. 25). Nahapiet & Ghoshal (1998) proposed three main dimensions for the study of embeddedness: structural, relational, and cognitive. This widely used conceptualization served for defining the broad themes discussed in sections 5.1, 5.2, and 5.3.

The subsections of these sections and section 5.4 are results of my inductive analysis, i.e., the act of coding the data based on new themes generated through an examination of the analyzed data. This process of inductive analysis enabled me to identify narratives that can help explain the interplay between network structures and researchers social capital.
Table 6.2: Proposed themes for the study of the interplay between network structures and researchers social capital.

<table>
<thead>
<tr>
<th>Predetermined Themes</th>
<th>Themes Generated Through an Examination of the Analyzed Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>The structural dimension of social capital</td>
<td>Ties to well connected researchers</td>
</tr>
<tr>
<td></td>
<td>Loose, large network</td>
</tr>
<tr>
<td></td>
<td>Heterogeneity and Homogeneity</td>
</tr>
<tr>
<td></td>
<td>Closure</td>
</tr>
<tr>
<td></td>
<td>Brokerage and structural holes</td>
</tr>
<tr>
<td>The relational dimension of social capital</td>
<td>Trust</td>
</tr>
<tr>
<td></td>
<td>Norms</td>
</tr>
<tr>
<td></td>
<td>Closeness</td>
</tr>
<tr>
<td>The cognitive dimension of social capital</td>
<td>Shared Language</td>
</tr>
<tr>
<td></td>
<td>Attention and time</td>
</tr>
</tbody>
</table>

The interview analysis discussed in sections 5.1, 5.2, and 5.3 were then used to explain these interplays between the networks (structure and change) and the research outcomes. I pulled the strands of my analysis together by proposing that it is the interaction between social capital and network structure that underpins the interplay between networks structure and research outcomes. These results are further discussed below in sections 6.2.2 and 6.2.3.

6.1.5 Qualitative Results: Bridging from Social Networks to Social Capital

As discussed above in section 6.1.4, the results of my interviews were used for interpreting in what ways the structure and change of the co-authorship, communication, acquaintanceship, and advice exchange ego networks of GRAND researchers interplay with their research outcomes. In order to do so, I showed how theory and research on social network analysis can be enriched with insights from the burgeoning research in the
field of social capital. As demonstrated, interviews, coupled with social capital literature, were crucial for interpreting the correlation found between network measures and research outcomes.

However, the measurement and conceptual development resulting from my social network analysis combined with my interview data, can also enrich the work on social capital within research networks. One of the *raisons d’être* of GRAND and similar networks is to enhance collaboration among researchers as a means of achieving a level of research output that is greater than what would have been achieved by working alone. As noted earlier, the research community increasingly celebrates collaboration, yet in many cases this collaboration does not yield the expected outcomes. As my literature review discussion indicates, a key factor in enhancing the outcomes produced by collaborating researchers is enhancing the resources and benefits they can gain based on their embeddedness in a social network.

Using my social network analysis and interview data as a bridge to the literature of social capital, there is the potential to harness the rigorous language of social network analysis to describe the properties of relationships. The graph-theoretic properties of networks such as “density” or “centrality” are measurable quantities that underlie the dynamic social processes of interest to social capital researchers (Wasserman & Faust 1994). Defined clearly, unambiguously, and with mathematical exactness, these network properties, if adopted, can allow social capital theories to be more precisely specified and tested (e.g., Wellman & Wortley, 1990).

Combining my interview findings and my social network analysis has highlighted thirteen constructs that translate and adapt the aggregate factors of social capital theory to the concrete field of research collaboration. Five of these constructs relate to the structural aspect of social capital: (1) brokerage and structural holes; (2) heterogeneous; (3) closure; (4) ties to well connected researchers; and (5) large network focus. Three of the constructs relate to the relational aspect of social capital: (6) closeness; (7) trust; and (8) norms. Two of these constructs relate to the cognitive dimension of social capital: (9) shared language; and (10) attention and time. These constructs can guide researchers who wish to study the formation of social capital within the context of research networks through highlighting some aspects that they should consider in their work.
My findings highlight the notion that it is difficult to separate form (i.e., network structure) from content (i.e., social capital). I argue that the most promising bridge combines the structure of networks with the content of social capital to better analyze research networks. Similar network structures based on different content will produce different outcomes. At the same time, shared values or norms based on different network structures will produce different outcomes. In short, the intersection of social capital and networks should improve our ability to study research networks. I hope that my findings will help inform researchers in this field in order to help frame future studies of research collaboration.

6.2 Significance of the Study

The intellectual contribution of this dissertation falls within several rubrics. I will next address these potential implications, namely: the difficulties of building a prescriptive model of research collaboration; bridging social network analysis and social capital; different predictors of research outcomes; and, complementary versus integrative research collaboration.

6.2.1 Difficulties of Building a Prescriptive Model of Research Collaboration

In their attempt to develop a theory of remote research collaboration, Olson et al. (2008) suggested more research is needed to understand the connections between the social and epistemic aspects of work organization and the circumstances under which they operate. Olson et al. are concerned with building a prescriptive model of remote collaboration that provides insights into the design of remote collaborative environments and predicts the consequences of certain decisions. Building this kind of model is an attempt to go beyond description to prediction; for example, prediction of what might happen to collaborative groups working remotely, if certain conditions are not met. I have no objection, in principle, to such a model; as indicated in my literature review, such a model can be a useful gauge for those who need direction. Furthermore, in some sections of my work, I built upon the model elaborated by Olson et al. However, the construction of a normative model of collaboration is very challenging.

