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Are two heads better than one? Intellectual capital, learning and knowledge sharing in a dyadic interdisciplinary relationship

Jue-Fan JF Wang and David DC Tarn

Abstract

Purpose – *Past studies have paid extensive attention to investigate learning issues in individual, organizational and team contexts. Learning activities in the workplace, however, often occur in the interdisciplinary dyadic context. Hence, the purpose of this paper is to clarify what factors make interdisciplinary dyads lead to better learning effects. The authors attempted to clarify two major agendas: What knowledge factors (intellectual capitals) owned by the parties of the dyads can induce better learning effects? What contextual factors (learning tasks) can make better learning effects during the dyadic learning process?*

Design/methodology/approach – *To examine the previous agendas, the authors first conducted in-depth interviews and an exploratory survey so that a four-element dyadic intellectual capital (DIC) architecture was circumscribed: knowledge interdependency, expertise similarity, collaborative routines and mutual trust. Dyadic learning tasks were classified as exploitative and exploratory learning. The authors then sampled 248 respondents for the formal empirical survey to examine the relationship between DIC, dyadic learning tasks and knowledge sharing.*

Findings – *The statistical evidences confirmed the positive relationships between DIC and knowledge sharing, and the results also signified the previous relationships with a mediating effect from exploratory learning, while the effect of exploitative learning was not supported. Thus, only dyads (the two heads) with knowledge interdependency and mutual trust can make the exploratory task better than that of one individual (the one head).*

Originality/value – *This study provides a new insight into the learning issue with an interdisciplinary dyadic perspective to supplement the existing gap between academic efforts and learning practices in the workplace.*

Keywords *Intellectual capital, Knowledge sharing, Dyadic learning, Interdisciplinary dyads*

Paper type *Research paper*

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1. Introduction

"Two heads are better than one" is a common proverb, meaning that the synthesis of intellectual capital (IC) from two or more parties can achieve better performance than that of one person only. The proverb seems very logical, but how two heads can be better than one is still a critical agenda – that is, *how can the elements of IC owned by two (or more) individuals be effectively synthesized, such that they lead to better performance?*

The IC concept has played a critical role since the 1990s. The literature from a broad array of disciplines extensively clarifies the impact of IC on diversified issues. As knowledge is an essential component of IC, many studies in knowledge management (KM) fields do pay efforts to IC-related studies (Zhou and Fink, 2003; Kweh *et al.*, 2014; Serenko and Bontis, 2017). IC is

originally advocated with *individual* as the unit of analysis (Hudson, 1993) and accordingly extended to nations (Tellis *et al.*, 2009), industries (Malo and Jesper, 2009) and organizations (Kweh *et al.*, 2014). Considering the contexts of the proverb, however, here we may consider an alternative agenda regarding IC-related issues: *can we treat a dyad (consisting of two heads) as a unit of analysis for IC?* Past literature tends to treat nation, industry and organization as a *unitary* unit of IC and KM, while neglecting a critical analysis unit of IC: *dyad*. In organizational practices, IC- and KM-related activities may take place under a dyadic interpersonal relationship (DIR). Past studies indicate that an individual performs variably when he/she works with different colleagues (Petkova and Gupta, 2005; Collins *et al.*, 2009). Recent KM studies clarify management issues with a DIR view, such as leader-member exchange (LMX, Tsui and O'Reilly, 1989; Avey *et al.*, 2008), master-apprentice relationship (Armstrong, *et al.*, 2004), collaborative relationship (Petkova and Gupta, 2005; Chen *et al.*, 2006; Tarn, 2015; Vătămănescu *et al.*, 2016) and vertical and horizontal dyads (Loi and Ngo, 2009; Grover and Saeed, 2007). Empirical evidences indeed indicate that behaviors and performances of each dyad may be divergent and are actually determined by contexts of the dyad (Delery *et al.*, 1998), many of which are IC-related factors such as background similarity, interpersonal trust (Isaac *et al.*, 2010) and cooperative experiences (Goldman and Goldman, 1981; Vătămănescu *et al.*, 2016). Thus, just like nation, industry and organization, IC may occur under the DIR contexts and should be treated as a KM issue.

To this end, another agenda may be induced here: *what is the difference between IC under the unitary and dyadic units of analysis?* Relative to unitary unit of analysis, DIR signifies the following specificities. First, each dyad involves two parties rather than only one under unitary context. Second, DIR usually accompanies collaboration between the parties; collaboration therefore plays important roles in DIR. Hence, it is reasonable to treat DIR as a *synthesis*, rather than *aggregation*, of the parties (Petkova and Gupta, 2005; Qureshi *et al.*, 2006). Take the proverb for example. IC of the two heads (the two parties) should converge as one (the synthesis) to create added value, rather than simply bring them to work together (Dattero, 2006). Third, DIR should be treated as a *particular* and *corresponding* dyadic relationship. Take a case with three parties (A, B and C) for example. Among them, A collaborates with B and C, respectively (namely [A, B] and [A, C]). As B and C possess their own specific IC, the purposes of knowledge activities of and IC generated from the collaboration [A, B] is different from that of [A, C] (Petkova and Gupta, 2005; Collins *et al.*, 2009). The previous three specificities may present an essential research question. Relative to the typical unitary contexts, we should further consider IC under DIR, i.e. dyadic intellectual capital (DIC), and how the IC gaps/similarities between the two parties are synthesized in the particular and corresponding collaboration. Therefore, the elements and architecture of IC under dyadic contexts may be different from those under unitary contexts. We now induce the first research question:

RQ1. What is the content and architecture of IC under DIR contexts?

The fourth specificity finally shows up. IC's conception is rooted in the knowledge issues; many factors of IC are originated from knowledge-related resources, such as knowledge, skill, experiences and information system (Cohen and Levinthal, 1990; Roos *et al.*, 1997), and knowledge-related activities, such as learning and experience of collaboration (Daghfous, 2004; Chen *et al.*, 2006; Vătămănescu *et al.*, 2016). IC studies are also highly linked with knowledge and KM issues (Spender and Grant, 1996; Wang and Noe, 2010; Serenko and Bontis, 2017), in which one critical practice in DIR is knowledge sharing (Hasty *et al.*, 2006; Sáenz *et al.*, 2009). Thus, we can infer that one important purpose of DIC is knowledge sharing between the parties. Accordingly, this study attempts to explore the association of the IC and knowledge sharing under DIR, based on the previous four specificities. Therefore, following the previous research question, this study extends the second one as follows:

RQ2. What is the impact of DIC on knowledge sharing?

