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EXPLORING SOCIAL NETWORK DYNAMICS DRIVING KNOWLEDGE MANAGEMENT FOR INNOVATION

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The competitiveness and sustainability of a modern organization depends on its ability to innovate successfully. It is accepted (Gratton, 2000; Iles, 1996) that knowledge, skills and competencies are the key drivers of innovation. Innovation is the combined activity of generating new knowledge and the subsequent successful exploitation of this for benefit (von Stamm, 2003; O'Sullivan and Dooley, 2008). A key contribution to our understanding of how knowledge produces innovations is that innovation rarely involves a single technology or market but rather a bundle of knowledge which is brought together into a configuration. It is about accessing and using knowledge about components but also about their integration (Tidd et al., 2005). Consequently, current perspectives of the innovation process view it as an interactive and networked system that spans organizational boundaries to draw on knowledge, experience and capabilities from diverse sources (Rothwell, 1992; Tidd et al, 2005). The result is that the locus of innovation and knowledge circulation lies in dynamic, competency-based, business networks (Voss, 2003; Walters, and Buchanan, 2001; Wright, and Burns, 1998).

It is also noted that managing an organization's knowledge assets within networks and converting it into commercially successful products and services is an intricate, complex and difficult to manage process (Jaffe, 1989; Balconi et al., 2004). For example, the resource-based view and knowledge-based view of the firm (Penrose, 1959; Eisenhardt and Schoonhoven 1996; Grant 1996; Nonaka et al. 2000) emphasise that access to external knowledge is required for innovation, however much knowledge is not easily obtained as it is of a tacit nature or is highly context specific, and thus may require certain capabilities in order to be absorbed. One such enabling capability is integration in innovation social networks (e.g., Sternberg, 2000; Fritsch, 2001; Borgatti and Foster 2003). A social network is a set of people or groups, called 'actors', with some pattern of interaction or 'ties' between them (Cross & Parker, 2004). While formally defined organisational networks and their pattern of ties are usually depicted in the form of an organisation chart, in the case of social networks this pattern of ties is usually not depicted in any chart. It is informal, invisible, intricately intertwined with organisation structures but yet distinct from them, uncontrolled and often unknown or not understood by the organisation.

However, identification of the optimal network structure and characteristics is still somewhat elusive. For example, research finds such characteristics as embeddedness in networks (Fritsch and Kauffeld-Monz, 2010) and spatial proximity to network partners (Audretsch & Feldman, 1996; Fritsch and Slavtchev, 2007) enable knowledge transfer and strong ties are important prerequisites for information and knowledge exchange (Fritsch & Kauffeld-Monz, 2010). But this and other research suggests caution in interpretation of the results. Fritsch and Kauffeld-Monz (2010) suggest caution as their study only investigated networks in the early stages of development. They argue that commensurate with social network theory (Granovetter, 1973), cohesiveness may also result in negative consequences such as cognitive lock-in over the longer term of the network. Thus they call for research on older more established networks. Other challenges are highlighted in Zheng's (2008) review of studies on the influence of social networks on innovation, which points to the failure of empirical studies to investigate the interaction effects of network variables. Still other research suggests that the actors in the network may be the illuminating factor. For example, Kasper, Lehrer, Muhlbacher and Muller (2010) investigated cross-site knowledge sharing practices and found that they varied systematically across the three different industries. Fritsch and Kauffeld-Monz (2010) investigated regional innovation networks composed of firms and research organizations and found that actors (university, service firms etc.,) performed differing roles in the network and there was significant variation in the benefits obtained by each actor. Consequently, they called for more in-depth analysis of the role of different types of actors (e.g universities and firms) in innovation networks. Thus, further exploration of how social network characteristics and specific actors in the network facilitate knowledge management over time for the purposes of innovation is fruitful.

The paper aims to analyse how a social network perspective can inform the key stages of a knowledge management for innovation process. To achieve this aim, the first objective of the paper is to identify determinant social network factors through which to analyse three university-industry knowledge networks. These determinant factors are based on those utilised in quantitative social network analysis (SNA) investigations but are adapted to allow exploration of the characteristics of the social network, its development over time and the consequences for knowledge management for innovation. Social network analysis (SNA) facilitates analysis of relationships among actors in a network. It describes a number of social network factors that are useful in analysing overall network structures, network content, the characteristics of interactions and identifying the impact they have on knowledge management for innovation efforts. Also, while it is accepted that the boundary of the set of all and only elites within a network is difficult to determine as network researchers recognise that the social world consists of many, perhaps infinite, links of connection, it is also possible to place reasonable limits on inclusion

(Wasserman and Faust, 1994). The networks of concern in this paper relate to the inter-organizational connections between universities-industry and industry-industry as well as the relevant connections between key actors within these organizational level networks. Then, the second objective of the paper is to analyse three case studies of knowledge networks within the life sciences sector. The developed SNA determinants will be used to illuminate the mechanisms through which collaboration for knowledge management for innovation is accomplished through these networks.

THEORETICAL BACKGROUND

The network perspective of knowledge management for innovation views the process as a continuous and cross-functional process involving and integrating a growing number of different resources inside and outside the organization's boundaries (Boer et al, 1999). Networks create value by synthesising information and knowledge, exploiting expertise and pooling resources across traditional boundaries in order to create new knowledge and achieve innovations outside of individual capabilities and the resource bases of individual organizations (Prasad and Akhilesh, 2002; Johnson et al, 2001; Ratcheva and Vyakarnam, 2001; Pawar and Sharifi, 2000; Trott 2008). The synergistic benefits of social networks depend, though, upon "how effectively linkages… are actually managed" (Gupta and Govindarajan, 1986: p.696).

An understanding of the implications and influence of specific network characteristics is key to facilitating effective knowledge management for innovation. The value of a social network perspective lies in it conceptualizing the whole, rather than the parts (Storberg & Gubbins, 2007). Social network characteristics which can be evaluated fall into one of the three dimensions of social capital; structural, relational and cognitive (Nahapiet & Ghoshal, 1998). In prior research on innovation, the most frequently studied and significant influencers on innovation examined under the structural dimension include the characteristics of centrality and relative position of an actor (actor, individual, organization, etc.) within the network, the strength of the ties between actors, the existence of or lack structural holes and network cohesiveness. In the relational dimension, trust is examined and in the cognitive dimension, the actors absorptive capacity and the cognitive distance between actors is examined.

Centrality refers to the position of an actor within a network. From a knowledge exchange and innovation perspective, different network positions represent different opportunities for an individual or organization to access knowledge within the network, with the actors occupying more central positions being better able to access desired knowledge and resources as inputs to their innovation effort (Tsai, 2001). The positional advantage of centrality also allows the organization to access information that can facilitate development and exploitation of ideas (Ibarra, 1993) more effectively than those actors at the periphery of the network. Central organizations become better informed about what is going on in the network, which increases the possibility for the central organization to initiate the formation of new alliances and innovative projects (Gnyawali and Madhavan, 2001). However, research also reveals that the benefits from central positions are contextually sensitive. Centrality was found to be a strong determinant with respect to administrative innovation but not technical innovation possibly due to the group involved being smaller and more specific in expertise (Ibarra, 1993). Additionally, the effects of centrality seem to vary for those whom were centrally positioned internally compared to externally (Perry and Smith (2006).

The strength of the ties within a network (Granovetter, 1973), specifically tie strength, has a positive effect on innovation as social interaction encourages resource exchange and combination and this promotes innovation (Tsai & Ghoshal, 1998) and frequent participation contributes to decisions to innovate (Landry et al., 2002). Leenders et al., (2003) found that the frequency of interaction has a quadratic relationship to creativity in a team with very low or very high levels of interaction frequency impeding creativity and moderate levels enhancing creativity. Focusing specifically on the effects of strong or weak ties, Hansen (1999) identified that weak ties are more likely to facilitate access to non-redundant information by comparison to strong ties due to the ability of weak ties to reach outside an actors immediate social circle. Strong ties as opposed to weak ties are found to be more effective in facilitating the transfer of both tacit and explicit knowledge across gaps in the network (Hansen, 1999). Zheng (2008) concludes from a review of studies on social networks and innovation that when the outcome of innovation is to create ideas or engage in exploration, weak ties are desirable and when the outcome is more reliant on collaboration and implementation such as exploitation, strong ties are more desirable. However, Kijkuit and van den Ende (2010) conclude that strong ties are positively related to success in both the initiation and development phase of an innovation. Thus there is still some variation with regard to the empirical conclusions.

