R&D MANAGEMENT

Knowledge exchange in networked organizations: does place matter?

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While many studies of knowledge exchange have been undertaken in private and service organizations, government and R&D enterprises, few have studied scientific inter-organizational collaborations. Furthermore, in the literature on international networks there has been a tendency to assume that knowledge exchange will be inevitably enhanced by global dispersion. Two linked dynamics deserving further study are the role of geographic proximity and the role of information and communication technologies in facilitating knowledge flow across international networks. Studies of intra- and inter-firm knowledge transfer, managerial work values and cultural norms all point to China as being a fascinating counterpoint for the way knowledge exchange might occur in Europe. So in this study of the ATLAS collaboration, a 'big science' global network of 3,500 physicists, we explore the perceptions of two subgroups: UK physicists working in Europe and Chinese scientists based in Beijing and HeFei. Findings from 24 interviews and non-participant observation reveal that face-to-face working at European Organization for Nuclear Research (Geneva) is not without its difficulties, but for a variety of sociocultural reasons, it is primarily the Chinese scientists who perceive themselves to be inhibited from full participation in effective knowledge exchange.

1. Introduction

Over the past decade, a strand of literature has forcefully proposed that due to globalization and institutional change, businesses that grow in isolation from the world economy are being superseded by universally applicable techniques (e.g. Geppert et al., 2002; Kostova and Roth, 2002; Dicken, 2003; Meyer et al., 2006). In particular, they argue that new information and communication technologies (ICTs) have the effect of enhancing the flow of knowledge by blurring nationally distinctive idiosyncracies, not just organizational and institutional, but also political and cultural. Others have challenged the inevitability of this thesis. In the realm of knowledge exchange in international R&D, two questions remain unresolved (Howells and Bessant, 2012). The first concerns the degree to which face-to-face working afforded by geographic proximity is necessary for international networks given the increased sophistication of ICTs to facilitate connectivity across dispersed sites. Boisot et al. (2011) argue that the assumed benefits of technology underplay the political choices of leaders; they maintain that, for all the advantages of common

ICTs across global operations, together with the application of standard protocols within a geographically dispersed value chain, at most the Internet should be seen as an *enabler*, rather than as a determinant, of good practice. Support for this comes from an intriguing study by Newell et al. (2001) which found that the introduction of intranet in a global bank failed to facilitate organization-wide knowledge sharing but actually reinforced existing functional and national boundaries with 'electronic fences'. The second, linked question concerns the role and relevance of cultural difference in international networks, namely: 'how it [knowledge] is articulated, and how it influences and is influenced by, other cultural, cognitive and social processes' (Howells and Bessant, 2012, p. 4). Because the judicious exchange of knowledge in R&D environments is conditional upon trust, and trust, in turn, is heavily influenced by host country norms, then culture becomes a significant ingredient for international knowledge-intensive networks.

The intention of this paper is to throw light upon these important issues. Theoretically, we challenge some of the conventional wisdom which equates improved ICTs and formal governance systems with enhanced global knowledge exchange. In particular, we find that although face-to-face working in international R&D settings remains important for exchanging tacit knowledge, even in co-located work settings, we should avoid the assumption that geographic proximity *automatically* enhances this mutual exchange. Among the practical contributions implied by this is that global R&D collaborations and project teams should take account of the sociopolitical and cultural dynamics that can interfere with trust building, as this can attenuate the effective transfer of knowledge between partners. We explore these issues via a qualitative study of scientists in a global R&D partnership, the ATLAS particle physics experiment based at the European Organization for Nuclear Research (CERN), near Geneva. How is knowledge exchange within and across ATLAS global networks influenced by geographic proximity and the opportunity for face-to-face interaction? In the world of global R&D networks, supported by sophisticated ICTs and knowledge governance mechanisms, does *proximity* matter, in terms of social, cultural and geographic distance? The ATLAS collaboration provides a rare and intriguing opportunity to explore these questions. We do this by taking two small subsamples and comparing the perceptions of scientists working in Europe who are based at (or physically proximate to) CERN with those working on the same global experiment in mainland China (Beijing and Heibei), who are physically remote and subject to very different cultural norms. Before reporting these perceptions, we review some salient literature which informs this enquiry, looking at the contribution of geographic proximity to effective knowledge exchange, with specific reference to Chinese cultural norms.

2. Geographic proximity, ICTs and knowledge exchange

2.1. Face-to-face working and ICTs

Implicit in the discussion of networks is the notion that strong ties provide access to more finely grained and high-quality information/knowledge, but this requires face-to-face interaction facilitated by the spatial proximity of network actors (Uzzi, 1997; Wei et al., 2011). Empirical support for this comes from a variety of sources and sectors. Dixon and Panteli (2010) concluded that ICT-mediated interactions do not substitute but rather complement face-to-face communications between collaborative project partners. In a study of eight globally distributed teams in hi-tech companies, social and informal contact between members proved important for team satisfaction, constructive work climate and correlated positively with virtual team performance (Bosch-Sjitsema et al., 2011). Bouty (2000) collected anecdotal data from 38 R&D scientists in six industrial sectors over two phases of their respective projects. In the early stages of networking with satellite partners, knowledge exchange was limited to that which was relatively non-controversial and non-strategic; over time, if these colleagues proved reliable and trustworthy they developed into 'heart partners' where equitable rather than simply profitable exchanges were made. This is similar to the notion of social capital, defined by Adler and Kwon (2002) as: 'the goodwill available to individuals or groups. Its source lies in the structure and content of the actor's social relations. Its effects flow from the information, influence and solidarity it makes available to the actor' (Adler and Kwon, 2002, p. 23). A study of 152 leaders in 12 UK universities by Bolden et al. (2008) revealed the presence of social capital derived from academic and professional credibility nurtured and sustained by a large network of contacts beyond their home institution. The parallels with ATLAS scientists operating from 175 research institutes are striking.