The contents of DIC are diversified due to particular collaboration tasks; therefore, linking them with knowledge sharing directly may omit alternative task-related considerations. Empirical evidence exhibits that the knowledge sharing in DIR are determined by the tasks. For instance, vertical dyads, such as master-apprentice relationship, tend to disseminate experienced and structured knowledge; thus, they need a higher class of exploitative learning (March, 1991). For those horizontal dyads like an interdisciplinary, cross-industry alliance, exploratory learning is more essential because the tasks are conducted in relatively innovative and unstructured contexts (March, 1991; Luo and Deng, 2009).

The above two learning behaviors, i.e. exploitative and exploratory, are identical to the classification of the organizational learning (Miller *et al.*, 2007; Kang *et al.*, 2007; Bierly *et al.*, 2009), and they are even treated as a dichotomy of knowledge strategy (Miller *et al.*, 2006; Miller *et al.*, 2007). Empirical evidence has detected that learning behaviors play mediating effects on knowledge sharing (Daghfous, 2004; Laycock, 2005; Bakker *et al.*, 2006; Stewart *et al.*, 2011; Matzler and Mueller, 2011; Liao *et al.*, 2012; Wu and Chen, 2014). For example, exploratory learning presents significant effects on knowledge sharing when the members are highly interdependent and the tasks need radical innovation (Miller *et al.*, 2007), while exploitative learning signifies better effects when the colleagues have similarity of expertise and the tasks need incremental innovation. Therefore, this study attempts to employ learning behaviors of DIR, i.e. *dyadic learning*, as a mediator to examine the impact of DIC on knowledge sharing.

A fiercely dynamic and competitive environment makes life span of knowledge get shorter, and specialized division of labor hence becomes insufficient. As a result, recent practical and academic efforts pay more attention to collaboration from interdisciplinary perspectives (Petkova and Gupta, 2005). Interdisciplinary collaboration is very different from that within a unitary or homogeneous field; it occurs when the backgrounds among the co-workers are heterogeneous, their expertise is interdependent and complementary, and the tasks require exploratory (rather than exploitative) learning to address unstructured problems (Tsui and O'Reilly, 1989; Moustafa-Leonard, 2007; Avey *et al.*, 2008). This study follows the recent attention to interdisciplinary issues and accordingly concentrates on knowledge sharing under DIR.

This study thus attempts to clarify the third research question:

RQ3. What is the mediating effect of dyadic learning (i.e. exploratory vs exploitative) on the relationship between DIC and knowledge sharing?

This study contributes to KM field in the next ways. First, the existing studies tend to treat KM as a unitary unit of analysis, such as a firm or an organization. Even if some studies endeavor to study KM issues under a dyadic context, they pay more attentions to vertical, homogeneous dyads, such as master–apprentice or supplier–manufacturer relationships. As interdisciplinary collaboration plays a growing role in recent business practices, this study provides a new insight to the KM issue under an interdisciplinary dyadic relationship. Besides, one primary purpose of a dyadic relationship is to share knowledge via the *IC* from the each party of the dyads, i.e. IC of the two heads. The recent KM studies, however, tend to treat IC under a dyadic relationship as its aggregation, but still neglect whether the IC from the parties can be integrated as synthesis. This study thus bases on the specificity of ICs under a DIR and clarifies the synthesis of IC from each party to explore the effect of DIC on knowledge sharing. Moreover, considered the exploration feature of DIR, this study attempts to clarify the association of knowledge sharing with the tasks of the dyadic learning by classifying as exploratory and exploitative learning. Such classification can clarify the effects of learning types on dyadic knowledge sharing.

Based on the previous backgrounds and motivation, the past efforts have well developed basis for IC-related theory, and some of them pay attention to the practices of

interdisciplinary dyads. On this basis, this study attempts to concentrate on clarifying the elements, contents and architecture of DIC, and to examine its effects on knowledge sharing under DIR. The findings of the study would be helpful to go deep into understand the IC issues under these specific contexts, in particular the IC framework and its impact. Such efforts could make a completed portrayal and explanation for IC issues of the future.

To answer the research questions, this study conducts thorough and elaborate efforts to supplement the past neglect of the sources and practices that generated IC under a dyadic context and lack of sufficient measurement of DIR, and to construct the basis for the DIC architecture, we build up a primary framework after preliminary literature review and an exploratory in-depth interview, and accordingly, we develop a draft scale for an exploratory empirical survey and construct a base DIC architecture from the results. We further review the literature based on the previous architecture and develops hypotheses regarding the research questions. Another survey is then conducted to reconfirm the DIC architecture and test the hypotheses. The procedure is listed as Figure 1.

2. The pilot study

2.1 Preliminary intellectual capital literature review

To develop the DIC framework, here we conduct a preliminary literature review on typical IC studies so as to set up a theoretical basis for the advanced efforts.

To converge the diversified IC perspectives and to circumscribe the scope of DIC architecture, this study reviews major IC-related literature and screens out their elements. To measure the elements of IC, Johnson (1999) and Bozbura (2004) made a completed review of the classification and taxonomy of factors of IC. They consequently measure IC with the most frequently cited dimensions: *human*, *structural* and *relational* capital. This study henceforth constructs the DIC framework based on this three-dimension framework.

2.2 The exploratory in-depth interview

This study then conducts exploratory in-depth interviews to build up a base architecture for DIC from the previous three-dimension framework. The term *IC* was brought up in the 1990s. The academia and practitioners responded to the IC concept from a wide range of disciplines (Bontis, 1998; Serenko and Bontis, 2017). Stewart (1997) defines IC as the aggregation of knowledge capabilities valuable for creating and sustaining the competitive advantages of organizations. Edvinsson and Malone (1997), Masoulas (1998) and Johnson (1999) echo Stewart's (1997) thoughts to regard IC as the aggregation of all intellectual assets, knowledge and capabilities. To clarify IC issues under the DIR context, this study follows Stewart's (1997) concept and defines DIC as *the synthesis of knowledge and capability generated from both parties of the dyad to create and sustain competitive advantages for the dyad*. Accordingly, each dimension is defined below in the text.

2.2.1 Human capital. Dyadic human capital is defined as *the synthesis of human intelligence from the parties of the dyad*. The components of human intelligence include knowledge, skill, experiences and attitudes (Cohen and Levinthal, 1990; Roos et al., 1997).