Structural holes, refer to unique ties to actors whom are otherwise unconnected (Burt, 1992), a position which consequently offers significant potential for the “knowledge brokers” (Hargadon, 2003) or “boundary spanners” (Donaldson and O’Toole, 2007). Knowledge brokers are argued to be valuable in that they initiate learning activities between organizations, establish new linkages for enriching knowledge and connect the innovation activity with wider scientific and institutional networks (Powell et al, 1996; Murray, 2002). Some studies suggest that at the innovation initiation stage where the task is problem perception and idea formation and implementation (Damanpour, 1991), more structural holes and exposure to diverse communities is beneficial, whereas at the idea implementation stage, which is about implementing plans and making revisions (Damanpour, 1991), more closure and solidarity is required (Zheng, 2008). Zheng (2008) concludes that at the individual level structural holes have a positive effect on innovation, while at the team and organizational level the findings are less consistent. Possible explanations for this include interaction effects between network variables and differences in the ultimate outcomes studied.

The strength of ties is sometimes equated with trust (Leana & Van Buren, 1999) and there are significant arguments indicating that trusting relationships lead to greater knowledge exchange (Tsai & Ghoshal, 1998; Levin and Cross, 2004; Dirks & Ferrin, 2001; Mayer et al., 1995; Tortoriello et al., 2012), interfirm knowledge transfer (Dodgson, 1993; Doz, 1996) and internal knowledge sharing (Hansen, 1999) and innovation (Zheng, 2008). Trust can help induce joint efforts (Ring and Ven de Ven, 1994, 1994), a willingness to take risks (West, 1990) and allow new ideas and methods to be experimented on (Zheng, 2008). Gubbins and MacCurtain (2008) summarise that as knowledge is a valuable commodity, trust is required for the most valuable knowledge to be shared (Andrews and Delahaye, 2000) and the source of the knowledge must be credible for that knowledge to be applied. However, Bakker, Leenders, Gabbay, Kratzer and Van Engelen (2006) find that trust may be a condition to knowledge sharing but does not have a positive effect on the sharing of knowledge per se. Gilsing et al., (2008) also argue that networks made up of strong ties and trust, which could be defined as dense networks may be highly effective in exploiting innovation and getting work done and ensuring understanding between participants, but they can also lead to a form of 'group think' that prevents the network from exploring new areas. Similarly, in exploring the specific phases of innovation, Kijkuit and van den Ende (2010) find that low density in the development phase of an innovation is related to failure and medium density to success and high density in the refinement phase is related to success. Gilsing et al., (2008) also emphasise the disadvantages for low density, in that the relative density of a network positively influences innovative capability with regard to assessing the reliability of sources of novel knowledge as well as understanding and evaluating these sources. Others also recognise that high density is associated with the necessary development of a shared language (Obstfeld, 2005) and absorptive capacity (Gilsing & Nooteboom, 2005). Thus it seems that the value of trust and the type of trust required varies with respect the phase in the innovation process.

As evident from previous discussions of characteristics of social networks, the balance between cohesion and division has varying implications and additional implications relate to cognitive distance and absorptive capacity. The cognitive dimension of social capital refers to shared representations, interpretations and systems of meaning among actors (Nahapiet & Ghoshal, 1998). Bathelt at al., (2004) highlight that knowledge exchange within ‘local’ networks can be informal and serendipitous in nature due to low cognitive distance within the community, however, as networks become more distant and ‘global’ in terms of geographic and cognitive distance then increased formalisation of linkages and investment is required to support their operations. The effectiveness of interaction will be influenced by the absorptive capacity of each of the network actors, the cognitive distance between partners and their mutual trust and collective understanding of purpose (Balconi et al., 2002; Hussler and Ronde, 2002). Cognitive distance across the network nurtures a culture where partner organizations challenge their existing models and assumptions and generate new knowledge. This is the basis for creativity and knowledge creation that offers the potential for future innovation. However, high cognitive distance and low absorptive capacity can pose challenges to capturing, articulating and contextualising ideas due to different systems of meaning. There is limited research exploring shared cognition and innovation and that available focuses on shared vision (Zheng, 2008), which is outside the remit of this paper.

UNDERSTANDING THE KNOWLEDGE MANAGEMENT PHASES OF THE INNOVATION PROCESS THROUGH THE SOCIAL NETWORK PERSPECTIVE

Evident from previous discussions of characteristics of social networks, the balance between; cohesion and centrality, strong ties, trust and absorptive capacity; and division and peripheral positioning, weak ties and cognitive distance has varying implications depending on the outcome required. It also seems that the optimal network characteristics for success vary for each phase of innovation. However, as identified, further research is required to extrapolate these characteristics over the duration of an innovation networks development and with respect to a precise type of network with defined actors. Tranfield et al. (2006) outline the phases of the innovation process and extrapolate the knowledge routines necessary to support each of the innovation phases- discovery, realisation and nurture. Table I highlights the interplay between the innovation and knowledge phases.

The first phase relates to discovery and involves searching the external environment to identify unfulfilled needs that provide the opportunity for potential innovations. The knowledge inputs for this phase of the innovation process necessitate the organization spreading as wide a net as possible to capture information from relevant knowledge sources. The broadness of the domain makes it impossible for any one individual (or even organization) to adequately search all potential sources. The use of social networks to search for, access and transfer valuable knowledge regarding emergent shifts in the external environment improves the organizations searching ability to identify appropriate opportunities for innovation. For example, based on their work with IBM, Cross and colleagues (2001; 2007) found that knowing what others know and having access to other people's thinking are essential characteristics for knowledge sharing, transfer, and innovation. As discussed previously, weak ties, strong ties (Granovetter, 1973) and filling structural holes (Burt, 1992) facilitate this search and access process.

Once the *search* process is complete, the more effectively an organization can *capture* and *articulate* the knowledge from these networks, the richer the opportunities they have to feed their innovation efforts. In order for meaningful knowledge *transfer* and learning to occur, the social networking process requires direct and intense interaction between individuals with relevant knowledge and expertise (Hansen, 1999) so that knowledge can be internalised and given expression in a form understood by those tasked with exploring its innovative potential. As discussed, the strength of ties (Hansen, 1999), the existence of trust (Levin, 1999; Levin and Cross, 2004), the absorptive capacity (Nahapiet & Ghoshal, 1998) and cognitive distance (Balconi et al., 2002; Hussler and Ronde, 2002) are key social network characteristics that influence this transfer, capture and articulation effort.

The second phase of the innovation process relates to *realisation.* This relates to how the organization can successfully implement the innovation and select from the range of available innovations those which the organization will work on. It involves firstly deciding which concepts from the search phase should be progressed and which abandoned. Selection decisions are based on available knowledge and expertise so the adoption of a team-based, consensus approach to decisions is facilitated by having access to a greater network of expertise, knowledge and diverse perspectives. It requires that the knowledge and innovations are articulated such that they can relate to each organizations context and particular challenges. Possessing a wide diverse network of actors and thus drawing on multiple perspectives, knowledge and expertise, can facilitate this contextualization and ensure effective selection decisions are made. Better informed decisions regarding the approval of concepts will enhance the likely success of the innovative actions pursued. At this exploitation phase, the social network literature highlights how similarity between actors is found to be attractive and distance in knowledge and cognition (cognitive distance) constitutes a liability. In contrast at the exploration phase, partner similarity is unattractive whereas cognitive distance forms an important asset (Gilsing et al 2008). In terms of diversity, where diversity facilitates exploration, density facilitates exploitation (Gilsing et al 2008).