We might assume that face-to-face, spatial proximity is important for enabling meaningful social interaction and knowledge transfer in *temporary* organizational systems (Kotabe et al., 2003).

Sammarra and Biggerio (2008) point to the geographical proximity as featured in industrial clusters as an important factor in assisting the emergence of new ideas in local contexts made up of personalized localized networks. In a qualitative study of open innovation teams, Chatenier et al. (2010) identified the ability to build trust and deal with low reciprocal commitment as important qualities for knowledge professionals; a finding supported by studies of industrial research organizations (Berends et al., 2006) and in new product development teams (Muethel et al., 2012). Rashman and Hartley (2009) found that trust and similarity of geography in a UK local authority, alongside capacity and political affinity, helped promote shared experiences. Although research evidence is building, reviews of the field suggest that the role of face-to-face, as against geographically distant, interaction requires more investigation in the context of knowledge-based temporary teams (Bakker, 2010), and we need to be careful not to assume that geographical proximity is equivalent to relational and cognitive proximity (Bahlmann et al., 2010).

2.2. Culture: the case of China

If effective knowledge transfer between partners in informal networks is heavily dependent on social cohesion around working relationships and individuals' willingness and motivation to invest time and effort in sharing knowledge (Meier, 2011), then we might also expect the socio-institutional heritage of different countries to exert a strong influence on the way such networks operate (Zaidman and Brock, 2009). The Chinese enterprise has been described as a political coalition and a sociopolitical community. The Confucian principle of hierarchy implies that individuals need to be conscious of their position in the social system and abide by it; this means managers need to cultivate vertical relationships with superiors as well as non-market exchange relationships with other enterprises (Walder, 1989). For example, in the case of China, Graham and Lam (2003) and Cardon (2009) point to the importance of *face* as a Chinese cultural characteristic; Chinese individuals typically believe that face can help to maintain or enhance positive public image and reputation. Face helps to accelerate the level of good relationship which, in return, furthers the opportunity for social exchange. Over the process of social exchange, trust can be developed.

In a society based on Confucian values, harmony, hierarchy, collectivism and personal relations are seen as paramount (Shenkar et al., 1998) and, given high-power distance (Hofstede, 1980), deference to leaders by subordinates and developing long-term relationships are likely to be critical for effective knowledge exchange. Chinese cultural traditions stemming from Confucian values attach considerable importance to hierarchical relationships and to collectivism (thinking and behaving the same) in order to maintain harmonious relationships between family members and by extension, to others in the clan, the organization, the community and society at large (Puffer et al., 2010; Yang, 2012). Another tradition known as *guanxi* in Chinese, provides moral guidance for the Chinese as to their behaviour which is reflected and expressed through the emphasis on harmony (Westwood, 1992; Wong and Slater, 2002). De Jong and Elfring (2010) point to the importance of trust for enhancing team performance. Trust is developed through long-term relationship guanxi which imposes reciprocal obligations on all parties concerned, and because of the need to maintain good guanxi and harmony, the Chinese will think and behave in ways that avoid conflict or confrontation with others. The way to maintain and enhance good guanxi is to give face, to respect hierarchy and to act according to others' needs.

On the other hand, Hong et al. (2006b) have suggested that culture and history can act as agents to facilitate collective learning. They state: 'collective learning as culture enables members to collaborate and undertake radical transformation, which in some cases may even be achieved without explicit standards or instructions' (Hong et al., 2006b, p. 1031). Therefore, the important Chinese cultural tradition of collectivism may enable the Chinese scientists to work productively on their own terms, for example, using similar patterns of behavior and thinking to create a dynamic of knowledge exchange through a learning process which emphasizes sharing, mutual support and collaboration (Chen et al., 2011). However, some studies (e.g. Li and Scullion, 2006; Huang et al., 2008) found that Chinese are unwilling to share their experience and core knowledge because of the fear of loss of knowledge power. In their meta-analytic review, Van Wijk et al. (2008) note that only three of the 75 studies considered the influence of cultural distance on knowledge transfer. Given the close connection between knowledge exchange, trust and cultural norms, this would appear to be an important gap in our understanding.

In this paper, we explore local interpretations of knowledge exchange in a global R&D collaboration; in particular we examine the opportunity for face-to-face working and the influence of national culture by comparing perceptions of UK and Chinese scientists.