A relation between the social and epistemic aspects of research collaboration cannot be seen as necessary and inevitable, because this relation is contingent upon specific settings (e.g., cultural and organizational context, and the nature of work). Therefore,
although social and epistemic aspects are bound to have an effect on the nature of collaboration and on research outcomes, it is difficult to predict the precise nature of their impact. Similar aspects of social and epistemic interactions among researchers can produce different outcomes in different settings and circumstances. For instance in my analysis, I show how one type of epistemic ties (size of co-authorship ego network) is negatively correlated with knowledge outcomes. Other studies that have looked at co-authorship ties among co-located researchers from the same discipline found the opposite results, i.e., positive correlation between the size of the co-authorship network was and knowledge outcomes (Cummings & Kiesler, 2007). Consequently, the social and epistemic aspects that are supposed to influence collaboration need to be explained rather than be assumed to be explanatory causes in themselves, because the relation between these aspects and the success or failure of collaboration is unlikely to be linearly causal.

Informed by social network analysis and social capital literature, the methodological position adopted in this dissertation is that research collaboration is best studied in terms of the processes through which researchers choose to collaborate. This investigation cannot be done by relying on an analytical framework that treats collaboration as a product and considers the social and epistemic aspects of work organization as precursor explanatory causes.

Accordingly, my premise is that collaboration is best studied by tracing how social and epistemic aspects interplay with different research outcomes produced the researchers. I argue that successful collaboration should not be discussed within the context of causal effects of social and epistemic aspects of research work. Rather, it is more constructive to talk about the conditions that are promoted by the form (i.e., network structure) of the collaborating researchers, and by the content (i.e., social capital) of these ties. Thus, the following sections describe the relations among the social and epistemic aspects of research work, and the conditions they foster for GRAND researchers.

6.2.2 Bridging Social Networks Analysis and Social Capital

This study lends support to the argument that social capital and social networks, when combined, yield richer theory and better predictions (Baker & Faulkner 2009). The social networks analysis conducted in this dissertation offer precise measures of the
social structure and of the change of the GRAND research network. The social capital-driven findings helped to move beyond the relations themselves to understand how investment in personal relationships or social structures can either facilitate or hinder the achievement of different research outcomes.

Although some scholars may be interested in definitions of social capital or in the microprocesses within ego networks as scientific ends in themselves, it is likely that most scholars care about these features of research collaboration as frameworks to be used to help better understand research networks. I have argued that when trying to understand the interplay between network change and research outcomes, scholars are better served by integrating the insights of social capital and social networks literature. My general point has been that it is difficult to divorce form from content. Thus, combining the structure of networks with the content of social capital can help to better understand the structure, change, and outcomes of research networks. More specifically, this study illustrates that full operationalization of social capital theory requires attention to the structure of social networks, as seen by the constructs presented in section 5.4 “Research Outcomes: Bridging Social Networks and Social Capital.” Simultaneously, full specification of the theory in social networks requires attention to the content of social capital that was analyzed through qualitative mechanisms (see section “Research outcomes: Bridging social networks and social capital”).

This study adds to the argument that no simple model of a collaborative arrangement, such as GRAND, would be of any value if social structure and social content were not taken into account. Many structural elements interact in the operation of a research network. However, this fact should not obscure the common attributes and perceptions that characterize most research networks. The size and composition of research networks and their epistemic and social structures (e.g., work, communication, acquaintanceship, and advice networks) are some of the key variables that were found to be related to the outcomes of the researchers. As my findings reveal, different network structures can prove to be constructive for some research outcomes and not for others. Thus, each type of network measure deserves careful consideration.
6.2.3 Different Research Outcomes and Different Predictors

In general, the study of research networks through the prism of social network analysis and social capital focuses on the evaluation of the role networks play in facilitating (or hindering) the achievement of research outcomes. This kind of study focuses on whether networks are effective, and to what extent they provide a constructive research environment. This is seemingly a straightforward proposition, although, as I have shown, in some cases, the results are more nuanced. This dissertation does not offer an evaluative study. Rather, it provides explorations of the use of SNA and social capital in ways that move beyond the relations themselves to understanding how investment in personal relationships or social structure interplays with research outcomes.

The findings of this dissertation suggest ways of looking at network structures and social capital properties that are useful for the study of research networks. More specifically, my findings show how, in most cases, network measures are only correlated with one type of research outcome and not with others (e.g., co-authorship eigenvector centrality is positively correlated with outreach outcome while it has no correlation with other research outcomes). There are only two cases where the same network measure is correlated with different research outcomes (density of co-authorship ego networks is positively correlated with both knowledge and collaboration outcomes; and, the effective size of the advice ego network is positively correlated with knowledge and outreach outcomes). Especially interesting is the fact that in one case a network measure (size of co-authorship ego network) is positively correlated with two research outcomes (outreach and collaboration outcomes) and negatively correlated with another outcome (knowledge outcomes).

Thus, my findings highlight that, in order to make SNA and social capital useful for the study of research networks, a primary question for researchers utilizing this approach should be: What are we expecting to get out of research networks in the first place? The efficacy of SNA should be driven by an understanding of what the research network aims at facilitating and fostering in the first place. For instance, if outreach and collaboration outcomes are the goal, it might be more constructive to encourage researchers to co-author papers with researchers they didn’t co-authored with in the past; whereas if
knowledge outcomes are the goal, it might be more constructive to encourage collaborating with past co-authors.