Figure 1 Research procedure
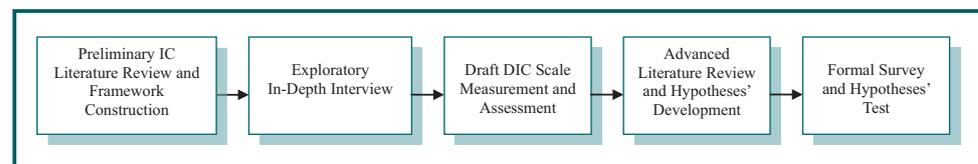
2.2.2 Structural capital. This study summarizes a broad range of arguments from Edvinsson and Malone (1997), Roos and Roos (1997) and Bontis (1999) and accordingly refers dyadic structural capital to *the synthesis of the supportive infrastructure generated from the parties of the dyad*, where supportive infrastructure consists of the routines, cultures and information systems.

2.2.3 Relational capital. Integrating the viewpoints of Cohen and Levinthal (1990), Roos *et al.* (1997), Bontis (1996), Bozbura (2004), Chen *et al.* (2006) and Vătămănescu *et al.* (2016), this study defines relational capital as *the totality of value generated from the mutual relationship between the parties of the dyads*; the relationship involves the ties, partnership and trust during the collaboration.

We target those subjects who match the next three considerations. First, the subjects have intensive collaboration and dyadic activities with their colleagues. Second, the dyadic collaboration contains a significant degree of DIC elements, learning and knowledge sharing. Third, the tasks of the collaboration are simplified and have less exogenous factors, such as marketplace competition, so that the study can concentrate on examining the conditions of the dyads. This study finally follows Hasty *et al.* (2006) and selects R&D researchers who are in charge of industry-academic cooperation projects and have frequent teamwork with practitioners or academicians in other disciplines, as the targets of in-depth interviews and the next surveys.

Fifteen researchers are invited as the interviewees, and the interview is conducted through a one-on-one method (one interviewer and one interviewee). Prior to the formal interview, the researcher designs three-item interview questions based on the three IC dimensions (listed as Appendix 1) and passes them to the interviewees. All contents of the interviews are recorded and then decoded jointly by two experts, who are business professors with professional major in IC and KM. After the decoding, the experts decide to set not less than half the sample scale of the interviewees, i.e. eight, as the acceptance threshold of response frequency. Table I summarizes the evidence. Based on the corresponding literature (Lee *et al.*, 2008; Jackson *et al.*, 1991; Van Vijfeijken *et al.*, 2002), this study subsequently draws 14 descriptors, consisting of six human capital, two structural capital and six relational capital descriptors, as the base of DIC.

IC dimensions	Descriptors of response	Frequency of descriptors
Table I Summary of in-depth interviews		
Human capital	Having supplementary expertise	12
	Having a professional background that is essential to me, but I do not possess	10
	Providing creative viewpoints from alternative perspectives	9
	Having similar expertise	9
	Having a common language in the teamwork	8
	Behaving with tacit understanding in the teamwork	8
Structural capital	Developing particular cooperation modes	9
	Forming some particular routines (such as norms, procedures or regulations)	8
Relational capital	Having mutual trust	13
	Forming a close bond between us	12
	Having the willingness for mutual connection	10
	Keeping intensive contact in the teamwork	9
	Having cooperative experience	8
	Having high frequency of communication and connection	8

2.3 The draft measurement and assessment

Based on the primary architecture, the two experts modify the previous descriptors to develop a 14-item draft DIC scale as listed in the left column of Table II. The items are measured with Likert's five-point scale (1 = strongly disagree, 5 = strongly agree) and are distributed to another 125 R&D researchers in charge of industry-academic cooperation projects as the respondents.

The survey uses exploratory factor analysis (EFA) to clarify the DIC architecture. According to the statistical evidence listed as Table II, this study extracts four DIC factors: knowledge interdependency, expertise similarity (both are elements of human capital), collaborative routine (structural capital) and mutual trust (relational capital). Hence, we now construct a primary DIC architecture, consisting of four elements from the three IC dimensions, as the base for further DIC issues (exhibited as Figure 2).

3. The formal study

3.1 Advanced literature review and hypotheses development

We further attempt to formally clarify the impact of DIC on knowledge sharing and the mediating effects of dyadic learning on such an impact, with an empirical survey following the previous model. The next section describes the findings from the literature review and hypotheses' development.

3.1.1 Intellectual capital and knowledge sharing. IC studies are frequently connected with KM and knowledge sharing in the past literature (Zhou and Fink, 2003; Kang and Hau, 2014; Mariano and Walter, 2015). They treated knowledge sharing as a critical element and

Table II	Results of EFA on the DIC architecture			
*Item descriptors**	*Factor 1*	*Factor 2*	*Factor 3*	*Factor 4*
9. We have mutual trust between each other	85	06	24	05
11. We are very willing to exchange our expertise and knowledge	83	19	−07	02
10. We have formed a close bond in the teamwork	72	15	28	02
5. We share a common language in the teamwork	13	74	22	−00
6. We have tacit understanding in the teamwork	26	68	04	10
4. I have a similar expertise background with her/him	−07	65	28	−04
13. We have a long-term cooperative experience	13	60	04	47
14. We have frequent communication and connection	35	59	16	36
3. She/he often provides me with creative viewpoints from alternative perspectives	−00	23	73	11
1. We have supplementary expertise	30	−03	65	31
2. She/he has a professional background that is essential to me, but I do not possess	22	34	64	−09
12. We maintain intensive contact in the teamwork	39	28	40	23
7. We have developed a particular cooperative mode in the teamwork	−16	−01	11	83
8. We have formed some particular routines (such as norms, procedures, or regulations) that we follow	27	21	12	60
Factor naming	Mutual trust	Expertise similarity	Knowledge interdependency	Collaborative routine
Eigen values	4.76	1.56	1.19	1.04
Cronbach's alpha	0.797	0.628	0.604	0.469
Note: The numbers in the front of the descriptors are corresponding to those in Table I				

Figure 2 Architecture of dyadic interdisciplinary IC
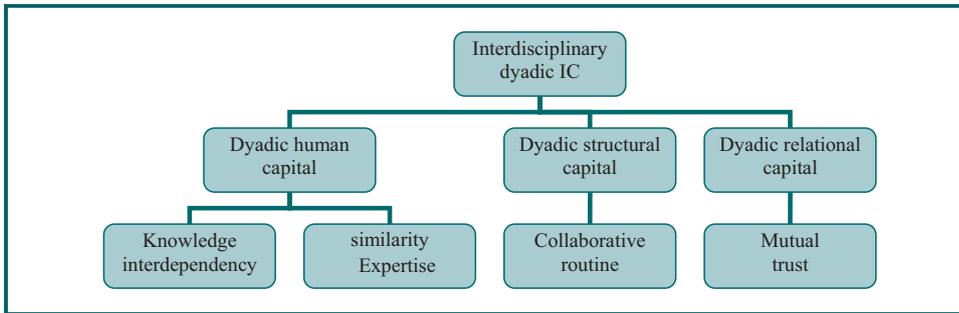
indicated that the success of KM highly relies on knowledge sharing with diversified perspectives (Tallman *et al*., 2004; Berman *et al*., 2002; Sáenz *et al*., 2009; Kang and Hau, 2014). Wang and Noe (2010) conduct a literature review on knowledge sharing efforts to develop a framework consisted of five major antecedents: organizational, interpersonal/ team, cultural, individual and motivational factors. Some of them are consistent with the DIC elements formed in the previous exploratory studies. The following sections list a detailed review.