3. Research design

The ATLAS experiment, one of four currently being conducted using the Large Hadron Collider (LHC) at CERN, is arguably the most complex and ambitious scientific experiment ever undertaken[1]. The ATLAS collaboration brings together over 3,500 physicists working in 174 institutes located in 38 countries. Having started in 2009, the ATLAS detector is searching for new discoveries in the head-on collisions of protons of extraordinarily high energy. The findings reported in this paper (part of a larger study designed to deepen understanding of knowledge exchange within the ATLAS collaboration) take research institutes as the unit of analysis. ATLAS comprises a wide range of R&D institutions, each supposedly treated in an egalitarian manner (for example, each partner institute, regardless of size or location, has a single vote when internal decisions are required). We chose, initially, to focus upon and analyse the interview transcripts of the entire Chinese subsample of 11 physicists who were working at the HeFei and Beijing Institutes. We also had transcripts for 13 UK scientists, based in British and other European Institutes, and we selected these as a contrasting subsample in order to explore the two research questions above. As can be seen from sample characteristics in Table 1, the UK scientists were frequent or occasional visitors to the hub of the ATLAS experiment at CERN, near Geneva, or worked there permanently now or in the recent past. While some of the Chinese subsample had been educated at western

Table 1. Demographics of interviewees

UK Respondents				
Code	Gender	Current home institute	Job role	Time spent at CERN in the last five years*
E1	F	Stockholm	Doctoral student	Six months per year
E2	F	CERN	Project leader	Permanent
E3	M	Stockholm	Systems developer	Occasional
E4	M	Queen Mary, London	Applied physicist	Permanent
E5	M	Birmingham	Coordinator	Occasional
E6	M	Liverpool	Coordinator	Permanent one year
E7	M	Birmingham	Project leader	Permanent
E8	M	Birmingham	Group leader	Frequent
E9	M	Rutherford Appleton	Coordinator	Frequent
E10	M	Queen Mary, London	Coordinator	Frequent
E11	M	Birmingham	Coordinator	Occasional
E12	M	Rutherford Appleton	Coordinator	Frequent
E13	M	Birmingham	Applied physicist	Frequent
China respondents				
Code	Gender	Current home institute	Job role	Time spent at CERN in the last five years
C1	M	Beijing	Professor	Occasional
C2	M	Beijing	Assistant Prof	Occasional
C3	M	Beijing	Assistant Prof	Two short visits
C 4	M	Beijing	Professor (retired)	None
C5	M	HeiFei	Senior scientistProfessor	Occasional
C6	M	HeiFei	Coordinator Assistant Prof	Occasional
C7	M	HeiFie	Coordinator Assistant Prof	Occasional
C8	M	HeiFei	Coordinator Assistant Prof	Occasional but not in the last three years
C9	M	HeiFei	Doctoral scientist	One year in France with visits to CERN
C10	M	HeiFei	Doctoral scientist	Six months in France and visits to CERN
C11	F	HeiFei	Professor	None

*Occasional: at least one month per year.
Frequent: more than one month per year.

universities and in some cases, had worked at CERN for periods in the past, their primary location was at the Beijing and HeFei Institutes. This allows a comparison to be made between those scientists who are geographically proximate to the hub of ATLAS at CERN to those who are geographically distant. (While each subsample comprises a mix of age, seniority, job role and gender, it should be noted that it was not possible to match the two precisely). All shared the same Internet facilities, although, as we shall see, the Chinese scientists were sometimes hampered by the reliability and quality of this service. In addition to interviews, our findings are informed by non-participant observation of ATLAS scientists more generally, by attending project meetings and less formal gatherings at CERN and in the UK over a period of time extending from July 2009 to September 2011.

All interviews were conducted at their respective institutes in the UK and China, although some of the former were interviewed at the Meyrin site of CERN in Switzerland. Interviews lasted between 45 min and 90 min and were tape recorded and then transcribed verbatim. We opted for semi-structured interviews which allowed us to pursue our main research interests, but to also explore aspects that we might not have considered a priori. We asked about researchers' views on how ATLAS functions, and how knowledge is produced, shared and advanced. Initial interview questions were informed by two sources: a paper on careers among knowledge workers (Kamoche et al., 2011) and a review of networked enterprises (Nahapiet, 2008), but follow-up questions pursued issues raised by the respondents themselves. Interviews in the Chinese partner institutions were undertaken in Mandarin, the first language of one of the authors. Given the potentially sensitive nature of the research (concerning trust, social capital, tacit knowledge, nuanced perceptions of network participation) conducting the interviews in their native language was seen as essential in order to build rapport with the interviewees and to explore the perceptual subtleties of this study. The translation was done by an independent research assistant and verified by one of the authors who is fluent in English and Mandarin. The transcripts were then examined using template analysis (King, 2004) within a 'contextual constructivist' discourse (Madill et al., 2000). Statements from the interviewees were initially clustered into two broad conceptual groupings, linked to our research enquiry ('differences due to geographic proximity' and 'differences due to national culture') and then gradually broken down into subsidiary constituent themes. These are highlighted in bold in the Results section and summarised in Tables 2 and 3. In what follows, we report verbatim quotations from UK and Chinese scientists; in this way, we hope to have captured the highly subjective and sometimes opposing ways in which participants invest their experience of knowledge exchange in ATLAS with meaning.