Furthermore, my findings highlight the importance of studying the different networks that connect researchers. I emphasize the notion that exploring a single manifestation of connection among researchers would fail to reveal the rich web of interactions that researchers engage in and, thus, would prevent us from fully capturing how network structures can interplay with research outcomes. As previously discussed in Chapter 3, Newman’s work states that “it is probably fair to say that most people who have written a paper together are genuinely acquainted with one another” (2004, p. 339). Many scholars who investigate research networks make assumptions of this kind, without supporting them with data. My dissertation findings stress the need to question such assumptions, and more importantly, to actually examine the different types of ties that exist among researchers, because different ties have different patterns of correlation with research outcomes.

On a practical level, I believe that funding agencies and research networks administrators can utilize my findings in the following manners:

1. Firstly, there need to be clear articulation of the intended research outcome. As my analysis shows, different research outcomes have different types of interplay with different network structures. Thus, before evaluating a research proposal or managing a research network there needs to be a clear understanding of what the intended research outcomes are. Only based on such understanding, can a constructive evaluation or management of research work take place. The Cummings and Kiesler (2005) framework offers a good frame for considering the different prospective research outcomes.

2. When evaluating research proposals, the evaluators can also look at the network structure of the researchers who are submitting the proposal. Through this type of evaluation it can be assessed weather the network structure of the researchers is one that has been found to be correlated with the type of research outcomes the evaluators wish to foster. This evaluation can be included in the overall estimation of the proposal.
3. Lastly, research network administrators can plan interventions that are aimed at fostering the network structures that are correlated with the type of research outcomes the research network wishing to promote. For example, if the administrators of a research network wish to foster new co-authorship ties among researchers, a pattern that is correlated with outreach outcomes, they can designate official “matchmakers” within the network. According to Hayat and Lyons (2010) a “matchmaker” is a researcher that co-authored with different groups of authors who have not co-authored with one another in the past. The members of these separate groups began co-authoring with one another after they first co-authored with the matchmaker. Potential matchmakers can be identified based on their past co-authorship patterns (see Hayat and Lyons, 2010), and then they can be given a formal role of bringing together new potential collaborators.

6.2.4 Complementary versus Integrative Research Collaboration

While interpreting how different network structures (e.g., size, density) within different types of the ego network (e.g., co-authorship, advice) interplay with research outcomes, a typology of collaboration emerged. GRAND researchers discussed collaboration as a continuum of different types, or levels, ranging from complementary (referred to by the interviewees as “minimal collaboration” or “consultation”) to integrative collaboration (referred to by the interviewees as “true collaboration”). In the case of complementary collaboration, a researcher interacts with other researchers who may be completely unaware of the problem or question the researcher is trying to address. With the knowledge gained, the researcher can then synthesize a solution by himself. In the case of integrative collaboration, new knowledge is co-created by interacting researchers who are continuously exchanging ideas with each other and actively integrating their different perspectives. According to my interviewees, this approach implicitly presents the need for both an awareness of another researcher’s distinctive knowledge/skill and the complementary fit of that knowledge/skill with the ongoing aspect of research.

Finding through the interviews also indicated that these two kinds of research work are supported by different kinds of interactions with other researchers; this shows that to maximize complementary collaboration, relationships between the researcher and the
resources they draw on do not need to be close, but that acquaintanceship ties are sufficient for this purpose. Within the context of GRAND, parties also need to have some skill at effectively communicating across: (a) distance and (b) disciplines because these are inherent barriers due to the structure of GRAND.

Integrative collaboration, on the other hand, is more intense, thus the relationship between the involved researchers needs to be stronger; in particular, they need to be able to understand each other well. The interviewees who discussed integrative collaboration indicate that the participants in such collaborations need to be fundamentally similar in language and background concepts.

When interpreting the interplay between network structures and research outcomes, I referred to the distinction between complementary and integrative collaboration. I believe that this is a fundamental difference that should be addressed explicitly in future studies of research collaboration.
Chapter 7: Conclusion

In this final chapter, I acknowledge some of the challenges and limitations that were encountered while conducting this research. In addition, I proposed some areas for future development of this research in order to address these challenges and extend the scope of the research presented in this dissertation.

7.1 Limitations

This study has three important limitations that need to be taken into account when considering the results and their contributions.

7.1.1 Data Sources

As with other studies, this analysis relied on the necessarily partial character of the data sources used. In my study of GRAND, I used surveys, online forums, and interviews to construct an account of how research collaboration occurred within GRAND. In fact, GRAND researchers were dispersed and ubiquitous. Due to these circumstances, I could not observe their actual work. Therefore, I had to rely on the researchers’ accounts of their interactions. I did not presume these accounts to be “objective” descriptions, but rather the participants’ perceptions of these interactions. A number of aspects may have influenced these perceptions, consciously or unconsciously, including how people felt that situations should be described, the desire to present themselves in a particular light, the reluctance to reveal some types of information, and the type of questions I asked. Additionally, in several cases, interviewees were asked to recall events that took place a year prior to the interview.