The third phase of the innovation process relates to nurturing the innovative actions approved from the realisation phase. The challenge of this phase is to transform the concept into a reality and align it with the needs of the market. This phase integrates technology and market information together with the organizations internal capability to develop the prospective innovation. The further along this phase an action is then the more difficult it is to change the design. Consequently organizations need to access information to ensure the design and subsequent development is correct. The opening of this phase of the innovation process to input from knowledge sources external to the organization enhances the expertise and knowledge available, increases the creative capability to solve problems encountered and ensures that relevant stakeholder requirements are incorporated into the design and development activity. Since potential errors are minimised by collective knowledge sharing, collaborative routines have the potential not only to develop technologically superior innovations but also to reduce the cost and time of development. However, as with the previous phase similarity across the actors, low cognitive distance and high absorptive capacity is required for success (Obstfeld, 2005; Gilsing et al 2008). The exploitation of value from the developed actions is the primary objective of this phase of the process. Many organizations succeed in making substantial technological breakthroughs during the discovery phase, only to be unable to secure benefit from the development. Knowledge inputs for this phase of the process relate to how an organization can ensure the market adopts the innovation and what mechanisms can be used to protect intellectual property from competitors. Organizations must be careful when securing intellectual property that the associated secrecy does not adversely affect the necessary knowledge flows to the innovation process or encourage behaviour by individuals within the network that undermines knowledge exchange for mutual benefit. Thus management of collaborative efforts within these constraints requires an understanding of collaboration mechanisms such as trust, as discussed previously. Table I and Figure 1. summarises the interplay discussed here between; the phases of innovation; the knowledge routines evident in each phase; the role of and application of social network characteristics to these routines; and SNA indicators that can ascertain how the knowledge routines are facilitated at each phase.

Insert Table I and Figure 1 about here

METHODOLOGY

The study involves case studies of three university-industry knowledge networks focused on collaboratively generating new knowledge within their particular area of life sciences. The research is approached from an interpretivist\constructivist perspective; it is concerned with how individuals make sense of situations and how their 'constructed sense' changes over time. A qualitative approach was adopted as literature argues that it *is "preferable when addressing the process, content and dynamics of networks, rather than purely structural matters (Lechner and Dowling, 2003; O'Donnell et al, 2001)"* (Jack, 2005; p. 1239) and *"to discover new relationships of realities and build up an understanding of the meaning of experience rather than verify predetermined hypotheses (Hunt, 1990; Perry and Coote, 1994)"* (Riege, 2003; p. 77). Such enquiry offered the potential of deeper understanding of the dynamics of network interaction and scope to explore the meaning of actions in developing capability to collaboratively generate new knowledge that advanced scientific frontiers and offered the potential for commercial exploitation. This qualitative exploratory methodology is also considered appropriate given the calls for in-depth research on interaction effects between social network variables, actor roles and the impact of network characteristics over phases of innovation network (Zheng, 2008; Fritsch and Kauffeld-Monz, 2010). The research process employed was informed by that outlined in Eisenhardt (1989) and Yin (2002).

CASE SELECTION

All cases were selected for their exploratory value. In such instances the question of representativeness of the cases need not be of major concern (Roche, 1997). Eisenhardt (1989) recommends that theoretically useful cases are selected, rather than employing random sampling. An initial search of UK and Irish based life science network cases was undertaken through preliminary discussions with domain experts and through secondary data research. The criteria to select suitable cases for study were: they should be collaborative endeavours within the life sciences area, possess both academic and industrial partners in the consortium, be established with the primary objective of collectively advancing the scientific knowledge frontiers within their chosen research area, be of sufficient scale (> 50 engaged researchers in the network) and have a long-term commitment by partner organisations with respect to the network's existence. From the generated shortlist of potential cases, a university-based lead academic was contacted to request access to study the network. Six networks responded positively and permitted access. Three of these networks are discussed in this paper as they allowed on-going access over five years, thus facilitating a longitudinal study of the network's dynamics and knowledge routines over this time period.

DATA COLLECTION AND ANALYSES

Data was primarily collected through semi-structured interviews with identified respondents in each of the three network cases. Each interview lasted between 1-3 hours and was guided by a written protocol to ensure a level of consistency and dependability in the data collected by researchers across the cases. The interview respondents were selected from members of the network's management team, as it was deemed that these individuals were best positioned to provide both strategic and operational level insights into the network functions and to reflect insights of both their 'parent' organization's interaction with the network and also the operation of the knowledge network itself. As the study was over an extended period, the network membership (companies and individual representatives) evolved over time. In all three cases, the initial point of contact was the lead academic since the initial network discovery activity had its locus within their university laboratories. This approach aligns with Lofland and Lofland's (1995) view of 'casting about' as an initial selection of interview respondents within the target population. From this initial contact, purposive sampling (Stewart 1998) was used to identify and interview respondents across the network stakeholders. Given that all three networks had the university partner in the centre node, then it is not unexpected that the interviewee list is skewed towards representatives of the academic partner institutions. However to ensure the validity and reliability of the data collected, all cases had industrial respondent interviews also.

Return visits to the network cases took place at 18 - 24 month intervals. Although guided by the protocol, researchers adopted a flexible approach to questioning, encouraging the respondents to opened up regarding their insights of the network's evolving knowledge generation capability. Since a number of key respondents were subject to multiple interviews over the duration of the study, it was possible to follow-up on themes and discrepancies from the previous interview round and seek clarification if necessary. A commitment regarding anonymity and confidentiality had to be given to all respondents and access to the network was granted subject to 'vetting' of research output. In total, 29 structured interviews took place across the three cases over three interview cycles (see table II). In all cases, each interview cycle began with an interview with the network's lead academic since their presence within the management team was constant. Following this, interviews were scheduled with other key individuals pertinent to understanding the network's knowledge routines and the experiences and expectations of contributing stakeholders. Supplementary data on each case was also gathered through other channels such as ongoing, informal contacts with key network individuals at both management and operational level within the network, internal network documents (e.g. annual/progress reports, minutes of meetings and press releases) and on-site observations made during visits and 'conversations' with network participants. This material allowed for triangulation of the interview data and increased confidence in the reliability of the emerging research themes and broader theoretical issues.

Insert Table II about here

The interview transcripts were analysed and various concepts and categories distilled through a 'constant comparison' approach (Strauss and Corbin, 1990), where general patterns of practice/activities both across the three cases and also within the various development stages of each case were identified. Following this reiterative process of analysis, an individual 'case-study' for each of the three networks was written up in accordance with best practice (Eisenhardt, 1991; Gummesson, 2000); all three case study write-ups focused on how the specific university-industry innovation network was established and developed to achieve its objectives. To ensure validity and reliability of the case in representing the reality of the network, the case was returned to the specific network's management team for review and amendment if necessary. The developed SNA determinants (Table I), which are based on those utilised in quantitative social network analysis (SNA) investigations, were then used as an analytical lens through which to illuminate the enabling processes for knowledge management for innovation within the three cases.

CASE STUDY: KNOWLEDGE CREATION NETWORK

Three life science case studies of inter-organizational network collaborations are studied. An overview of the three cases is provided in Table II. Evidence from these cases is used to illustrate; the characteristics of collaborative social networks in practice during the phases of innovation (Tranfield, 2006); the influence of these characteristics on knowledge sharing and consequently innovation and; how these network characteristics enabled or hindered knowledge sharing and/or innovation.

All three network cases were established for the purpose of generating and advancing the knowledge base of their scientific discipline for development of future medical treatments. By participating in knowledge networks, organizations gain privileged access to knowledge-producers involved in discovery, translational and clinical research activities that facilitate their innovation process. In all three cases, the motivating factor for partners to collaborate was to access 'valuable' knowledge areas which they lacked internally.

> *"We wanted access to their compounds for our research and they [industry organizations] wanted access to our capability and discoveries in order to accelerate the development of these compounds into lead for drugs and new forms of income for the company"* [Case 1].

The selection of network members was crucial as a consortium of partner organizations had to be established where individual organizations not only possessed knowledge that was valuable to other network members but also had knowledge gaps that could be filled by other partners knowledge. Secondly, participating organizations required the 'absorptive capacity' (Cohen and Levinthal, 1990; Zahra & George, 2002) not only to acquire but also to recognize the value of the new knowledge being accessed. All three networks are focused on emerging areas of their scientific field where a disruptive shift has resulted in industry lacking the required capability or scanning capacity. Achievement of the appropriate balance of knowledge synergy and mutual reliance was deemed by interviewees as a fundamental foundation for building a successful knowledge network for innovation as it aligned strategic direction and motivation.