4. Results

4.1. *Differences relating to geographic proximity*

For a number of reasons, the UK scientists in our sample expressed very positive views about the opportunities to work regularly in geographic proximity to the headquarters of the ATLAS project, the campus-like facility at CERN, where the LHC and detectors are located. In part this is due to the very evident sense of shared purpose. While it is true that all scientists across the 137 national Institutes in the ATLAS collaboration are dedicated to discovering the Higgs' boson, the passion is especially palpable at CERN:

> I think the driving thing is everyone's here because they want to do this experiment, and if that wasn't the case it would be really difficult to get them to work together. Everyone is so motivated by the same goal and also they're all – they're all physicists, right, so there's a sort of overlap of science language if you see what I mean. (E2)

Even though the scientists at CERN come from diverse backgrounds, they have developed a common language and understanding of the world. For example, a UK scientist reported that the ATLAS researchers were all 'world citizens' since they had done their education in one country and then worked in a different country. Thus, most speak several languages and have learned to adapt to different cultures. In addition, ATLAS researchers, regardless of their origins, speak and understand a clear common language to communicate about physics. Another distinct advantage to being present at CERN is the opportunity to engage in informal discussion:

> . . . . I think that seeds of ideas were planted in different places, something that you take from a talk or something very often that comes up over coffee, or a discussion over dinner. . . . . and those ideas get planted and take on a life, and very often it's the person who just happens to have the time to think about something and come up with a new answer who contributes and then that adds on. (E1)

Table 2. How is knowledge exchange influenced by geographic proximity? Comparative summary of UK and Chinese scientists

Dimension	UK	China
Geographic proximity to CERN	Resident at , or a frequent visitor to, CERN 'You can read some documentation and it says what you do, it doesn't tell you why or that tacit bit of . . . the philosophy behind it, it's much easier to talk face to face with someone in order to develop a real understanding' (E7).	Based remotely with limited visits to CERN 'I think it is related to the regional and geographical factors. Hm . . . [Sigh] We are remote from CERN. You have to know that the physical distance did play a role psychologically. You can feel the distance. Those who are physically closer to CERN, would feel they have ownership to the happenings over there' (C4).
Face-to-face interactions at CERN	Ample opportunities, informal discussion over coffee and dinner: being present at scientific meetings, socializing '. . . . it's the gathering that matters and it's the, sort of, having coffees and having beer, that sort of thing, rather than during the meeting, is when things often actually start to crystallize' (E7).	Highly valued, but few opportunities, limited social contacts and networks 'We might speak to the wrong person or spent a whole day to talk about the problem which was very inefficient, it takes time to learn from each other (building guanxi or a network), for Europeans, they are working systematically, but when they were dealing with relationship, they would have different pattern' (C7).
Attitude towards ATLAS collaboration	High inter-generational trust; a network of friendships and bonds developed from previous collaborations 'This is often the way in particle physics. There was a core of the groups that had worked on the UA1 experiment at CERN and many of them had also worked on the H1 project. . . . . . So these were people who knew each other very well and had worked together before on similar projects' (E9).	Relative latecomers, playing 'catch-up'. Unreliable ICT systems hamper communication with rest of collaboration 'Every group will send their best people there [CERN], so that they can have real time communication with the people who are working on the software and hardware and analysis . . . but we have only email communication, sometimes we will have a delay of half a day. The difference is so significant' (C8).

Underlying much of the narrative, from both UK and Chinese scientists, is the perceived value of working face-to-face with colleagues. According to one Chinese professor, the best way to collaborate is face to face: 'I do not prefer to communicate with offline methods such as emails . . . It is not my mother language . . . it is not as effective as having face-to-face discussion. I use body language to visualize my message, and facilitate the communication process' (C1). This is corroborated by his UK counterpart: 'I don't think anything happens in a formal meeting where somebody stands up, gives a 15 min talk and sits down again. The best meetings in the world are the ones where there is the informality, the coffee breaks where people put down the formal mindset and relax' (E4). This notion of talking about work issues, either in the cafeteria or over a drink in the evening was a common theme among respondents. It seems that, despite being a well-connected global network using state of the art communication technologies, and despite a plethora of email traffic documenting every meeting and posting the latest web conferences, face-to-face encounters remain crucial. What makes the collaboration scientifically successful[2], as well as personally exciting, is the fast and fluid exchange of tacit knowledge, which by definition is unlikely to be codified.

Physical proximity also allows the nuances of knowledge and its context to be readily comprehended: 'You can try and document that but it's much easier to talk face to face with someone in order to develop a real understanding of that, It's a massive advantage to be out here' (E7). This is something greatly missed by the scientists in China, as one professor recalls somewhat wistfully: '10 years ago, when I was at CERN, we kept on having keen discussion and argument. Such brainstorming and challenging one another was a dynamic process that could lubricate the exchange of new ideas. CERN is such a big place where creativity dominates. This is what I called the right atmosphere' (C11).