Focusing specifically on my social network data, it is important to note that I found surprisingly little work done on the issues of validity, reliability, and measurement error in social network data. One challenge in assessing the value of such data is that it is difficult to ascertain whether the reported and true networks are the same (Holland & Leinhardt, 1973). Knowledge of the true network is usually impossible to obtain (e.g., in this case, I do not know which GRAND members actually know each other). There has been some empirical work on the accuracy of network measurement. The accuracy of various network name generators has received the most attention, but there is little research on this approach validity because criterion data from other sources are unavailable (Marsden, 2005). The literature does offer recommendations for how to best
use name generators and interpreters and on how to maximize informant accuracy (Marsden, 2005). Lessons learned from these recommendations were incorporated in the survey portion of this study. To increase the degree of trust in the network data collected, several steps were taken that were described in full detail in the Chapter 3.2: Data Instruments.

Furthermore, in conducting a social network study, the validity of the study must be addressed (Strauss & Corbin, 1998). Although pure validity is not possible, certain techniques were applied to maximize the accuracy and relevancy of the study. Specifically, member checking was employed to authenticate the interview data (Creswell, 2002). During the interviews, I constantly checked my understanding of the answers I received from the interviewees by utilizing techniques such as paraphrasing and summarization for clarification. In every interview, I also asked for permission to contact the interviewee again if I had any questions about his/her answers, and in two cases I have contacted the interviewees in order to clarify answers.

Additionally, in accordance with the member checking technique, random interviewees from GRAND were asked to review specific statements from their interviews in order to evaluate accuracy, include additional information, and clarify vague and/or unclear responses. By interviewing researchers who came from different disciplines and organizational origins, the differing viewpoints and positions of GRAND researchers allowed for a cross-comparison analysis. Since information on the team came from multiple participants and perspectives, the variation in data collection methods was intended to enhance the dependability of this study.

7.1.2 Participatory Researcher

Another important limitation of this study arose from the fact that I was a participatory researcher (I was a member of the NADEL project). It is important to note this element because I conducted the interviews, and I solely conducted all of the data analysis presented in this dissertation. Despite some advantages of being the data collection instrument, there were also shortcomings and biases that might have had an impact on the study. One of the challenges of being a researcher-participant was that, by working closely with GRAND researchers, I brought certain biases to this study. Part of the challenge was to set aside or suspend some of my attitudes and positions about
GRAND characteristics. It was important to listen to the voices of the interviewees and avoid imposing any of my own biases.

Rather than trying to eliminate these biases, it was important to identify them and to monitor how they shaped the collection and interpretation of the data (Merriam, 2002). I tried to be reflective about my assumptions, because they shaped the way I interacted with my study participants and, more importantly, influenced the ways in which I interpreted the data (Merriam, 2002). I tried to address this process when describing my methods and data analysis.

7.1.3 The Boundary Problem

As I have indicated in many parts of this dissertation, studies of research networks often encounter problems of boundary definition. My efforts to address this issue only scratch the surface of this problem. Research networks cross geographical and disciplinary boundaries (just to name a few). While a number of methods can be employed to define the boundaries of a research network (e.g., the people, artifacts, relationships, practices that are to be included in the study), it is important to remember that, regardless of the method used and its efficiency, the choice of a method and the resulting sample greatly affect the outcome of a study.

In this dissertation, I identify the population of interest by including all individuals indicated as GRAND researchers (based on GRAND administrative records). My data on these researchers was collected through surveys, online forums, and interviews. Thus, I exclusively used the data recorded through these sources in my analysis. Nevertheless, my methods failed to include individuals that possibly are directly involved in GRAND research but who are not identified as GRAND researchers (e.g., graduate and post-doctoral students). This group might also include members involved with administrative work as well as technical support groups; these individuals are physically present and actively involved in GRAND. Despite being absent from my analysis, they may be important for the study of research collaboration.

7.2 Future Work

The questions addressed in this dissertation beg further research, given that the results from this study are limited to the population of GRAND. Furthermore, as discussed in the previous section, the methods presented in this dissertation is not without
limitations. Further research can extend our understanding of the change of the GRAND research network and similar networks.

An obvious avenue for potential research is to deal with the limitations outlined in the previous section. In particular, the first limitation (data sources) discussed above points to many possibilities for future research. For my dissertation research, I could only collect quantitative data relative to four types of interactions (i.e., co-authorship, advice, communication, and acquaintanceship). What other collaborative activities can be documented to complement and inform the study of research collaboration? The list is potentially endless. Some examples include citation patterns, co-word networks, data from collaborative software coding, and private email communication.

Citation networks can be constructed by looking at which authors are connected to each other based on the authors they cite in their research work. Co-word networks can also be constructed to depict the intellectual connection among researchers based on the full texts of their research work. In a technology-driven environment like GRAND, collaboration is not limited to traditional research artifacts; much work goes into the development of software that will enable researchers to collaborate remotely with one another. Many software coding projects at GRAND are collaborative and are handled using version control systems. Gathering and analyzing these data could provide insights into the collaborative practices of software coding. Finally, private email exchange is, naturally, the most revealing form of communication, but also the hardest to obtain because of privacy and confidentiality issues. An analysis of email traces could expose very accurately the effect of email communication on the propagation of research ideas and research collaboration.