3.1.2 Knowledge interdependency. Following Bailey *et al*.'s (2010) definition, knowledge interdependency refers to the extent to which the dyads interact with and are interdependent of each other when exchanging knowledge to accomplish their works. Some descriptors in the exploratory interview can be attributed to knowledge interdependency, including having supplementary expertise, professional and essential experiences and providing alternative viewpoints (Table I).

Parties in the DIR attempt to acquire alternative knowledge domains from their colleagues via collaboration. They also look for knowledge domains that are heterogeneous, diversified (Tenkasi and Boland, 1996; Rodan and Galunic, 2002; Bonner and Walker, 2004; Echajari and Thomas, 2015) and complementary (Kneser and Ploetzner, 2001; Shenkar and Li, 1999; Ortiz *et al*., 1996) to the existing knowledge that they originally own.

Each party of the dyad has a particular experience and expertise, which are beneficial for the purpose of DIR. Thus, one critical successful factor of DIR is creating synergy through interdependent knowledge activities (Petkova and Gupta, 2005; Palazzolo and Clark, 2007; Cheng *et al*., 2014) and a good blending of diversified knowledge domains from each party (Kogut and Zander, 1996). Many studies have revealed the importance of knowledge interdependency. Kneser and Ploetzner's (2001) survey on students' observations finds that knowledge interdependency between students leads to better learning and problem solving through their teamwork. Palazzolo and Clark (2007) show that higher knowledge complement makes members of the dyads mutually interdependent and trustworthy, which in turns induce better knowledge sharing (Gittell, 2000). The literature of transactive memory theory argues that team members possessing diversified, but complementary knowledge tend to be interdependent and share their knowledge (Nevo and Wand, 2005). Based on the previous review, we now construct *H1* as follows:

> *H1.* Knowledge interdependency between the parties of DIR is positively associated with knowledge sharing.

3.1.3 Expertise similarity. Some respondents in the interview mentioned human capital-related factors, including similar expertise, sharing a common language and tacit understanding during the collaboration, which can be categorized as expertise similarity. The similarity/dissimilarity dichotomy plays a major role in management-related fields, such

as the effects of the similarity between supervisors and subordinators (Collins *et al.*, 2009), leaders and members (Loi and Ngo, 2009) and LMX (Armstrong *et al.*, 2004).

The interchange of knowledge background is a critical factor in DIR. Based on self-categorization theory and transactive memory theory, a similar background between the individuals leads to higher identification and thus is beneficial for experiences sharing (Jackson *et al.*, 1991; Armstrong *et al.*, 2004; Nevo and Wand, 2005). Thus, the similarity of backgrounds enables the dyads' knowledge activities. Grant (1996) and Loi and Ngo (2009) lay emphasis on the context of a common knowledge basis, arguing that it is essential for better identification and knowledge exchanges for the dyads. Newcomb's (1956) empirical results exhibits that people with similar backgrounds are inclined to like each other more, i.e. a similarity-attraction effect, such that individuals tend to select colleagues/co-workers sharing similarities with themselves (Lincoln and Miller, 1979).

Moreover, the literature finds that members with high differences in knowledge level and expertise background spend a longer time and exert greater efforts during the knowledge sharing procedure (Szulanski, 1996; Makela *et al.*, 2007) due to the dissimilarity resulting from knowledge asymmetry (Grant, 1996). Thus, this study infers that expertise similarity in the DIR conduces to common language and mindset for collaboration, which results in smooth communication and knowledge exchange. We now present the next hypothesis:

> *H2.* Expertise similarity between the parties of DIR is positively associated with knowledge sharing.

3.1.4 Collaborative routines. Collaborative routine refers to the rules and norms that are embedded in the DIR collaboration. The pilot interview points out some related statements, including particular cooperative modes, established regulation and routines. In DIR practices, the dyads naturally build up routines beneficial to the collaboration. The routines include tacit contents like culture, operations, network and communication procedure (Hargadon, 1998; Wu and Chen, 2014; Vătămănescu *et al.*, 2016), management mechanism, such as job rotation, and explicit contents including documentation of knowledge base and operation manual (Qureshi *et al.*, 2006).

Practical, tight organizational routines can improve collaboration and mutual interaction. Feldman and Rafaeli (2002) regard routines as a collaboration mechanism, in which proper routines can raise homogeneity and social ties of the members, thus inducing knowledge exchange and combination (Larsen, 1992; Nahapiet and Ghoshal, 1998; Ferguson and Taminiau, 2014). Dyer and Nobeoka (2000) find that routines can reduce the time and energy for problem deliberation and solving and thus prolong the collaborative relationship. The evidence from Larsen (1992), Petkova and Gupta (2005), and Kang *et al.* (2007) reveal that routines during the dyadic relationship have positive effects on the frequency and quality of knowledge sharing. Zellmer-Bruhn's (2003) empirical results exhibit that routines significantly influence the knowledge transfer of the teams. Thus, this study builds up the next hypothesis based on the previous inferences:

> *H3.* The degree of collaborative routine of the DIR is positively associated with knowledge sharing of the dyads.

3.1.5 Mutual trust. Mutual trust is used to construct relational capital under a dyadic context. Relational capital is the total value created and maintained by possessing, nurturing and managing good relationships in a network between a firm and its main stakeholders. For parties in the DIR, relational capital is helpful to create good image, loyalty, satisfaction and interpersonal link with their partners to get the value of the DIR, including knowledge, expertise and technology (Bronzetti *et al.*, 2011). In the pilot study, the responses regarding relational capital include having mutual trust, a closer bond, willingness to connect, cooperative experience and frequency of communication, which are close to the Morgan and Hunt's (1994) commitment-trust perspective in an inter-firm relationship. We thus name it as mutual trust.