This issue of ownership surfaced in other comments from the Chinese scientists. An assistant professor at Beijing referred to certain 'rules of the game' that were predetermined by CERN and had to be learnt by outsiders. (C3); and another Chinese

Table 3. How is knowledge exchange influenced by cultural factors? Comparative summary of UK and Chinese scientists

Dimension	UK	China
Knowledge exchange	Shared, leaders actively engage in discussion, supporting and facilitating knowledge sharing, openly express ideas regardless of seniority: 'Some people can be very, very bright, but very divisive and a divisive figure is probably not someone you want high up the chain. You know, these things do have to work as a collaboration' (E7).	Paternalistic, seniors/leaders mentor and groom juniors on knowledge creation, juniors do not question seniors, cautious/reluctant expression of ideas: 'The degree of power is equivalent to the structure, the hierarchy. Spokesperson is the big boss, then coordinator and different leaders, like a ladder, very clear . . .' (C11).
Cultural values	High initial trust. Shared history, common reference frames community of practice: 'Part of it was because we've been working together for 15 years. . . . So some of what you said, a few words could mean a lot, we both understood and didn't have to spell it out. It would have been different had there been someone there who had no . . . other than you (laughs) who had no background reference' (E1).	Low initial trust outside guanxi relationships. Psychologically distant, language barrier, high power distance: 'One of the obstacles is language barrier. You may think our language proficiency is fluent, and it might be for day to day work communication, but we are not yet there to be good teachers . . . we need to make things crystal clear . . . we haven't had time to sit down and sink in our learning' (C5).
Language (and tacit knowledge exchange)	Knowledge experts are recognized as those with valuable, un-codified 'know-how' which is accessed via adept use of language: 'What happens is that the people who have experience of trying to make these complicated systems work, know what the intricacies are, know what the dependencies are [doing this] intuitively without having to look at a manual. . . . So actually you become very valuable as an expert because of that tacit knowledge' (E5).	Tacit knowledge arises spontaneously in ongoing conversations, which requires fluency in English: 'I like to have face to face talk. . . . this is soft knowledge . . . we have lots of side talks, these may seem irrelevant during the conversation, like a transmitting line, but it may trigger some creative thoughts' (C8).
Cultural history	Egalitarian meritocracy and democratic decision making: 'There is no hierarchy in this field . . . one of the things I like about it. If you've got a young student who is very good and they work hard . . . they can start in CERN and really do some important jobs' (E11).	Legacy of low trust and deference (especially among older generation) stemming from Cultural Revolution 'I was a spokesperson some time ago. We had a lot of problems at that time. We had a Cultural Revolution decades ago, it damages mutual trust among Chinese. We had no security and trust in others' (C6).

colleague stated: 'One might not tell you the trick directly. There might be conflict of interest, but this would be resolved as time went by, and we got better acquainted. We may not have much credit when we ask questions during the warm-up period.' (C1). Once again, the importance of face-to-face relationship-building emerges as a crucial factor for negotiating the power implicit within knowledge exchange.

4.1.1. Attitude towards ATLAS collaboration

The strong cultural norms and code of conduct arising from immersion at CERN are not always viewed in a positive light, even by the UK scientists. For example, some of the students seconded to CERN spoke of the commitment of colleagues, and their willingness to help out with technical problems; however, the downside of this intensive and constant involvement in the experiment is that: 'it gets a bit overwhelming . . . because the office is there so you can stay there the whole time and it's probably not healthy, you should probably spend time with people' (E3). The same respondent also spoke of an unwritten pressure to perform:

> I always feel that I have to prove that I'm a good physicist but I don't know if it's because

> I'm a woman. . . . . . . every now and again we'll be sitting and having a pint or a coffee or something and we'll be like someday someone's going to realise that I'm a complete fraud and don't know any physics and I'm just here at CERN. (E3)

One of the hallmarks of the culture at CERN is the informality, the apparent democracy and the collaborative nature of the way in which decisions are made. This informality brings its own difficulties for those who find themselves present at CERN but, for a variety of reasons, excluded from important communities of practice. This may be due to gender, ease in speaking English, relative prosperity of home institution/country, age, nationality and proximity to CERN. By way of summarising the importance of geographical proximity to effective knowledge exchange, Table 2 provides the constituent themes – together with illustrative quotes – arising from the data analysis.

4.2. Differences associated with national culture

At a cosmetic level, it would appear that knowledge exchange in ATLAS is conducted in a truly cosmopolitan manner, benefiting from the cultural diversity of scientists from 37 countries treating each other as equals. As a UK Coordinator at CERN states: '. . . I don't care about the nationality of a person if I'm working with them and I think that's true of most people as well. I guess it's the sense that there's this greater goal that you're trying to work towards' (E10). Some of the Europeans also recognize that language can be a barrier for those whose first language is not English: 'So for a new person making their career, they've not only got to learn physics, they've got to be at least capable of writing it up in English and discussing in English, making presentations in English. So that puts an extra burden on someone who's not so good at languages' (E2). But beyond language, awareness of deeper cultural differences emerges in our transcripts. One difference concerns attitude towards authority (age or grading) and hierarchy. One of the Chinese professors was able to elaborate:

> In Western culture, there is no doubt that it's dominated by democracy. . . . Sometimes, democracy means no efficiency, right? . . . In our collaboration, I observed that there is power ladder. This is our cultural background. Right? (C1)

Cultural values surfaced in other ways. One Chinese professor also remarked that because the younger generation 'dare not challenge their senior' this actually hinders constructive conflict and creativity. Possibly due to this, the notion of actively 'mentoring' and 'grooming' occurred in several interviews, with the more senior Chinese scientists recognizing that full participation in a global partnership required a different style: '. . . we have to groom successors and make them even stronger than we are . . . in the LHC research field, it emphasizes cooperation. It can't be accomplished individually or within only a small group' (C11).