Another interesting starting point for further research would be to study the interplay of network structure and change and research outcomes within the context of other case studies of research networks. There is still considerable work to be done in pinpointing network structures and properties that are most meaningful in the context of research networks. The challenge is to distinguish what is the most effective network structure for achieving the desired outcomes. On this point, the SNA and social capital literature is ambiguous. For instance, a great number of studies combining social capital and SNA have been utilized to examine business performance as the key dependent variable, by
looking at aspects such as sales, patents, and innovation. However, the network variables utilized range from structural holes (Ahuja, 2000), network density (Valente, 1996), and centrality (Owen-Smith & Powell, 2004), to name only a few. As this handful of studies demonstrates, there is still a great deal of diversity of thought on what constitute the key network variables.

Several studies have begun to recognize that different types of research work are better supported by different network structures. One of the first to do so was Borgatti (2005), who argued that radical innovation is facilitated by sparser and clumpier networks, while incremental innovation is better served with denser networks. The work of Monge and Contractor (2003) on very large computer-based communication networks may be instructive in this regard, as well. That work began to lay out a theory regarding which network structures best suit different purposes—purposes such as exploring new information, exploiting existing resources, mobilizing action, swarming (acting together), or bonding among members.

My findings join this body of literature by highlighting how and why different structures of different networks are correlated with different research outcomes. It would be worthwhile to test the findings that emerged from this dissertation on similar, or related, research networks including the different types of networks (i.e., co-authorship, advice, communication, and acquaintance), different structures within these networks (i.e., different centrality measures, heterogeneity, effective size, and density), and the nature of the work conducted by the researchers (i.e., complementary vs. integrative collaboration). This direction for future study is especially relevant, as research collaboration continues to increase both in scope and in importance (Sonnenwald, 2007). As fresh challenges emerge and introduce new goals for researchers and as the contexts continue to evolve in which research work takes place, new approaches and propositions for the study of research collaboration will be required.
References


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Appendix A: Online survey

 PAGE 1

The Network Assessment and Validation for Effective Leadership (NAVEL)

The Graphics, Animation and New Media Network of Centres of Excellence (GRAND) is studying the collaborative relationships of the scholars and practitioners involved in its work. Part of GRAND’s mandate is to create a community of professionals engaged in collaborative research, innovation, and knowledge transfer. Understanding the relationships among them is crucial for understanding how GRAND achieves its mandate.

The Network Assessment and Validation for Effective Leadership (NAVEL) is a special project of GRAND which assists its decision-making. NAVEL’s goal is to trace the formation and evolution of the relationships among GRAND’s participants. This is our baseline survey. It will capture how professionals in GRAND are connected to each other before the network is fully operational. The survey asks about your relationships with other participants in GRAND including questions about who you collaborate, exchange advice, or network with, how strong your relationships with them are, and what technology you use to communicate and collaborate with them.

This survey takes between 30 and 40 minutes to complete. You can stop at any time and come back to the survey later. It will be helpful to have your address book nearby when working on this survey.

We know that there are constraints on your time but it is only with your help – and with the input of as many of GRAND’s participants as possible – that we can learn about the way our community functions. We will send you feedback on your own professional network in GRAND and we will make the results of the study available to the community. Our staff will provide tips for the efficient utilization of the collaborative tools that GRAND’s members use most often. We appreciate every bit of information you are able to give us and we thank you in advance for your participation.

NEXT

Clicking on the NEXT button takes participants to the Consent form
CONSENT FORM

I have read the Letter of Introduction from Professor Barry Wellman and I understand the purpose of the Network Assessment and Validation for Effective Leadership (NAVEL) project as well as its potential benefits and/or risks to me. My questions have been answered to my satisfaction. I have received a copy of the Invitation Letter and Consent Letter for my records. I will receive feedback about my personal network in GRAND. Based on this, I voluntarily consent to participate in the survey.

I understand that my participation is voluntary and that I may withdraw from the survey at any time or I may decline to answer any questions. I can withdraw by choosing the “Decline” button or, if I have already submitted some information, by contacting the research team (contact information below) and notifying them that I withdraw from the research. My information will not be included in the data. My withdrawal or my decline to complete the survey will have no consequences.

I have been assured that I will not be identified in any specific way. My name will be replaced by an identification number, the computer files with the data will be password protected and kept in a secure location, and hard copy documents will be kept in locked storage. The original hard copy documents and computer documents will be destroyed upon completion of this work. The list containing the identification numbers and names will be kept separately from the dataset on a password protected computer. Only members of the research team, working directly with the dataset and bound by a confidentiality agreement, will have access to the data.

I will remain anonymous and my identity will be protected in all reports and publications based on this research. I have been promised access to these reports and publications.

With these safeguards in mind, I agree that the findings from the survey can be used in reports, scholarly publications or presentations at scholarly meetings.

I understand that I may contact the research team at dima@chass.utoronto.ca or directly the Office of Research Ethics at the University of Toronto ethics.review@utoronto.ca or 416-946-3273 for further clarification of my rights as a respondent.

☐ I agree  ☐ I decline

Participants can proceed only after clicking the box next to “I agree”.

179
SECTION 1. ABOUT YOU

Name ____________________________________________________

Primary affiliation_______________________________________________

Position  _______________________________________________________

Highest degree received  ______________________________________

Drop down menu

Bachelors

Master’s

Ph.D.