SEARCHING FOR KNOWLEDGE

In all three cases, the impetus for venturing into the external environment to locate suitably interested organizations came from the lead academic within the university organization. These key individuals foresaw the significant opportunity for their own organization and potential partner organizations, should collaboration occur and thus actively promoted the virtues of collaboration to interested parties. All three lead academics fit the mould of "knowledge brokers" (Hargadon, 2002) by providing the 'weak' ties (Granovetter, 1985) that nurture embryonic relations into a collaborating network. Each of the lead-academics had established a reservoir of influential contacts as a legacy of their past endeavours and could exploit these contacts to establish linkages with potential organizational partners.

The attraction for partnering organizations was that network participation enhanced the scientific scanning abilities of each organization, allowed access to proprietary knowledge and compound libraries and provided a cost-effective mechanism for undertaking the research work.

> *"On the one hand we had all the technology about the target worked out prior to this and we were able to help them [Industry] to do their studies about the mechanism of action of the drug and on the other hand their drug was actually a very important research tool for us to study how the protein kinase actually worked and what it did*" [Case 1].

While initial discussions regarding network formation took place between lead academics and like-minded scientific peers within industrial organizations, once interest was established, the size of the network increased as individuals from the organizations became involved to formalise contractual terms of reference for the interaction and protect their organization's position. This increased the bank of sources of knowledge available for the knowledge sharing and innovation process. In the cases investigated, this process of gaining awareness of each partners knowledge initially begun on a formal basis as all three networks were established as closed networks, where partner selection was based on alignment of competencies, expertise and interest in the knowledge generating activities of the network. During the formative stage of the network, the academic members had to 'sell' the network by communicating the latent expertise and its value to prospective partners.

> *"We went around to lots of different organizations hawking ourselves, trying to persuade people to join our consortium and become involved in it"* [Case 1].

As the network evolved into the operational phase, individuals at the core of each of the networks were fully aware of the competencies and expertise of other individuals within the network and the scientific discovery knowledge being generated. To develop the knowledge sources available further and ensure awareness of the expertise of these knowledge sources, these individuals further championed the network within their 'home' organizations by linking relevant employees with network members and activities. This serves to increase the size of the network and thus the search capability.

> *"Each company has assigned an individual to get value from the consortium and to get the information out to the relevant people within their organization however this puts enough a lot of responsibility on this individual and the success of the consortium and the relationship between the consortium and the individual companies is very much based on the relationship with that individual*" [Case 1].

In all three cases, there is an obvious bias towards interaction by industry personnel with university researchers (due to this being the locus of the networks research capability and also because of competitive fears). This suggests the academic institutions are in central positions in the network. However there is evidence within certain networks of increased awareness of competitor industry's competencies and fledgling collaborations between synergistic industrial partners.

> *"Significant synergies have grown up between specific partners… but as all are conscious of IP contamination, [new] projects are in a different space"* [Case 2].

This is suggestive of strong ties between university-industry partners and weaker but developing ties between industry-industry partners. Universities are therefore acting more as knowledge brokers and enablers of network development rather than the ultimate and only benefactors of the network. This is key as industrial partners need to obtain advantages from the network or they will quit the network. Thus indications of developing ties between industry and industry within this network should serve to strengthen the search capacity of the network and ultimately the knowledge sharing and innovative capability of the network.

CAPTURING AND ARTICULATING KNOWLEDGE

Possessing connections to and awareness of knowledge sources is only valuable to the extent to which this knowledge can be accessed, captured and articulated in a way that makes the knowledge useful to a party. Access to the knowledge sources in the cases explored was facilitated through a number of structured and informally emerging channels. Structured channels included those formally agreed as part of the network's institutional agreement or internal routines. These included scheduled on-site visits at university laboratories, access to centralised laboratory information systems and intranets and formalised project and annual reports. These are important channels in that they exchange explicit (the 'what') knowledge that has been generated by the networks scientific endeavour.

> *"The companies are coming three times a year for three days for meetings and each research team makes a presentation of their progress to the collective*" [Case 1].

However, the ability of these channels to exchange more tacit knowledge (the 'how') is poor. More informal channels of knowledge exchange evident in all three networks included co-location of industry staff in university for short periods, one-to-one discussions between researchers following on-site visits, during social gatherings following such events, during conferences or during follow-up communications via email and telephone.

The formalised agreements guided the partner interaction and enabled collaboration during the early stages of the network, so that knowledge sources could be accessed and some knowledge shared. Then a 'tipping point' was reached where trust in the scientific output and motives of the other network partners was established and more informal channels emerged.

> "*Things gradually built up to a point where everyone trusted what the other is doing… experimentally and after that point deliverables became much easier*" [Case 3].

> *"So they want a water tight agreement with everything in place so then they can avoid that happening. And of course this was an issue for a number of years because it is only after you have interacted, had the consortium going for a number of years that people stand back and turn around and realise that, things are going well….. these people aren't leaky…. they don't tell other people…. and once that happens then the people began to open up a bit more and there is more trust and there is some more interesting compounds begin to come through to you. And that's the benefit of having this consortium run for many years because it takes a significant amount of time to allow that trust to develop between people"* [Case 1].

This higher level of interaction and increasing levels of trust between individuals is required to facilitate the capture and articulation of knowledge so that it can be contextualised and considered for its innovative value (Hansen, 1999).

> *"As you get to know people better and work with them, then deeper trust forms between each and reduces fears between partner [organizations]"* [Case 2].

The increased interaction of individuals and the sharing of expertise also enriches the absorptive capacity of partner organizations, which is a necessary for knowledge capture and assimilation.

The majority of the networks' initial discovery research was centred within the university actor laboratories, with other organizational actors contributing specified resources to support this effort and periodically scanning the research outputs for interesting leads and developments. Thus the collaboration was university driven and predominately university contextualised. However over time, as participants validated the network's collaborative value, evidence of deeper interaction and knowledge transfer between the various network actors became evident. In case 1, this manifested itself in the form of additional compounds and equipment being donated to the university laboratories by partner organizations so as to enhance the scale and capability of the network and the fact that "*it was much easier to get the partners to sign-up again during the [network] renewal phase as their doubt had been answered*" [Case 1] by the network's operations and output. Similarly, in case 2, in addition to their collaboration within the existing network, previously unconnected partners "*formed sub-groups of the larger consortium to follow-up new funding calls and pursue research opportunities that are outside the scope of the network*" [Case 2]. This increased interaction and stronger ties between individuals allows organizations better access to the knowledge and skills they required, facilitates greater sharing, enables capture and articulation of the knowledge and is more conducive to collaboration that generates 'new' knowledge and innovations.

The capture and articulation of discovered scientific knowledge involves an engrained process of conceptual thinking common to research scientists. At a generic level, the scientists have an encultured knowledge of language and expert-knowledge associated with the discipline. As research scientists from the partner organizations interact at scheduled meetings of the network and through informal communications, trust and friendships develop.

> *"Trust is important… things have evolved into fairly sincere friendships [between researchers] which ultimately eases the potential for conflict"* [Case 3]

This increased affinity also narrows the cognitive distance between individuals, increases absorptive capacity and provides a ready basis for knowledge transfer.

TRANSFERRING KNOWLEDGE: CONTEXTUALISE/APPLY

The realisation phase of innovation requires that the knowledge is contextualised and applied to particular organizational contexts. The highly encultured language and expert knowledge associated with the scientific disciplines is potentially a significant barrier to successful knowledge transfer and absorption. However, given that all individuals engaged in the networks possess scientific qualifications (majority being Ph.D.'s) and all are motivated by similar discovery focus, then the networks have actually become communities of like-minded peers. *"It comes down to the science in the end"* [Case 3]. Irrespective of their particular organizational origins, the network members firstly view themselves as research scientists, whose purpose is to better understand their scientific domain. Yet despite this common foundation, each network member has their own particular area of science and expertise that challenges others assumptions and mental models and creates the creative tension necessary for learning and scientific discovery. While the initial network founders often have a previous legacy of interaction that has validated their scientific credentials and thus facilitates trust and cognitive proximity, newer members require time and interaction to achieve similar contentment. This common frame of reference and absorptive capacity is the minimum requirement for contextualising and applying knowledge to particular organizational contexts.