Connected to this deference in Chinese culture, is the fear of feeling shame. If scientists made any wrong comments, they would worry that their counterparts look down on them, then they would feel shame about it and lose face:

> After I had stayed overseas, I knew how to deal with foreigners when we had conflicts. The foreigners would respect you, and would be willing to discuss the issues. Chinese do not use the same approach. They are concerned about mianzi, their face. When we have to handle disputes, we make use of the 2 degrees that we earned upon graduating from school, one is physics, and the other one is politics. [Laughing]. (C4)

In general, one of the Chinese cultural characteristics is not to question seniors. Maintaining harmony is important as it helps to keep good guanxi and give face to the other side. Confucian's important value is to keep relationship in a 'middle way': not too close but not too distant. As a result, politeness and deference are influential social values. Two further dimensions of cultural difference are language, because the emergence of tacit knowledge often arises from fast-paced, free-ranging and complex discussions and cultural history, because this shapes issues like trust (see Table 3 for quotations from UK and Chinese scientists).

An assistant professor at Beijing commented: 'I think Westerners may not tell you directly of how to do something. . . . how to say something . . . Sometimes, we had to learn from instinct' (C2). And another Chinese colleague stated: 'They might not be willing to share at the beginning. We had to go through a period of water testing. At the beginning, we might have difficulty in expressing ourselves. . . . . In the initial stages of working together, this appeared to be referring to a language issue, which was gradually overcome by relaxing together and socialising . . . they think that before we work together, you should have met certain requirements. But after more interactions, like dining out together, they became opened up and shared more. [Laughing]' (C3).

Combined with this is the unwritten norm of reciprocity. 'Sometimes, if we have questions on certain documents or codes, it's always better to query them. If you raise your queries, people would always be happy to discuss with you. Otherwise, if all you did is to pick the low hanging fruit, they would be reluctant to be the provider of solutions without gaining anything back from you' (C11). Indeed there was evidence of frustration among the Chinese respondents concerning access to up to date information. In part, China was invited to join the research project at the quite later stage. It thus appeared that the Chinese side appeared to be due to lack of familiarity with the ATLAS systems; among issues mentioned were the need for a better interface design for the project website, improved ways of retrieving updates in Powerpoint files and PDF files and the need for a common terminology or website platform. Linked to this is the way different cultural backgrounds impact on learning styles: a reluctance on the part of, especially junior, Chinese scientists to confront other's ideas and the more ebullient style of their counterparts: 'I'm in the standard model group, which is dominated by Europeans. They tend to have strong belief in their own ideas. For us we would be in a minority and our voice would fade out easily . . .' (C8). This extends from exchange of knowledge to its dissemination: 'I think the Asians would be better, as they would publish the findings only after confirming it's fine to do so. Whereas I think the Europeans and Americans would hurry to give voice to their findings' (C11). Table 3 provides the main conceptual groupings arising from the data analysis; these subthemes together with illustrative extracts, summarise some of the key ways knowledge exchange is influenced by cultural factors.

5. Discussion

As a high-energy physics experiment, ATLAS is marked by a massive presence of discourse within an astonishingly intricate web of communication pathways, made up of threads of talk, emails, meeting presentations and informal cafeteria exchanges at CERN and intranet exchanges around the world: 'a constant humming of the experiment of itself to itself' (Knorr-Cetina, 1995, p. 130). This matches well the notion of an open-source network where knowledge is shared generously through the use of the Internet, and anybody can contribute to the further development of this new knowledge (Raymond, 1999). At first glance, ATLAS appears to exhibit the key tenets of innovation one would expect of path-breaking physics, namely: open access to data supported by leading edge technology, an ethos of sharing not hoarding knowledge based on a built-in necessity of interdependence, peer review as the means to validate and celebrate new knowledge and a close working relationship between the producers and users of this new knowledge. Our analysis of interviews with a small number of UK and Chinese scientists reveals a more complex story. Proximity matters to knowledge exchange within the big scientific network. The reliability and the type of ICT application (e.g. offline modes) used to support knowledge flows within the ATLAS can limit the effectiveness of exchange due to the lack of cultural and institutional proximity between communicating partner institutions. Geographic proximity provides the opportunity for the development of relational/social proximity, which seems to be a prerequisite for knowledge sharing with partners from institutionally distant countries. While it is not easy to quantify the cumulative impact of these findings upon the effectiveness of the ATLAS collaboration, here we make three observations which have potential relevance for international R&D networks operating in the knowledge based economy.

5.1. Physical presence at the knowledge hub does not guarantee productive knowledge exchange

Previous research has emphasized the value of geographical proximity for effective knowledge exchange (Uzzi, 1997; Gertler, 2004; Fernandes and Ferreira, 2013), demonstrating that face-to-face working improves international team performance (Bosch-Sjitsema et al., 2011) and builds essential trust over time (Bouty, 2000), which in turn creates social capital (Adler and Kwon, 2002) or what Nicolini et al. (2007) describe as *socialware.* Our findings generally support this. ATLAS operates with loose and flat structures, relies on high trust and mutually beneficial goals and therefore benefits from the productive, sometimes serendipitous, exchange of tacit knowledge. Observation of the main cafeteria at CERN near Geneva, for example, is testimony to this highly fruitful bazaar of knowledge sharing. This does not happen by chance and requires the development of 'relational/social proximity' (Amin and Cohendet, 2004). Newcomers arriving at CERN as part of the ATLAS collaboration are socialized into strong norms and inducted to an informal code of conduct. This has obvious benefits in terms of facilitating inclusion and contribution. By the same token, it creates difficulties for those scientists not geographically proximate to the R&D hub at CERN. The global experiment is designed to be modular in that all participating institutes in 38 countries, contribute vital knowledge (with regard to superconducting magnets, visualisation systems, specialised detectors, data analysis and so on). However, it seems that those located at a distance from CERN, in our case those operating in China, consider themselves disadvantaged in the mutual exchange of knowledge.