Mutual trust refers to the extent of interpersonal confidence and commitment in the collaboration. Among the four elements, mutual trust is the most frequently mentioned one of all. Recent studies have paid intensive attention to trust issues and treated it as a primary factor of collaboration under the DIR contexts (Garcia-Marza, 2005; Morgan and Hunt, 1994). Many studies confirm that trust plays a critical role in inter/intra-organizational relationships and knowledge sharing (McAllister, 1995; Chowdhury, 2005), even treating it as an essential antecedent (Portes, 1998; Gupta and Govindarajan, 2000). Past studies also indicate that trust raises the possibility of social exchange and frequency of interaction, thus inducing the success of collaboration (Putnam, 1995; Coleman, 1990; Van den Hooff and Van Weenen, 2004; Wu and Sukoco, 2010).

Although most past studies investigate trust issues with organization/firm as the unit of analysis, recent efforts are drawing attention to it in DIR (Moustafa-Leonard, 2007). In DIR practice, heterogeneity from an interdisciplinary background leads to a higher degree of selfishness, opportunism and difficulty in communication. Mutual trust, nevertheless, reduces the previous negative effects, increases the willingness to perform constructive collaboration (Morgan and Hunt, 1994) and promotes resource exchange and combination/ integration (Larsen, 1992; Tsai and Ghoshal, 1998), which are helpful for knowledge sharing (Hislop, 2003). Thus, *H4* is inferred as follows:

> *H4.* The degree of mutual trust within the DIR is positively associated with knowledge sharing of the dyads.

3.1.6 The mediation of dyadic learning. Prior sections have shown the direct effects of DIC on knowledge sharing, yet DIC may be not the sufficient factor to explain knowledge sharing. In fact, higher knowledge interdependency may accompany complicated organizational backgrounds and perspectives so that produces difficulty in coordination and cooperation (Bailey *et al.*, 2010). Therefore, knowledge interdependency does not work on knowledge sharing without effectively integrating the diversity between the members (Wageman, 1995; Wageman and Baker, 1997; Van der Vegt *et al.*, 2003). Expertise similarity brings about competition between the parties and thus produces factors that obstruct knowledge sharing such as opportunism and knowledge protectionism (Tsai, 2002; Van der Vegt, 2003). Therefore, the willingness of sharing is an essential factor that induces these negative impacts (Wilhelm, 2011). Moreover, collaborative routines and mutual trust can be supportive factors to enforce the effects of knowledge interdependency and expertise similarity based on sufficient knowledge acquisition (Im and Rai, 2008; Liao *et al.*, 2012).

Hence, the impact of DIC on knowledge sharing should be on the basis of knowledge integration (for knowledge interdependency), willingness to share (for expertise similarity) and knowledge acquisition (for collaborative routines and mutual trust), all of which are the primary elements of organizational learning (Crossan *et al.*, 1999; Laycock, 2005; Kang and Snell, 2009; Ferguson and Taminiau, 2014). Following the above basis from organizational learning, this study denominates it as *dyadic learning* to clarify how learning behaviors mediate the relationship between DIC and knowledge sharing.

Past studies indeed have explored the association between learning and knowledge sharing. Dibella, Nevis, and Gould (1996) advocate that organizational learning is the capability for using and sharing experiences so as to sustain a good performance. Gherardi and Nicolini (2000) and Chauhan and Bontis (2004) define that learning behavior is the process of expanding and disseminating task-based knowledge of the organizations. Im and Rai (2008) classify knowledge sharing as knowledge exploitation and exploration and find that they both can effectively explain knowledge sharing. Therefore, this study attempts to involve dyadic learning as the mediator.

Just as with Im and Rai (2008), the literature is used to classify organizational learning with the exploitation-exploration dichotomy. Miller *et al.* (2007) and Bierly *et al.* (2009) even

define them as two major types of knowledge strategies. The dichotomy is adopted broadly, most studies indicate that each of them suits particular contexts and may crowd out one other (McNamara and Baden-Fuller, 1999). *Exploitative learning* refers to using the existing experiences and practices to seek a profound understanding of the existing knowledge (Kang *et al.*, 2007). It is more suitable for routine and experienced tasks, while it may perform worse in raising innovativeness and creativity due to insufficient renewal (Levinthal and March, 1993) and *familiarity trap* (Ahuja and Lampert, 2001). *Exploratory learning*, however, means fundamentally pursuing new knowledge domains, even replacing the existing ones, to create new values and to achieve significant improvement (Danneels, 2002; Eisenhardt and Martin, 2000; McGrath, 2001), but it also brings higher cost and risk and induces difficulties in coordination and knowledge accumulation (Katila and Ahuja, 2002). Therefore, the recent literature tends to regard organizational learning as a balanced arrangement (McNamara and Baden-Fuller, 1999) and a state of ambidexterity (Kang and Snell, 2009; Im and Rai, 2008).

The literature review signifies that the learning issues studied under the contexts of organizations and teams can be extended to the specific context of DIR. According to the concept of the similarity-attraction effect, individuals and organizations tend to seek partners (or collaborators) with similar backgrounds for a start (Newcomb, 1956; Lincoln and Miller, 1979). Under the DIR contexts, however, perspectives with diversified disciplines are the essential factors for collaboration. The interdisciplinary tasks also imply that the similarity and homogeneity are valueless, and past experiences and routines become useless. Parties in DIR require innovativeness and stimulation from diversified fields, knowledge interdependency and even risky adventures to solve their existing problems (Nonaka and Takeuchi, 1995; Palazzolo and Clark, 2007).

Miller *et al.* (2007) explore the impact of exploitation and exploration on innovation performance, finding that an exploration strategy performs better under radical innovation, while an exploitation strategy has better effects on incremental innovation. Mom *et al.* (2007) attempt to link learning types with knowledge flows (horizontal vs vertical). Their evidence indicates that both types are related to vertical knowledge flows, while only exploratory learning can explain the outcomes of horizontal knowledge flows. This study's DIR is just attributed to horizontal flows.

Kang *et al.* (2007) also indicate that the breadth of knowledge scope is helpful for exploring new product development and applications. Relatively, the literature tends to claim that background similarity between colleagues helps them in sharing in-depth experiences and profound knowledge, which are suitable for exploitative learning (Burt, 1997; Nahapiet and Ghoshal, 1998; Feldman and Rafaeli, 2002). Based on the previous review, we can infer that exploratory learning is more suitable for the tasks of DIR than exploitative learning and thus offer the next hypothesis:

H5. Dyadic learning mediates the positive association between DIR and knowledge sharing; the mediating effect of exploratory learning is stronger than exploitative learning.