A number of mechanisms are utilised to contextualise and apply the knowledge to members' contexts. The knowledge available within the organizational actors is applied to solve specific scientific problems which are agreed as mutually beneficial to the network participants. This occurs through specified research projects, where relevant network members contribute knowledge, compounds, staff and capacity to achieve objectives and generate new knowledge through scientific discovery. The new knowledge generated through exploration provides inputs and leads for exploitation within the innovation processes of the network's organizations. Dependent upon contractual conditions agreed during the network's formative phase, the newly discovered knowledge will be exploited unilaterally or collectively and result in patents, leads for new treatments, licensing agreements, new operational processes or even the creation of new joint ventures.

> *"What the company share between them is all the unpublished results of all participating laboratories all the reagents we have, the proteins, the technology and they share the first rights to license our IP but what is not shared is something that anyone individual company gives to us for testing"* [Case 1].

Once research discoveries are achieved within the network laboratories, they are communicated with network members as per channels defined in the contractual agreements. While these channels remain as the networks mature, additional communication channels evolve organically. All three cases have established centralised information systems for sharing information and have regular on-site meetings of the network members to discuss operations and nurture the exchange of both explicit and tacit knowledge between members. These communication channels have been supplemented by telephone and email communication between peers which is driven by specific scientific challenges, as well as informal meetings at conferences and site visits. In case 1, the opportunity for industry partners to place a researcher in the university laboratories for a defined period was deemed necessary to facilitate the transfer and contextualisation of knowledge which was more tacit and "sticky" in nature. Similarly in case 3, *"people from here [the university actor] have gone to the US partners and worked and experienced the industrial setting… and that experience has effected the way they now work here"* [Case 3].

Evidence of the transfer and contextualisation can be found in the outputs achieved to date from the networks collaboration. Respondents highlight that the early years of network operations were occupied establishing the culture, routines and project portfolios for the network. This period demanded partner commitment for little immediate value other than an enhanced scientific scanning capability. However, the later years resulted in 'real value' being transferred to the partner organizations from the network generated knowledge. Tangible outputs evident included the production of Ph.D. graduates and scientific articles, leads for new compounds, patents, parallel collaborative projects, together with enhanced understanding of the underlying science from explicit and tacit knowledge transfers.

> *"We've just recently filed two patents, which cover the discoveries of recent years… these now allow us publish freely and we have a significant wave of publications coming through at the moment"* [Case 3].

In case 2, the most valuable output of their five years in operations was viewed as the enhanced collaborative capability that now existed within the network and formed the foundation for the next five years.

ABSORBING KNOWLEDGE: EVALUATE/SUPPORT/RE-INNOVATE

All three case studies have evolved and expanded in terms of size and scope over the period of study providing indications of the success of the networks to date. In case 2, since the networks original formation, it has grown by approximately 30% in headcount and 50% in research activity. Case 1 also added new partners during the re-negotiation phase and increased required resource inputs from partners as existing members felt "that the new entrants were exposed to much less risk now that the consortium had proven to work" and thus should pay a premium. While much of the detail regarding direct support provided by network members was specified in the consortium agreements, certain partners surpassed their indicated support by allocating additional equipment, compounds and personnel to their network. This generosity was not completely altruistic and instead often could be linked to a specific research project where the organization had a particular interest. In case 1, one partner gifted specialist equipment to the university as it was heavily reliant on the testing service provided as part of the network's outputs and wanted a more efficient process. While member support of the network was primarily in terms of financial funds, contribution of staff in terms of full-time equivalents and background IP in terms of patents and scientific compounds, some of the most valuable contributions occurred organically as research scientists interacted together within the context of specific and synergistic scientific problems. The partners to each network not only transferred knowledge back to their home organization but also championed the collaboration by developing linkages with appropriate new researchers within their organization to enhance the networks value.

> *"Each company has assigned an individual to get value from the consortium and to get the information out to the relevant people within their organization"* [Case 1].

Indications of support for the network such as those outlined here provide a foundation for supporting knowledge transfer and innovations arising out of the networks collaboration.

As the external environment is constantly evolving, the networks themselves have recognised the need to adapt to remain relevant and valuable to the collaborating partners. Cases 2 and 3 are reaching the end of their first cycle of engagement and case 1 is currently in its third reiteration. As networks reach the end of their agreed cycle, there is evidence in all three cases of efforts to evaluate the networks most appropriate trajectory and requirements for sustainability into the future. Case 2 identified that industrial partner's experience of previous collaboration alliances was advantageous in contract negotiations *"as they knew they had to compromise with other stakeholders to make it [the network] operate successfully".* In all three cases, the re-innovation of the network was led by the university actor that managed interaction with existing and potential organizational partners. Contract re-negotiation has resulted in partners requiring alterations to the focus of certain projects, right of veto over entry of new members and modifications regarding the networks governance. The key challenge facing Case 1 is that after a decade of interaction and learning, the industrial partners no longer view the university's research expertise as internally lacking within their own researchers. This reduces the central position of the university and consequently the knowledge and power gains the university can obtain from the network, thus risking isolating it to the periphery of the network. Foreseeing this fact, the lead-academic has incorporated an emerging *"interesting"* scientific area as a minor part of the third cycle and this is likely to become a more significant part of the next cycle in order to maintain scientific and commercial relevance of the university actor to partner organizations. Similarly in case 2, the network evolution has resulted in partner organizations within the network establishing smaller, parallel consortia to pursue new opportunities identified during interaction. Rather that this being viewed as a treat to the original network, it is seen as evidence of deepening relations between organizational partners and added value of participation. The results of this analysis, together with the specific social network indicators used for assessing the level of each social network determinant is summarised in Table III and Figure 2.

Insert Table III and Figure 2 here

DISCUSSION

It is acknowledged that while prior research identified some of the implications of specific social network characteristics on knowledge management for innovation efforts, these studies are inconclusive with variation in what are the optimal social network characteristics. This is argued to be in part due to a requirement for greater specificity about the phase of network life-cycle under investigation, the role and influence of differing network actors and network interaction effects that occur over time. This study contributes to these discussions by: first, focusing on a specific type of network, that is a university-industry partnership: and second, evaluating the characteristics, evolution and effects of network characteristics at different phases of an innovation process. In this regard, this study illustrates one set of substantive findings. The set of findings reflect the evolution of the three components of social capital; that is the structural, relational and cognitive (Nahapiet and Ghoshal, 1998), such that the most valuable characteristics are present at each of the phases of the innovation process.

First, structurally, the network began with a set of weak ties with predominately disconnected industry partners and the university as the central actor. This enabled the search phase. It then evolved to an internally cohesive network of university-industry partners, which enabled the articulation phase. The network further evolved, upon reaching the re-innovation phase, to maintain internal cohesion but occupy new structural holes and develop new weak ties. This evolution reflects, in action, a recommendation by Soda et al. (2004), which suggests that the most effective networks are those that have a cohesive core conducive to knowledge sharing and trust but continuously develops new connections on the periphery to access non-redundant knowledge. Additionally, the cohesiveness is required for greater success in the exploitation phase of the innovation process (Kijkuit and van den Ende, 2010; Zheng, 2008). Long-term, the result of the increasing density in the network and narrower cognitive distance between the university and industry partners is that the industry partners developed stronger connections with each other and the university partner moves from a central to a peripheral position in the network. This is a beneficial evolution as Perry-Smith's (2006) study emphasised that actors on the periphery of the network had higher creativity when their outside ties were more. This move is necessary for the long-term sustainability of the network and the re-innovation phase in terms of developing new external ties and bringing new knowledge and ideas to the network. However, while increasing network size is generally found to reap benefits for innovation (Zheng, 2008), actors also need to be judicious about the diminishing returns associated with increasing network size (McFadyen & Cannella, 2004).

The role of the knowledge broker, in this case the university, emerged as central to the success of various phases of the innovation process, most especially the search and re-innovation phases. It is evident from the preceding discussion how the knowledge brokers' role evolved and was effective. The university partner's first task in the search phase was to emphasise the benefits to potential industry partners of both joining and engaging in the network and establish access to new knowledge through developing these weak ties (Granovetter, 1973). This is commensurate with social exchange theory, which argues that individuals evaluate the perceived ratio of benefits to costs and base their decisions on whether to share knowledge or not on the expectation that it will deliver benefits (Blau, 1964; Emerson, 1981). While this initially placed the university partner in a central position, the centrality position decreased over time as a number of the industrial actors began to move into the structural holes existing between themselves and other industrial partners. This is consistent with research on structural holes, which emphasises that the benefits to be gained by the boundary spanner are short-term as actors begin to develop their own ties to other actors in the network (Soda et al., 2004). Then, however, the role of the university actor further evolves cyclically at the re-innovation phase where it returns to its original role of building weak ties to new network members and thus re-igniting the network.