Other (Please specify) ____________

Discipline, in which currently working______________________________

(Please type)

Year of birth: 19 _____

Gender  □ Male    □ Female
SECTION 2. YOUR GRAND NETWORK

In this section, we ask you about who you know among the people involved in GRAND. By *know* we mean you have talked at conferences or meetings, discussed professional matters, or worked together on a publication or a project in the past 12 months. Your interaction with them does not necessarily have to be related to the work of GRAND. For instance, you might have met a participant in GRAND because you both sit on an advisory board of your provincial government or on a student thesis committee. Even though your interaction is not related to GRAND, this person is a member of your network.

Below is a list of participants in GRAND, grouped by organization. Please check the boxes next to the names of the people you know.

<table>
<thead>
<tr>
<th>University</th>
<th>Name</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Carleton University</td>
<td>Brent, James</td>
<td>☐</td>
</tr>
<tr>
<td></td>
<td>Wilson, Emma</td>
<td>☐</td>
</tr>
<tr>
<td>Dalhousie University</td>
<td>Corman, Antony</td>
<td>☐</td>
</tr>
</tbody>
</table>

SECTION 3. YOUR PROFESSIONAL NETWORK

Our next questions are about the participants in GRAND who you not only know but with whom you also work, exchange advice and ideas, or network. They are part of your professional network. Quite likely, not all the people you know in GRAND are also members of your professional network.

Your interactions with the members of your professional network do not have to be necessarily related to GRAND. For instance, you might work with a participant in GRAND on a project outside GRAND. This person is a member of your *professional network*. Such information will help us understand how the members of our community connect to each other.

The table below includes the participants in GRAND you told us you know. In columns two to four, please check the boxes for EACH person:

- **WHO YOU HAVE WORKED WITH** on new media and technology issues in the past 12 months such as collaborated on a research project, consulted, or wrote a paper
- **WHO YOU GAVE ADVICE TO** in the last 12 months when they had a question or a problem
WHO YOU RECEIVED ADVICE FROM in the last 12 months when you had a question or a problem

<table>
<thead>
<tr>
<th>Name</th>
<th>I WORKED with</th>
<th>I GAVE Advice to</th>
<th>I RECEIVED Advice from</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brent, James</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wilson, Emma</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

PAGE 6
SECTION 4. YOUR RELATIONSHIPS

Not detailed as the questions covered in this section were not used in my thesis.
SECTION 5. YOUR COMMUNICATION AND COLLABORATION TECHNOLOGY

The participants in GRAND come from different locations and typically use media to communicate and work together. Our next questions are about how you communicate with the members of your network, what tools you use, how often you contact your colleagues, and where you work from. These results will help us to assess how communication and collaborative technologies support GRAND’s dispersed community.

In the table below, please use the drop down menu in the second column to tell us, for EACH person, the **TOP THREE MEDIA** which you use to contact this person. Media might include in person meetings, emails, phone calls, etc. Don’t worry about the limited number of the media or their order. We understand that you probably use more than three media to get in touch with each person. Please select the three media which you use most frequently.

Next, in the third column, please tell us **HOW OFTEN** you use EACH of the TOP THREE media. For instance, you may email colleagues from GRAND daily but meet them only once a year. We understand that your answers give averages and the frequency of use for each media may vary at different times.
Name | TOP THREE media | HOW OFTEN used
---|---|---
*Brent, James* | Email | Weekly
 | Phone | Monthly
 | In person | Monthly

*Wilson, Emma* | Email | Weekly
 | In person | Less than once a year
 | Phone | A Few Times a Year

**2 DROP DOWN menus**

**Drop down menu for MEDIA Categories:**
- In person
- Email
- Mobile Phone – one-to-one
- Texting
- Landline Phone – one-to-one
- Voice over IP (e.g., Skype, Google Talk) – one-to-one
- Audio or and Video-conferencing
- Online forum
- Social Networking sites (e.g., LinkedIn, Facebook)
- Instant messaging or chat (e.g., MSN Messenger, Skype)
- Other

**Drop down menu for FREQUENCY of Communication Categories:**
- Several times a day
- About daily
- Weekly
- Monthly
- A few times a year
- Yearly
- Less than once a year

*PAGE 8*

Not detailed as the questions covered in this section were not used in my thesis.
SECTION 6. YOUR FUTURE GRAND NETWORK

Not detailed as the questions covered in this section were not used in my thesis.

SECTION 7. COMMENTS AND REVIEW

Would you like to send us additional comments?

This is the end of our survey. If you would like, please take a moment to review and edit your responses.

Thank you for participating in this survey. You help is truly appreciated.
Appendix B: Surveys/interview invitations and consent forms.

NAVEL Invitation Letter

Dear GRAND participant,

We are asking for your help in an important study of our community - the NAVEL Gazing study. It is a key project of GRAND: specially commissioned to understand the collaborative relationships among the scholars and practitioners involved. Part of GRAND's mandate is to create a community of professionals engaged in collaborative research, innovation, and knowledge transfer. Understanding the relationships among the members of our community is crucial to understanding how GRAND achieves its mandate. In turn, this understanding will be used to improve the support for collaboration and knowledge transfer in the community.

NAVEL's goal is to trace the formation and evolution of the collaborative relationships among GRAND's participants as well as the ways they work together. We start with a baseline network survey that will help us to understand how professionals in GRAND are connected to each other before the network is fully operational. The survey will ask about your relationships with other participants in GRAND such as who you collaborate or network with, how strong your relationships with them are, and what technology you use to communicate with them. The survey results will produce a map of the collaborative relationships among the members of our community.