5.2. Good technology and governance mechanisms are necessary for effective knowledge exchange but not sufficient

Too often, the very mechanisms set up to facilitate knowledge flow militate against it (Newell et al., 2001). This is because they are often instituted in a top-down way, they are cumbersome and the bridges of trust across which prized know-how travels fail to get built. As a result, staffs are drowned in a deluge of mundane intranet messages, while innovative ideas and serendipitous insights are routinely missed. Within ATLAS, we found an organization characterized structurally by democratic decision making, the avoidance of any 'overmighty' individual or group and by the practical necessity of interdependency: all scientists in the experiment are reliant upon accurate and timely knowledge from all the other participants. It is professional peer pressure rather than corporate compliance that shapes ideas – whoever has them – and this leads to highly motivated and energized workforce. Our interviews reveal that this is less about formal governance, and more about a strong ethic of active collaboration, of unusually high trust and intensive immersion into the scientific community at CERN. ICTs underscore all they do and produce and the Chinese scientists were quick to point out the disabling effects when Internet connections with CERN were disrupted or web platforms were difficult to navigate. As Knoben and Oerlemans (2006) point out, a firm can set up temporary, geographical proximity, but it seems unlikely that, 'without enough organizational and technological proximity, such an effort will be very fruitful' (Knoben and Oerlemans, 2006, p. 87). Face-to-face communications in conjunction with technology-mediated interactions provide a basis for 'virtual continuities' (Dixon and Panteli, 2010), which are crucial to ATLAS, a project which relies on virtual working with fellow physicists around the world. Spatial proximity also enables access to cognitively more diverse knowledge (Huber, 2012) required for scientific breakthroughs because face-to-face interactions make it easier to communicate about heterogeneous knowledge. However, there is a caution here. The fragmented and specialized nature of knowledge and the rapid move towards division of labour in complex R&D environments can lead to a so-called dendritic evolutionary pattern of development, where individuals at the frontier edge of knowledge domains find themselves unable to meaningfully exchange with those at the frontiers of other knowledge domains, due to earlier radical breaks in the way knowledge in their field has evolved (Howells, 2012).

Janowicz-Panjaitan and Noorderhaven (2009) propose that corporate-level boundary spanners from collaborating firms exercise the important function of shaping the infrastructures and systems of the alliance and do so in a calculative manner, to ensure appropriate cost-benefit outcomes; while operating-level boundary spanners work within these parameters set by their seniors and rapidly build trust through the everyday tasks of the alliance reliant upon the trading of tacit knowledge. Our data tend to support this: the technological infrastructure needs to be in place and reliable, but beyond this is the important space it creates for less-predictable but meaningful interchange between partners.

5.3. Culture influences the flow of tacit knowledge on several levels

Interview data from the Chinese scientists surfaced a hierarchical dimension to the issue of knowledge sharing across networks, suggesting that seniority, proximity to the strategic nexus of respective partner organizations and access to resources may all play an important part in the nature of knowledge shared, as noted by Antcliff et al. (2007). Clearly, who gets included and excluded from either formal or informal networks will affect the volume, quality and direction of knowledge flows within an international network (Allen et al., 2007), and we found plenty of evidence to suggest that national culture interferes with this (see Table 3 for examples). Although the Chinese scientists were appreciative of particular individuals who went out of their way to include them in the overall ATLAS collaboration, due to the CERN-based, informal and self-selecting nature of communities of practice, some individuals or groups found themselves barred from forums where important tacit knowledge is generated. As we found, the issue here is partly to do with the Chinese culture; but it may also derive from a perception that control over knowledge flow remains with the dominant partner, a finding reported in United States–China joint ventures (Lin, 2005). The ATLAS case seems to support the argument of Willem and Scarborough (2006) concerning the potentially negative effect of power on the role that social capital plays in knowledge flows, leading to a highly selective form of knowledge exchange. It also lends credence to the counter-intuitive finding that an *over-reliance* on socially embedded relationships can be detrimental in inter-organizational collaborations by undermining effective partner selection (Newell and Swan, 2000), by limiting the exchange of knowledge and information (Edelman et al., 2004) and by leading to over-densed networks which reach a point of diminishing returns (Uzzi, 1997), particularly when the network is engaged in exploration rather than in exploitive activity (Lechner et al., 2010).