Evolution in the relational content of the network is also evident in the form of trust. Social exchange theory points to the importance of trust in knowledge sharing relationships (Robinson, 1996) with affect and cognition based trust demonstrating positive influences on knowledge sharing at dyadic and team level (Chowdhury, 2005; Mooradian, Renzl & Matzler, 2006; Wu et al., 2007). Where initially in the networks studied, trust was lacking, formal organisational systems such as contracts and formal communication mechanisms were required such that the discovery phase could progress. However, as the network evolved and trust developed, first between the university partner with each individual industry partner and subsequently between industry partners, the formal mechanisms became less important. Instead, informal communication mechanisms, such as co-location of staff and one-to-one discussions, became utilised. Such channels enabled and are key to tacit knowledge sharing (Hansen, 1999; Levin and Cross, 2004), which is a key source of advantage (Kridan and Goulding, 2006; KPMG, 2000). It is this relational component that turns mere potential to access knowledge in connected social networks into actual transfer of knowledge (Hansen, 1999). This is vital for the knowledge capture routine and even more so for the phase of innovation realisation. Caution does need to be exerted with regard to the extent to which trust develops in the network as Sondergaard, Kerr and Clegg (2007) suggest that unjustified trust could cause a potential user to refrain from questioning the usefulness of the knowledge and its context for application leading to misapplication or misuse of the knowledge.

Third, alongside trust development was reducing cognitive distance and increasing absorptive capacity between individuals, industries and university-industry. Absorptive capacity reflects the individual's or networks ability to assess, assimilate and apply new knowledge (Cohen and Levinthal, 1990). Essentially, in line with an information processing model, absorptive capacity is key at the noticing and encoding phases of information processing (Hinsz et al., 1997). In terms of the knowledge routines, the absorptive capacity of those individuals involved in the search phase influences the extent to which they will 'notice' valuable knowledge. It was evident from the cases studied that common knowledge about the discipline of science provided foundational absorptive capacity so as to enable the university partner notice and source relevant industrial partners based on the relevance of their knowledge to the network. Furthermore, when the level of industrial partner interaction increased, prior research finds that high absorptive capacity is also necessary for knowledge to be assimilated given the absence of tacit knowledge sharing at the outset (Griffith and Sawyer, 2010). More specifically still, this study identifies that specific forms of absorptive capacity developed and became more relevant as the network evolved. Greater levels of absorptive capacity in the form of specialist science and industry or academic contextual knowledge was required for the purposes of capturing, articulating and contextualising the knowledge made available by multiple actors with cognitive differences (see Cohen and Levinthal, 1990). As the partners interacted with increasing frequency and as their knowledge sharing progressed from sharing explicit to tacit knowledge, the actors began to gain a greater understanding of each other's science specialisms and contexts. The increasing collaboration, enabled through the strength of the relationships, built higher levels of absorptive capacity and counter-acted some of the interpretive differences emerging as knowledge crossed contextual and science specialism boundaries. Bresman (2013) finds that such high levels of collaboration are key as it is together the seeker's absorptive capacity and the source's transmission capacity (the ability of the source to recognise the value of its knowledge) that ensure knowledge sourced can be molded to new contexts.

There is significant evidence in the practitioner environment of failure in inter-unit, inter-organizational and university-industry networks. This study provides insight for practice into the processes and time required to obtain a return on investment from a multi-actor network. Evident, from the study is that the benefits for industry only truly began to emerge in the latter half of the second phase of the innovation process, which is realisation. This study provides a basis to caution industrial partners not to exit such networks too early. It also provides some practical suggestions with regard to managing or facilitating such networks. For example, it is important to identify the right knowledge broker commensurate with the tasks that s/he must execute in the search and re-innovation phases. It is imperative to facilitate the enabling conditions to help the network progress effectively. These include formal mechanisms to replace trust in the early stages and then working to enable trust in the middle to latter stages. It also includes encouraging the sharing of formal and informal knowledge so as to reduce cognitive distance and enable capture and realisation.

Finally, this study progresses a notable gap in the research on social networks. While, Nahapiet and Ghoshal (1998) originally identified three components of social capital, namely, structural, relational and cognitive and while there is significant work elucidating the structural characteristics conducive to knowledge sharing, the relational and cognitive dimensions, although recognised as important (Kang et al., 2007; Nahapiet & Ghoshal, 1998), have received much less attention (Makela & Brewster, 2009). Borgatti and Cross (2003) equally highlight how less is known about the ways in which kinds of relationships condition information flow and learning in networks. This study illuminates the value of the relational component of trust and the cognitive components of cognitive similarity and absorptive capacity at specific phases of a successful innovation process, which should serve to encourage greater depth of research on these aspects in the context of network evolution.

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Table II: Case Study Overview

	Case 1	Case 2	Case 3
Network scientific focus	Protein kinase	GI disease	Cell plasticity
Network partners	1 university and 5-6 industrial partners*	1 university, 1 public research centre (PRC) & 2 industrial partners	2 university partners & 1 industrial partner
First Established	1998	2003	2004
# of contract renewal cycles	3rd cycle	Transitioning to 2nd cycle	1st cycle
Collaborative researchers	Approx. 200 researchers	Approx. 120 researchers	Approx. 90 researchers
Network centre	University centred	University centred	University centred
# of Interviews	13 interviews	8 interviews	8 interviews
Network partner Country of Origin	UK, Germany, Switzerland, USA.	Ireland, UK.	Ireland, USA.
Entry of new partners since establishment	Yes; Multiple	Yes; One	No
Future	Preparing for transition to 4th cycle	Entering 2nd cycle	One year extension to 1st cycle.

* Over contract cycles industrial partner number fluctuated due to mergers & new entrants

Table I: Innovation Phases, Knowledge Management Routines Within & Social Networks in Use

Innovation Phase	Description	Knowledge Management Routines	Social Networks Application	Example Social Network Analysis Determinants
Discovery	Searching & scanning the environments to pick up & process signals about potential innovation, such as needs, opportunities arising from research, regulatory pressures, or the behaviour of components.	*Search:* The passive & active means by which potential knowledge sources are scanned for items of interest	Casting a broad search net through the available social networks. The larger the network, the wider the search net will be cast.	• Determine the position of the organization/individual within the network • Determine extent to which people are aware of others expertise. • Determine the ease with which a person can gain access to another with required knowledge. • Determine the extent to which an individual is willing to support knowledge transfer. • Determine the likelihood that knowledge shared can be combined. • Determine the similarity or difference in contexts/knowledge base between organizations/individuals • Determine the channels by which knowledge is exchanged • Determine the level of structural holes and ongoing efforts to close them. • Determine the strength of the relationship • Determine the routines and protocols surrounding knowledge exchange practice. • Determine member's perception of trust in others. • Determine the types of knowledge being transferred. • Determine who acquires information from whom.
		Capture: The means by which knowledge search outcomes are internalised within the organization	Access to a greater pool of diverse competencies of relevance to the knowledge accessed will enhance the absorptive capacity of the network & thus its ability to capture & articulate the knowledge	
		Articulate: The means by which captured knowledge is given clear expression		