4. Research methods

4.1 Research framework

According to the previous hypotheses, the empirical study consists of three primary constructs: DIC, dyadic learning and knowledge sharing. DIC is constructed by the four elements based on the three original IC dimension. Dyadic learning is classified as exploitative and exploratory learning. As for knowledge sharing, this study follows Bartunek *et al.* (2001) and Lin (2007) so that we use knowledge sharing behavior as the measurement base. Figure 3 lists the framework.

Figure 3 Research framework
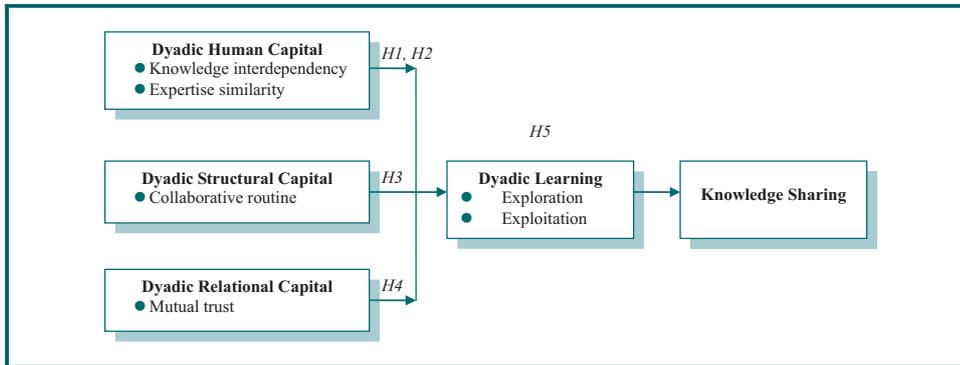
4.2 Operational definitions and the measurement

Appendix 2 lists the definitions and measures of the constructs. DIC is measured by the descriptors gained in the draft measurement. The measurement of the other constructs uses the existing scales in the literature. All the scales are designed as Likert's five-point scale.

Considering the potential effects of the demographic variables, here we also survey the backgrounds of observations as the control variables, including gender, background of the subjects (science vs social science) and past working experience.

4.3 Sampling and the samples

To be consistent with the efforts in the previous interviews and survey, the empirical survey selects R&D researchers in charge of industry-academic cooperation projects in Taiwan as the samples for the survey; 350 respondents are sampled by personal sampling. After deleting insufficient observations, 248 effective respondents (70.85 per cent in rate) are finally collected. A chi-square test result indicates that the sample structure between distributed and collected samples is consistent ($p > 0.29$). Table III lists some critical statistics.

4.4 Factor structure assessment

The first task of statistical analysis is to assess the factor structure of the DIC model with confirmatory factor analysis (of LISREL). The evidence signifies that the λ coefficients are all higher than 0.50 with statistical significance ($p < 0.05$). The goodness-of-fit indicators are qualified up to the standards of GFI ($0.96 > 0.90$), AGFI ($0.93 > 0.90$), CFI ($0.97 > 0.90$), NFI ($0.92 > 0.90$) and RMSR ($0.03 < 0.05$). The above results confirm the model's reliability and goodness-of-fit of the 4-element, 11-item DIC scale originating from the draft measurement.

Based on the previous confirmation, we employ Pearson's correlation analysis for a further assessment to examine the collinearity (listed as Table IV). The statistics indicate that all of the coefficients are significantly positive, among which the highest collinearity occurs in the correlation of knowledge interdependency and sharing ($\rho = 0.458$). All the coefficients are significantly distant from the perfect collinearity ($+1.00$ and -1.00) and most are around 0.30, meaning that it performs with medium discriminant validity. The degrees of Cronbach's alpha (ranging from 0.543 to 0.821) indicate good internal consistency as well.

Table III Measurement of the constructs (the empirical survey)

Constructs	Operational definitions	Item descriptors	Statistics mean	sd	λ
Dyadic intellectual capital					
Knowledge interdependency	The extent to which the dyads interact and are interdependent on each other	We have supplementary expertise	3.56	0.84	Fixed
(α = 0.67)		She/he has a professional background that is essential to me, but I do not possess	3.96	0.79	0.91
		She/he often provides me with creative viewpoints from an alternative perspective	3.82	0.74	0.76
Expertise similarity	The homogeneity of expertise background between the parties of the dyads	I have a similar expertise background with her/him	3.38	1.07	0.99
(α = 0.72)		We share a common language in the teamwork	3.89	0.74	0.96
		We have a tacit understanding in the teamwork	3.59	0.79	Fixed
Collaborative routines	The regulations, rules, and norms embedded in the process of collaboration	We have developed a particular cooperative mode in the teamwork	3.45	0.80	0.50
(α = 0.54)		We have formed some particular routines (such as norms, procedures, or regulations) that we follow	3.61	0.72	Fixed
Mutual trust	The extent of interpersonal confidence and commitment in the collaboration	We have mutual trust of each other	3.72	0.72	0.85
(α = 0.79)		We have formed a close bond in the teamwork	3.34	0.86	Fixed
		We are very willing to exchange our expertise and knowledge	3.86	0.71	0.71
Dyadic learning					
Exploitative learning	The degree of using the existing experiences, routines, and practices to seek a more profound understanding to the existing knowledge	We pay more emphasis on getting the job done, rather than making it innovative	3.64	0.76	
(adapted from Atuahene-Gima and Murray, 2007; α = 0.70)		We used to use routine ways to accomplish the tasks	3.62	0.71	
		We use familiar methods to improve the outcomes of the tasks	3.92	0.56	
		We used to follow experienced methods during the collaboration	3.96	0.67	

(continued)

Table III

Constructs	Operational definitions	Item descriptors	Statistics		λ
			mean	sd	
Exploratory learning	The degree of fundamentally pursuing new knowledge domains to create new values and improvement in performance	We used to look for something experimental and risky to accomplish the works	3.58	0.75	
		We prefer to search for innovative information and methods to get the job done, even though they may be very different from what we are using now	3.70	0.69	
(adapted from Atuahene-Gima and Murray, 2007;		We work for collecting new knowledge from other expertise domains	3.62	0.71	
α = 0.82)		We enjoy collecting new information that we did not experience before	3.75	0.69	
		We often push each other to gather and learn new knowledge to make the tasks better	3.79	0.71	
Knowledge sharing					
Knowledge sharing	The willingness of the dyads to share owned knowledge and expertise with each other	She/he often shares experiences about our tasks	3.84	0.75	
(adapted from Lin, 2007; α = 0.82)		She/he is willing to provide her/his expertise and knowledge without sparing any details when I am in need of assistance		0.68	
		She/he often expresses her/his opinions on the tasks	3.88	0.68	