6. Practical implications and limitations

Despite the exploratory nature of our data, a number of practical implications follow from the findings so far reported. First, that for all the advantages, indeed necessity, for virtual operations in the knowledge era, some face-to-face working is necessary for building rapport, trust and shared schema to facilitate tacit knowledge exchange. As we discovered with our ATLAS scientists, geographic proximity offers immense learning potential to multicultural networks for surfacing radically different know-how. This includes: unfreezing the cognitive maps of participants, loosening conservative structures and processes, preserving healthy levels of doubt and debate, confronting negative stereotyping and prejudice; however, these benefits will only accrue if the organization is intentional skilful in facilitating multicultural team working (Sparrow et al., 2004). Second, firms/networks need to be aware that the very informality and self-selection of this type of knowledge sharing *can* lead to marginalizing and the exclusion of 'out-groups', not just those physically distant and therefore unable to participate in the exchange of tacit knowledge (like the Chinese scientists) but also those on site but barred for more subtle reasons from such discussions. In the case of CERN, pressure to conform to subcultural norms, a willingness to socialize after hours and being fluent in English language were among such reasons. This echoes the observation that, despite the profusion of knowledge technologies, knowledge often remains 'stubbornly localized around the comparatively small number of highly skilled knowledge workers engaged in high orientation networks . . . we still live and work in narrow social networks' (Howells, 2012, p. 1014).

Third, the power asymmetries hidden beneath universally available ICTs should not be underestimated by globally networked organizations. Despite the fact that ATLAS is avowedly non-hierarchical and transnational, we found echoes of the headquarters-subsidiary power imbalances typical of multinational corporations (Hardy, 1996; Lin, 2005). While China retains *financial* autonomy (albeit small in relative terms[3]) and *voting* power (ATLAS operates a one vote per country rule), the scientists in Beijing and Hebei are heavily dependent on a key resource from ATLAS colleagues at CERN, namely up-to-the-minute, Internet-enabled data, contextualized by vital tacit know-how. Linked to this is a fourth implication: individuals will only be willing to invest time and energy in fostering networks across a complex organization if they feel psychologically involved, as well as technologically supported. This means they need to feel that they have a personal stake in the future success of the collaboration. It is noticeable that several European scientists referred to the ATLAS collaboration outlasting their personal careers, and for this reason they were intent on preserving the scientific integrity of their contribution and passing on their legacy intact to the next generation. This sense of continuity, future focus and ongoing community transcends parochialism, and is a salutary counter to the short termism of many private multinationals and R&D partnerships.

We recognize that some of the cultural observations made in this paper are not absolute, and this may, in part, be due to the hybrid nature of our two subsamples: some of the Chinese scientists had spent time at CERN (albeit, mainly in the past) and some of the UK scientists were infrequent visitors. We also acknowledge that our subsamples are small and hardly representative of the wider population of scientists. Despite these caveats, our research design produces some rich and revealing accounts of knowledge exchange, and we suggest that the four implications discussed above concerning geographic and cultural proximity, merit further systematic research.

7. Conclusion

Exploiting maximum benefit from multiagency and multinational knowledge networks remains a high priority of private firms and R&D networks alike. While the ATLAS collaboration is by no means typical of such knowledge-based enterprises, our findings offer some insights on effective knowledge exchange across non-hierarchical international networks. We find support for the underlying thesis of this paper that UK scientists working regularly at CERN are likely to benefit from, and contribute to, the overall ATLAS experiment more fully than their Chinese counterparts for geographic, technological and cultural reasons. However, the picture is by no means clear-cut. We find countervailing factors operating in both directions which serve to stall or expedite the exchange of tacit knowledge across this global network. Furthermore, there is some evidence that HQ, in the form of CERN, tends to exert power over meaning by shaping 'corporate' culture, 'codes of practice and standard operating procedures, which then become institutionalized' (Ferner et al., 2012, p. 9). This notion of what we might call institutional distance, which is well researched in MNCs, deserves further research in the typically less-hierarchical domain of global science and R&D networks. And given that such analysis needs to focus on the contesting of power between the centre and less geographically proximate parts of the network, a purely functionalist account which regards knowledge as a neutral commodity will prove inadequate (Mabey and Nicholds, 2014). Future studies require a more critical account, capable of assessing not just the effects upon *individuals* as they negotiate the linguistic, cultural and geographic boundaries of professional networks but also the hegemonic influence of *institutions* over the way resources are shared and knowledge exchange processes are enacted.

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Notes

1. CERN, the European Organization for Nuclear Research, is one of the world's largest and most respected centres for high-energy physics. At CERN, complex scientific instruments are used to study the basic constituents of matter – fundamental particles. By studying what happens when these particles collide, physicists learn about the laws of nature. The instruments used at CERN are particle accelerators and detectors. Accelerators boost beams of particles to high energies before they are made to collide with each other or with stationary targets. Detectors observe and record the results of these collisions. Founded in 1954, the CERN Laboratory sits astride the Franco–Swiss border near Geneva. CERN now has 20 Member States and relies on annual financial contributions from 38 partner countries to sustain the multimillion euro experiment.
2. During the course of this research, Professors Higgs and Englart were awarded the Nobel Prize in Physics for their role in discovering the last remaining piece of the particle physics model: the Higgs' boson.
3. The ATLAS experiment has been a consistently high priority by UK Government, which contributes £90m p.a. to the project. By contrast, applied science is a relatively low priority for the Chinese Ministry of Education which contributes £380,000 p.a.

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