Realisation	How the organization can successfully implement the innovation. It involves selecting from the potential innovations those which the organization will commit resources.	*Contextualise:* The means by which articulated knowledge is placed in particular organizational contexts *Apply:* The means by which contextualised knowledge is applied to organizational challenges	Selection decisions on which potential innovations to pursue are based on available knowledge & expertise so having access to a greater network of expertise, knowledge and diverse perspectives to enlighten the selection process and improve the selection decisions.	• Determine the strength of the relationship • Determine the types of knowledge being transferred. • Determine who acquires information from whom and how frequently. • Determine the cognitive distance between individuals. • Determine what methods are used to transfer *both* explicit & tacit knowledge • Determine the extent of trust in the network • Determine the similarity or difference in contexts/knowledge base between organizations/individuals
Nurturing	This is the phase of nurturing the chosen option through providing resources, developing the means for exploration.	*Evaluate:* The means by which the efficacy of knowledge applications is assessed *Support:* The means by which knowledge applications are sustained over time *Re-Innovate:* The means by which knowledge & experience are reapplied elsewhere within the organization.	The opening-up of this phase of the innovation process to input from knowledge sources available throughout the immediate and external social networks of the organization enhances the expertise & knowledge available, increases the creative capability to solve problems encountered and ensures that relevant stakeholder requirements are incorporated into the design & development activities. Potential errors are minimised by collective knowledge sharing, collaborative routines have the potential to develop technologically superior innovations & reduce the cost & time of development.	• Determine the 'real value' of knowledge transferred. • Determine the extent mutual benefit occurs as a consequence of knowledge exchange. • Determine the sustainability of the network. • Determine the types of knowledge being transferred. • Determine the sources of 'valuable' knowledge • Determine who acquires information from whom and how frequently. • Determine the extent of trust within the network

Adapted from Tranfield et al., (2006): Columns 1-3 from Tranfield et al., (2006), Columns 4-5 based on social network literature (see authors)

Table III: Summary Social Network Analysis across the Three Cases

Knowledge Management Routines	SNA Determinants	Case Evidence
Search: The passive & active means by which potential knowledge sources are scanned for items of interest	Determine the strength of the relationship	The impetus for venturing into the external environment to locate suitably interested organizations came from the lead academic within the university organizations All three lead academics fit the mould of boundary spanners and provide the 'weak' ties that nurture embryonic relations into a collaborating network. *Indicator: Initially weak ties which became stronger between lead academic and industrial representative; weaker ties between industrial representatives.*
	Determine the position of the organization/individual within the network	In all three cases, there is an obvious bias towards interaction by industry personnel with university researchers. This places the academic institutions in central positions in the network. There is evidence within certain networks of increased awareness of competitor industry's competencies and fledgling collaborations between synergistic industrial partners. *Indicator: Central position of universities. Evidence of industrial partners increasing their connections between other industrial partners & thus their centrality.*
	Determine extent to which people are aware of others expertise.	During the formative stage of the network, academic members had to 'sell' the network by communicating the latent expertise and its value to prospective partners. Periodic, on-site meetings act as a catalyst where industrial partner representatives identify and nurture linkages between the PI and appropriate scientists in their organization. Lead academics promoted benefits of the network externally to attract suitable new industrial partners. As the network evolved, individuals at the core of each of the networks were fully aware of the competencies and expertise of other individuals within the network and the scientific discovery knowledge being generated. These individuals further championed the network within their 'home' organizations by linking relevant employees with network members and activities. *Indicator: Stronger ties between lead academic and industrial representative increasing likelihood of awareness; stronger intra-organizational ties, weaker ties between industrial representatives.*
	Determine the ease with which a person can gain access to another with required knowledge.	Network established as a hub and spoke model where majority of interaction occurs through the university at the centre of the network. As a consequence of continued interaction at periodic, on-site meetings, the industrial representatives have behaved as knowledge brokers and informal linkages between certain industrial partners have developed in recent years as a consequence of research synergies. *Indicator: Central position of university in the network ensures high access between university and individual industrial partners; access constrained between industrial partners but improving as network cohesion increases*.

	Determine the level of structural holes and ongoing efforts to close them.	The lead academic and industrial representatives act as knowledge brokers and network architect in connecting the knowledge holders together, whether this is internal or external of the network. This has resulted in new industrial partners joining the existing consortium, primarily driven by their ability to enhance the overall scientific capability of the network. *Indicator: Knowledge brokers scanning the existing network operations, establishing new relationships and growing the network with suitably knowledgeable partners.*
Capture: The means by which knowledge search outcomes are internalised within the organization	Determine the extent to which an individual is willing to support knowledge transfer.	In the early years of collaboration, knowledge transfer was primarily unidirectional from the university but as network evolves and both scientific and interpersonal trust builds between individuals, then higher levels of collective knowledge sharing is evident to advance both the scientific projects of the university and sharing between industrial partners. *Indicator: Increasing levels of knowledge transfer between partners due to increased trust and realisation of actual benefits of collaboration.*
	Determine the channels by which knowledge is exchanged	Explicit knowledge could be exchanged through access to centralised laboratory information systems, intranets, formalised project and annual reports and at the regular presentations of university findings. More tacit knowledge could be exchanged through on-site visits at university laboratories, secondment of industrial personnel into the university, co-location of industry staff in university for short periods, one-to-one discussions between researchers following on-site visits, during social gatherings following such events and during international conferences. As familiarity has increased within the network, more informal communications (via telephone and email) between specific individuals across the networks developed. *Indicator: Increasing strength of ties developing between network members, increasing levels of trust and evidence of multiple channels for achieving knowledge transfer.*
	Determine the routines and protocols surrounding knowledge exchange practice.	Through a process of trial and error over the past decade, the networks have developed a set of structures and processes that facilitate the long-term sustainability of the network. These routines include management structures regarding the responsibilities of network members, procedures regarding entry and exit into the network, sanction and reward procedures and agreements regarding intellectual property ownership and opportunity exploitation. This was facilitated by the partners in all cases adopting a long-term focus regarding their commitment to collaborate. *Indicator: Common agreement among partners regarding routines of practice and a long-term focus regarding interaction.*

	Determine peoples' perception of trust in others.	As the network has evolved over time, so have the relations between partners. This has resulted in new ties developing that have enhanced the cohesion within the group. Certain industrial partners have surpassed their contractual obligations in order to increase the innovation capability of the network. Also some of the initial structures developed to prevent knowledge spill-over between partners have become obsolete as greater trust develops. *Indicator: Increase in number of strong ties evident between network members, greater perception of trust evident both qualitatively and by actions taken.*
Articulate: The means by which captured knowledge is given clear expression	Determine the likelihood that knowledge shared can be combined.	Given the specific nature of the network's scientific research, all participants share common ontology and cognitive capacity to interpret and abstract the knowledge transferred. However, evidence in cases that individuals require an initial period of 'due-diligence' to validate scientific capability of knowledge being transferred, prior to it being readily absorbed and combined. *Indicator: Strong level of absorptive capacity within network from outset due to strong scientific capability of partners participating in the network. Initial validation of scientific capability at level of individual necessary prior to knowledge absorption and combination.*
	Determine the similarity or difference in contexts/knowledge base between organizations/individuals	The highly encultured language and expert knowledge associated with the scientific disciplines is potentially a significant barrier to successful knowledge transfer and absorption. However, given that all individuals engaged in the networks possess scientific qualifications and all are motivated by similar discovery focus, the networks have actually become communities of like-minded peers. Despite this common foundation, each network member has their own particular area of science and expertise that challenge others assumptions and mental models. While the initial network founders often have a previous legacy of interaction that has validated their scientific credentials and thus facilitates trust and cognitive proximity, newer members require time and interaction to achieve similar contentment. *Indicator: Similar knowledge base, diverse contextual bases in terms of area of science and industrial or organizational perspective.*
Contextualise: The means by which articulated knowledge is placed in particular organizational contexts	Determine the cognitive distance between individuals.	Although all individuals engaged in the network are research scientists who strive for knowledge creation and are capable of absorbing knowledge transferred, there is significant cognitive distance between the industrial and academic communities (at the organizational level). This distance facilitates innovation by maintaining a constant balance between explorative and exploitative forces. With increasing affinity the cognitive distance between individuals and organizational partners narrows thus increasing absorptive capacity and providing a ready basis for knowledge transfer. *Indicator: High cognitive distance between organizational partners signified by diversity of contexts of origin, diverse views and opinions regarding path forward and research methodology. Closer cognitive proximity at individual level facilitates in nurturing increased affinity.*