Note: λ : Lambda values of LISREL analysis

Table IV Cross-construct correlation analysis

Constructs	Means	s.d.	α	1	2	3	4	5	6	7
Independent constructs										
1.knowledge interdependency	3.784	0.614	0.669	1	*5.44*	*4.75*	*5.76*			
2. expertise similarity	3.620	0.692	0.694	0.413*	1	5.03	5.08			
3. collaborative routines	3.532	0.631	0.543	0.296*	0.350*	1	3.25			
4. mutual trust	3.640	0.643	0.789	0.452*	0.355*	0.303*	1			
Mediating constructs										
5. exploitative learning	3.786	0.492	0.697	0.242*	0.273*	0.384*	0.193*	1		
6. exploration learning	3.686	0.539	0.817	0.317*	0.347*	0.288*	0.297*	0.393*	1	
Dependent constructs										
7. knowledge sharing	3.916	0.603	0.821	0.458*	0.330*	0.334*	0.384*	0.200*	0.482*	1

Notes: *$p < 0.01$; The left-lower coefficients in the cells of independent constructs are Pearson's correlation coefficients; the right-upper italic ones are LISREL's standard errors between the constructs

5. Results

To test the previous hypotheses, this study uses hierarchical regression analysis to exhibit the evidence in Table V. Here, Model 1 (M1) lists the results of the null model, Models 2, 3, 4 and 5 (M2 to M5) show the explanation of knowledge interdependency and dyadic learning on knowledge sharing, and so forth. Models 18 to 21 present the overall models involving all the four DIC elements. The details are stated as follows.

5.1 Dyadic intellectual capital and knowledge sharing: the direct effect

The direct effects of the four DIC elements on knowledge sharing are each exhibited as M2, M6, M10 and M14. The β coefficients locate between 0.29 and 0.54 ($p < 0.01$), and the overall model F values are all statistically significant. Of the four elements, mutual trust and knowledge interdependency perform the best explanations, while expertise similarity has the worse effect on knowledge sharing. Here, M18 lists the simultaneous explanations of the four DIC elements. The result is identical to those of the respective models, e.g. all of the β values are significantly positive except expertise similarity, among which mutual trust and knowledge interdependency have better explanations. The results confirm the inference from *H1* to *H4* that DIC factors perform positive effects on knowledge sharing (Castro and Neira, 2005; Bartunek, 2007; Luo and Deng, 2009). Under a DIR context, the parties of the dyads need more connections to build mutual trust, should raise knowledge interdisciplinary by seeking colleagues and coworkers with supplementary expertise, rather than just having similar background and heterogeneous expertise. Mutual trust and interdisciplinary knowledge are essential factors for knowledge sharing of the dyads.

5.2 Mediation of dyadic learning

5.2.1 Exploitative learning. To test *H5*, we add exploitative learning in the previous models to examine the mediating effects (listed as M3, M7, M11, M15 and M19, respectively). The *f* statistics of all the five models reach the $p < 0.01$ significance. The β coefficients range between 0.08 and 0.18, and the mediating effect only significantly occurs in the case of expertise similarity. Moreover, the incremental amounts of the coefficients of determination ($\triangle R^2$) are quite small (less than 0.02), signifying that exploitative learning fails to produce a significant mediation with the association between DIC and knowledge sharing.

Table V Results of regression analysis

	Null model	Knowledge interdependency				Expertise similarity				Collaborative routines				Mutual trust				Overall Models			
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21
Intercept	3.85a	2.15a	1.80a	1.05a	1.01a	2.84a	2.28a	1.52a	1.45a	2.76a	2.35a	1.31a	1.36a	1.89a	1.49a	0.85a	0.85a	1.10a	1.03a	0.44a	0.57a
Gender	0.06	0.07	0.03	−0.04	−0.04	−0.02	−0.07	−0.11	−0.11	−0.07	−0.10	−0.15b	−0.15b	0.03	−0.00	−0.06	−0.06	−0.02	−0.02	−0.08	−0.06
Subjects	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.15	0.16	0.13	0.14	0.14	0.15	0.10	0.11	0.12	0.12	0.11	0.11	0.12	0.12
Working experience	−0.02	−0.02	−0.03	−0.02	−0.02	−0.02	−0.02	−0.02	−0.02	−0.02	−0.02	−0.02	−0.02	−0.01	−0.02	−0.02	−0.02	−0.02	−0.02	−0.02	−0.02
Knowled interdepen		0.45a	0.42a	0.33a	0.33a													0.20a	0.19a	0.15a	0.16a
Expertise similarity						0.29a	0.26a	0.17a	0.17a									0.05	0.05	0.00	0.00
Collaborat routines										0.33a	0.29a	0.23a	0.24a					0.12b	0.11b	0.09	0.11b
Mutual tust			0.12				0.18				0.18			0.54a	0.53a	0.45a	0.45a	0.41a	0.40a	0.36a	0.36a
Exploitation				0.44a	−0.01			0.49a	0.03			0.50a	−0.02		0.18	0.39a	−0.00		0.03		−0.07
Exploration					0.44a				0.48a				0.51a				0.39a			0.34a	0.36a
F	0.81	16.17	13.51	24.72	20.53	7.89	7.03	18.29	15.19	7.96	7.03	19.85	16.49	30.70	25.54	38.20	31.70	22.52	19.65	26.48	23.64
p	0.49	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
R^2	0.01	0.21	0.22	0.34	0.34	0.12	0.13	0.28	0.28	0.12	0.13	0.30	0.30	0.34	0.35	0.45	0.45	0.40	0.40	0.48	0.48
Adj. R^2	0.00	0.20	0.21	0.33	0.33	0.10	0.11	0.26	0.26	0.10	0.11	0.28	0.28	0.33	0.34	0.43	0.43	0.38	0.39	0.48	0.46

Notes: a: $p < 0.01$; b: $p < 0.05$

5.2.2 Exploratory learning. We note that M4, M8, M12, M16 and M20 exhibit the mediating effects of exploratory learning. The result is just opposite to that of exploitative learning. The β coefficients are located from 0.34 to 0.50 ($p < 0.01$), and the explained variance percentage significantly rises ($\triangle R^2$ ranges from 0.12 to 0.18). Hence, coefficients of the original DIC elements are reduced, but still statistically significant. The previous evidence confirms that exploratory learning imparts partial mediation, particularly in the case of collaborative routine. Thus, *H4* is partially supported in the empirical survey.