In addition, to understand better your experiences and practices, the NAVEL team will also conduct interviews with some GRAND members at the Ottawa meeting and afterwards. The interviews include questions such as how our members communicate and collaborate on projects, and what technology they use.

Of course, we will make the findings of the study available to you. While the results will directly assist GRAND's staff in planning networking events or providing technology, all participants in our community will benefit from the improved support of their work. On a personal level, you will be able see your network in GRAND and this can help you to better understand your own collaborative practices, direct your networking efforts, and focus your collaborative ideas.

Participation in this study is voluntary and the data is treated as confidential. If you have any questions or concerns about this study, please feel free to contact us by email at navel@surveys.grand-nce.ca. We appreciate every bit of information you are able to give us and we thank you in advance for your participation.

Sincerely, Barry Wellman, FRSC S.D. Clark Professor of Sociology, University of Toronto

Network Investigator & NAVEL project leader
CONSENT FORM

I have read the Letter of Introduction from Professor Barry Wellman and I understand the purpose of the NAVEL project as well as its potential benefits and/or risks to me. My questions have been answered to my satisfaction. I have received a copy of the Invitation Letter and Consent Letter for my records. I will receive feedback about my personal network in GRAND. Based on this, I voluntarily consent to participate in the survey/interview.

I understand that my participation is voluntary and that I may withdraw from the survey/interview at any time or I may decline to answer any questions. I can withdraw by choosing the “Decline” button or, if I have already submitted some information, by contacting the research team (contact information below) and notifying them that I withdraw from the research. My information will not be included in the data. My withdrawal or my decline to complete the survey/interview will have no consequences.

I have been assured that I will not be identified in any specific way. My name will be replaced by an identification number, the computer files storing the data will be password protected and kept in a secure location, and hard copy documents will be kept in locked storage. The original hard copy documents and computer documents will be destroyed upon completion of this work. The list containing the identification numbers and names will be kept separately from the dataset on a password protected computer. Only members of the research team, working directly with the dataset and bound by a confidentiality agreement, will have access to the data.

I will remain anonymous and my identity will be protected in all reports and publications based on this research. I have been promised access to these reports and publications.

With these safeguards in mind, I agree that the findings from the interview can be used in reports, publications or presentations.

I understand that I may contact the research team at navel@surveys.grand-nce.ca or directly the Office of Research Ethics at the University of Toronto ethics.review@utoronto.ca or 416-946-3273 for further clarification of my rights as a respondent.

Name ____________________________________________

Address ____________________________________________

Date ____________________________________________

Signature ________________________________________
**Appendix C: Outcome survey**

**GRAND Research Outcomes Survey**

**The original survey included additional questions; I am only including here the questions that were used in this thesis**

**Researcher Name:**

This short survey is intended for studying the research outcome of GRANDs’ researchers. The below table lists the different research outcomes we wish to study. Below each item you will see a list of potential research outcomes that can help you assess your performance, as well as the performance of your main GRAND project. Please circle your ranking for each of these research outcomes on a scale ranging from 1 (very low) to 7 (very high).

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Very low outcomes</th>
<th>Low</th>
<th>Below average</th>
<th>Average</th>
<th>Above average</th>
<th>High</th>
<th>Very high outcomes</th>
<th>Not relevant</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Knowledge outcomes:</strong> if you developed/achieved</td>
<td>Very low outcomes 1</td>
<td>Low 2</td>
<td>Below average 3</td>
<td>Average 4</td>
<td>Above average 5</td>
<td>High 6</td>
<td>Very high outcomes 7</td>
<td>Not relevant</td>
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<tr>
<td>- new model or approach in field;</td>
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<td>- new grant or spin-off project</td>
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<td>- patent application</td>
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<td>- conference presentation</td>
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<td>- new publications</td>
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<td>- awards for contribution to fields.</td>
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<tr>
<td><strong>Tools outcomes:</strong> if you created/generate</td>
<td>Very low outcomes 1</td>
<td>Low 2</td>
<td>Below average 3</td>
<td>Average 4</td>
<td>Above average 5</td>
<td>High 6</td>
<td>Very high outcomes 7</td>
<td>Not relevant</td>
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<td>- new methodology</td>
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<td>- new software or hardware</td>
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<td>- new dataset, new materials, or data repository</td>
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<td>- website to share data or conduct online experiment</td>
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<td>- new kind of instrument</td>
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<tr>
<td><strong>Training outcomes:</strong> if your grad students / post-docs</td>
<td>Very low outcomes 1</td>
<td>Low 2</td>
<td>Below average 3</td>
<td>Average 4</td>
<td>Above average 5</td>
<td>High 6</td>
<td>Very high outcomes 7</td>
<td>Not relevant</td>
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<tr>
<td>- finished thesis or dissertation</td>
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<td>- got academic or industry job</td>
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<td>- received training</td>
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<tr>
<td><strong>Outreach outcomes:</strong> if you formed/established</td>
<td>Very low outcomes 1</td>
<td>Low 2</td>
<td>Below average 3</td>
<td>Average 4</td>
<td>Above average 5</td>
<td>High 6</td>
<td>Very high outcomes 7</td>
<td>Not relevant</td>
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<td>- partnership with industry</td>
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<td>- community relationship through research</td>
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<tr>
<td>- collaboration with researchers</td>
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<td></td>
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<td></td>
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<tr>
<td>- collaboration with museum or community institution</td>
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<td>- collaboration with healthcare institution</td>
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</table>
Thank you very much for taking the time and filling in this survey!