	Determine the channels by which knowledge is exchanged	Explicit knowledge could be exchanged through access to centralised laboratory information systems, intranets, formalised project and annual reports and at the regular presentations of university findings. More tacit knowledge could be exchanged through on-site visits at university laboratories, secondment of industrial personnel into the university, co-location of industry staff in university for short periods, one-to-one discussions between researchers following on-site visits, during social gatherings following such events and during international conferences. As familiarity has increased within the network, more informal communications (via telephone and email) between specific individuals across the networks developed. *Indicator: Multiple channels for achieving knowledge transfer, increasing focus on channels for enabling tacit knowledge transfer.*
Apply: The means by which contextualised knowledge is applied to organizational challenges	Determine what methods are used to transfer both explicit & tacit knowledge	The knowledge available within the organizational actors is applied to solve specific scientific problems which are agreed as mutually beneficial to the network participants. This occurs through specified research projects, where relevant network members contribute knowledge, compounds, staff and capacity to achieve objectives and generate new knowledge through scientific discovery. The new knowledge generated through exploration provides inputs and leads for exploitation within the innovation processes of the network's organizations. Dependent upon contractual conditions agreed during the network's formative phase, the newly discovered knowledge will be exploited unilaterally or collectively and result in patents, leads for new treatments, licensing agreements, new operational processes or even the creation of new joint ventures. *Indicator: Methods increasingly focus on organizational problems and opportunities.*
Evaluate: The means by which the efficacy of knowledge applications is assessed	Determine the types of knowledge transferred	Both tacit and explicit knowledge transfer occurs between the university and industrial partners through periodic, on-site meetings and employee secondments. As social networks develop through this interaction, deeper ties develop to allow transfer of tacit knowledge across structural holes. *Indicator: Both tacit and explicit knowledge being transferred between partners.*
	Determine the 'real value' of knowledge transferred.	Tangible outputs evident included the production of Ph.D. graduates and scientific articles, leads for new compounds, patents, parallel collaborative projects, together with enhanced understanding of the underlying science from explicit and tacit knowledge transfers. The networks operations have also resulted in advancement of the state of the art, with these contributions being documented in journal publications. The knowledge store of each of the partners has also been increased which increases both their and the networks innovative capability. *Indicator: Quantifiable number of patents, product/process developments and publications. Qualitatively a perception of increases knowledge store among partners within the strategic knowledge area of the network.*
Support: The means by which knowledge applications are	Determine the sources of 'valuable'	As university holds central position in the network, it uses its position power to manage network interaction and ensure all partners are contributing to an acceptable level. Certain industrial partners have surpassed their contractual obligations in order to increase the innovation capability of the network.

sustained over time	knowledge	*Indicator: Knowledge brokers regularly traverse structural holes and external boundaries of network to enhance its scientific capability.*
Re-Innovate: The means by which knowledge & experience are reapplied elsewhere within the organization.	Determine who acquires information from whom and how frequently.	The networks provides advice and insights to the multiple research projects ongoing within the university hub. The portfolio of projects is decided by the network's management team, which consists of representatives from each of the organizational partners. The flow of information is strongly influenced by the specific project and its scientific challenges. *Indicator: High frequency of both formal and informal information transfer from all partners.*
	Determine the sustainability of the network	The networks evolution is guided by the lead academic, with the support of the industrial partners. This helps maintain the balance between discovery and commercial forces and ensure relevance of the networks scientific output going forward. The lead academic also traverses organizational boundaries to attract new partners into the network that can contribute synergistic knowledge to advance scientific discoveries and guides the future scientific trajectory of the network. Defined in the consortia agreements of the cases, is a specific point in time of network review, where individual cost-benefit can be assessed, new members attracted in and network strategic re-focusing undertaken. *Indicator: Strong cohesion in network, duration of the network operations and attractiveness of the network to new membership, evidence of increasing membership and increasing resource commitment.*
	Determine the extent mutual benefit occurs as a consequence of knowledge exchange.	The cases have defined cycles of renewal where all partners were able to exit the consortium if desired. However, in all three cases, there is informal support by network members to continue their involvement into the next cycle of the network and increase the scientific capability of the network. Case 1 is currently transitioning from its third to fourth cycle; case 2 from its first to second cycle and case 3 is currently approaching its point of renewal. The collaborating partners view the re-engagement decision as primarily based on cost-benefit criteria and a perception that they are not being exploited by other network members. *Indicators: Strong cohesion in network, duration of the network operations and stability of the network membership.*
	Determine the extent of trust within the network	In all three cases the level of trust is increasing. In case 2, the network evolution has resulted in partner organizations within the network establishing smaller, parallel consortia to pursue new opportunities identified during interaction. Rather that this being viewed as a threat to the original network, it is seen as evidence of deepening relations between organizational partners and added value of participation. *Indicators: Greater collaboration outside of contractual obligations, perception of greater trust, increasing interaction between industrial partners whom had weaker ties to each other initially than they had to the university partners*

Figure 1: Expected Social Network Enablers over the Phases of Innovation

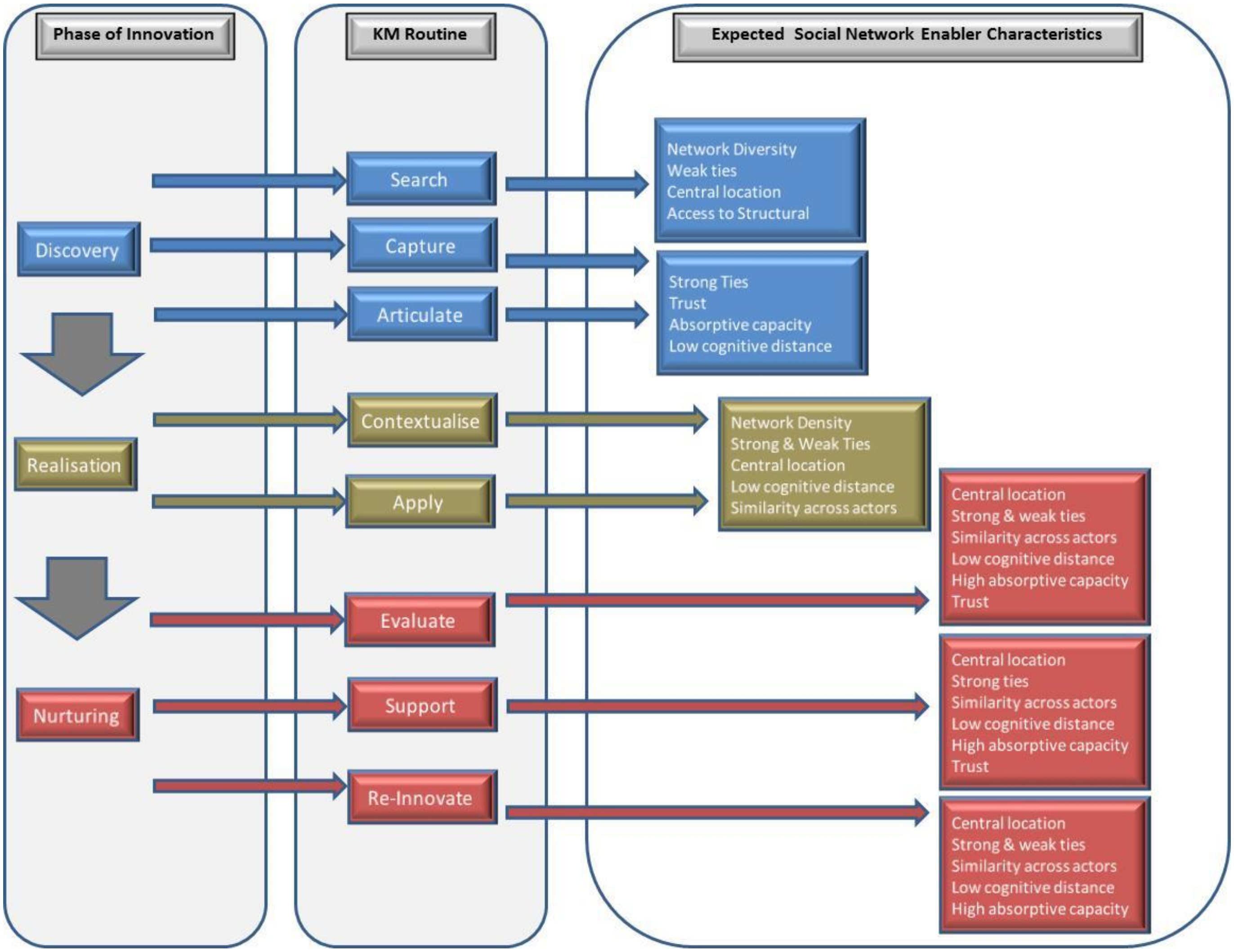

Figure 2: Evolution of the Social and Formal Network over the KM Routines Phases