The NAVEL team
Appendix D: Interview protocol

NAVEL Gazing Interview Protocol (produced by the NAVAL team)

**The original protocol included additional questions; I am only including here the questions that were used in this thesis.

Section A. Getting involved in GRAND

Q1. How did you get involved in GRAND: Did someone you knew from before invite you to join? Did they start a new project where your expertise was needed?

Q2. You joined GRAND after it has existed for some time. Does this affect your experience in any way?
   - How? For instance, clearer expectations, or harder to fit in, develop agenda?

Q3. Do you have research projects outside GRAND?
   - What proportion of your research work would you say is in GRAND?
   - Does GRAND research differ from your other projects? How?
     If yes, does the difference make them more important? Less important?

Section B. Multidisciplinary Work

Let’s talk about how you work with other GRAND members.

Q1. Which is your primary project? ______________________________

Q2. Who in your project do you work closely with?
   - Do you work together on a daily basis?
   - Are they in the same discipline / field as you are?
   - Are they in the same location as you are?

Q3. Do you work with project members outside your field / disciplines?
   - How did it start? (whose suggestion or project arrangement?)
   - Why do you need to collaborate with them? What was the common ground? How did you find the common ground?
   - What do you do together? What are your tasks? What are theirs? Who depends on whom? Who made the division?
   - Have you asked for advice each other? Was it helpful?
   - Have you shared new ideas and findings?

Q4. How does working with people outside your field / discipline differ compared to working with people from the same field / discipline?
Q5. Do you work with team members from other locations / institutions on your project?

- How did it start? (whose suggestion or project arrangement?)
- Why do you need to collaborate with them?
- What do you do together? What are your tasks? What are theirs? Who depends on whom? Who made the division?
- How frequently do you communicate with them? How do you keep each other informed?
- Have you asked for advice each other? Was it helpful?
- Have you shared new ideas and findings?

Q6. How does working with people from other locations / institutions differ from working with people from the same location / institution?

- Were there any specific challenges during the collaboration [that would not exist when collaborating with colleagues in your university]? Any communication issues?
- Conflicts? Misunderstanding? How did you solve it?
- Is this due to distance or to institutional differences?
- How did you benefit from this experience?

Section C. Networking and Relationship Management in GRAND

My next questions are about networking and relationships in GRAND.

Q1. Do you know the other researchers and students in your project?

Q2. Would you like to collaborate with others in your project/GRAND? Why or why not? Or: what do you expect the benefits of collaboration with your research project/GRAND members might be?

Q3. Did you make efforts – above and beyond completing your work on the project - to build a rapport with other project members? Or with other GRAND researchers you know?

- How did you do it?
- Are there practices - on project level or on GRAND level - that help building relationships among team members?

Q4. Did you meet new collaborators in GRAND who you did not know before GRAND?
- How did it happen? Did you or the other member contact each other directly? Did someone introduce you?
- Would that relationship have happened without GRAND? What resources did GRAND provide? Events and initiatives?
- What do you do together? Did you start a new project? Do you exchange ideas? Advice?

**Q5. Do you think the network in GRAND may sometimes hinder your work?** For instance too much information or too much people.

### Section D. Coordination and Communication

I have a few questions about the coordination and communication on your projects.

**Q1. How is the work on this project coordinated?** (How do people know what to do?)

- Is there a person who does most of the coordination work on the project?
- Is this a formal position (coordinator, manager, etc.)?
- Are there any GUIDELINES - either online or in paper – that spell out things like division of work, communication, or other project practices? Can you share it with me? *ASK THEM TO SEND it.*
- Is it working for the team? [*Rationale: Efficiency, achieving goals*]

**Q2. How do you keep informed about what is happening on your project(s)?**

- *Probe for emails, meetings, opportunistic events*
- Is there a person who keeps the rest of the team informed? What is the position: coordinator, manager, etc.?

**Q3. What technology do you use – wikis, etc. - to work together?**

**Q4. How do you keep informed about what is happening in GRAND as a whole?**

*Website, broadcast emails, committees. Personal emails, project leader.*

- Do you feel you are in loop when it comes to GRAND events, activities, or policies? *Why?*

**Q6. How do you go about reporting at the end of the year?**

- How do you organize it? *Why?*
- Does it work/ is it effective for your team?

### Section E. Outcomes

Our last questions are about the outcomes of GRAND.

**Q1. What do you think is a successful collaboration?** What is a success for individual researchers? What is a success for a project?

- What is a successful or a good outcome? *E.g., artifact, or publications, or funding.*
- Could you share with me an example of a successful collaboration that you participated in? What made it successful?

- Could you describe an example of a collaboration that was not successful? What made it unsuccessful?

**Q2. What was the best outcome from the collaboration in GRAND so far?**

- How specific is this outcome to GRAND: Would this have happened outside GRAND, in a different research project?
- Would the outcome have been slightly different outside GRAND, in a different research?
- Are you satisfied?
- What other outcomes are you expecting?
- Any negative outcomes?

**Q3. Do you think your participation in GRAND has affected your research agenda or your career? How?**

- How specific is this outcome to GRAND: Would this have happened outside GRAND, in a different research?
- Would the outcome could have been slightly different outside GRAND?

**Q4. How do you think you or your project can maximize the benefits from the GRAND network?**

- Suggestions for the future.

Thank you!