5.2.3 Joint mediating effect. After the respective analyses, M5, M9, M13, M17 and M21 involve both exploitative and exploratory learning to test their joint mediation effects. The results very consistently indicate that all the β coefficients of exploitative learning do not reach the significant standard (located from -0.07 to $+0.03$). While these of exploratory learning are all positive, even their β and R^2 values only approach those same ones in the cases involving exploratory learning (M4, M8, M12, M16 and M20). Thus, the results of joint effects indicate that the marginal effect from exploitative learning is not obvious, but exploratory learning plays a significant mediating role.

The previous results partially support the inferences of *H5* that dyadic learning is a mediator in the relationship between DIC and knowledge sharing. Of the two learning types, only exploratory learning plays a positive mediating role in both the mono and joint models, while exploitative learning does not show any significant mediation, neither in the mono models nor in joint models. Besides, exploratory learning has a stronger effect on knowledge sharing than exploitative learning. Under a DIR context, thus, the management has to raise exploratory learning of the dyads by proper organizational design, cross-boundary staffing, assignment of innovative tasks and encouraging the members to use experimental, rather than routinized, methods. Only two heads with interdisciplinary integration and exploratory learning can make the tasks better than that of one head.

5.3 Findings of the empirical studies

This study uses interviews and surveys, targeting the collaboration of R&D researchers, to explore the DIC architecture and clarify its effects on knowledge sharing and the mediating effect of dyadic learning behavior. The evidence leads to the following findings.

First, the results of 15-observation interview summarize 14 DIC descriptors listed as Table I, which point out the DIC content. Accordingly, this study collects 125 R&D researchers to examine the previous model. Results of factor analysis suggest extracting four factors from the original items. Hereafter, the four-element, 14-descriptor model is established as the DIC base model (the draft measurement). The base model is confirmed by LISREL/CFA examination of a 248-observation empirical survey. The regression analysis (listed in Table V) exhibits that the four elements can predict up to 40 per cent of the variance for knowledge sharing. Thus, the four-element DIC model can reflect the knowledge activities under DIR contexts.

Second, the examination of *H1* to *H4* indicates that all the four DIC elements present a positive and significant explanation for knowledge sharing. Based on the results of M2, M6, M1 and M14, the scale of β coefficients significantly locates between 0.29 and 0.54 ($p < 0.01$). Among them, the best predictor goes to mutual trust ($R^2 = 0.34$), the next is knowledge interdependency, while expertise similarity is the worst factor ($R^2 = 0.12$). Interestingly, the previous sequence is consistent with the frequency in the exploratory interview.

Third and finally, *H5* predicts that dyadic learning behavior plays a mediating role in the relationship between DIC and knowledge sharing. The empirical evidence from the hierarchical regression exhibits a consistent result: exploitative learning does not show the mediation significantly, neither in the mono models nor in the joint models, while exploratory learning plays a partially positive mediating role in both models. The results

partially support the prediction of *H5*, and they clarify that exploratory learning has a stronger effect on knowledge sharing than exploitative learning.

6. Discussions and conclusions

6.1 Discussions

The previous efforts induce some meaningful discussions. First, the exploratory in-depth interview discovers an interesting consistency with the empirical survey: the most frequently mentioned descriptors in the interview also offer a better explanation on knowledge sharing in the survey. Specifically, the descriptors regarding mutual trust, such as mutual trust (n = 13), closer bond (n = 12) and intensive contact (n = 10), are highly mentioned by the interviewees; knowledge interdependency-related items, including supplementary expertise (n = 12) and professional and essential experiences (n = 10), are major descriptors as well. The previous elements also show higher parameters in the regressions (Table V). We designed in-depth interview questions and item descriptors by reviewing related literature. The results of interview and empirical survey also supported the arguments regarding the positive effects of DIC on knowledge sharing. Thus, even though the methods are different, the empirical evidence indicates identical results. The previous results are consistent with the past literatures that take an organization or a firm as the unit of analysis, which pointed out that IC leads to better knowledge sharing (Tsai and Ghoshal, 1998; Cheng *et al.*, 2014; Vătămănescu *et al.*, 2016). Considering that the existing studies paid less attention to KM and IC issues of DIR so that we lack appropriate architecture and measurement for DIC, this study constructed a DIC scale by exploratory interview and empirical surveys. The results from the previous efforts indicate that the architecture could be a referable basis for the development of IC issues under a dyadic context.

Second, the empirical surveys indicate that, among the DIC elements, mutual trust exhibits the strongest explanation for knowledge sharing, even in the models with the mediation of dyadic learning. Under the DIR contexts, each party of the dyad has her/his own particular resources, ideology and expertise, thus inducing the hurdle of communication and cooperation, as well as suspected selfishness and opportunism from other parties. Hence, mutual trust smoothens the divergence and decreases the previous negative feelings, thus leading to more active knowledge activities (Morgan and Hunt, 1994; Tsai and Ghoshal, 1998; Hislop, 2003). The concern of this study is different to that of the past IC-related studies. Some past studies endeavored to explore how tangible knowledge assets (such as information and network systems, knowledge and data base and technology) of an organization work on knowledge sharing (Hargadon, 1998; Wu and Chen, 2014). The empirical results of this study, however, indicate that intangible IC, such as relational capital, provide better explanations instead (Ferguson and Taminiau, 2014; Vătămănescu *et al.*, 2016), particularly when the parties come from different fields. Thus, the relative effects of tangible assets to intangible IC would be a meaningful issue for the future KM studies.

Third, this study constructs dyadic human capital with two elements, i.e. knowledge interdependency and expertise similarity, and both are empirically confirmed that they positively explain knowledge sharing. However, the scale of the parameters signifies that knowledge interdependency (M2 to M5, M18-M21) has a stronger impact than expertise similarity (M6 to M9, M18-M21). Such gaps between the two elements may be due to the particular demand of DIR. DIR are usually formed for the purpose to create synergy through interdisciplinary knowledge activities (Palazzolo and Clark, 2007; Cheng *et al.*, 2014), to keep a contact with outsiders in different knowledge domains (Kogut and Zander, 1996), and to solve particular problems with interdisciplinary teamworks (Gittell, 2000). They seek new and even risky opportunities from the cooperation. However, evidence from past studies still leaves controversy over the effects of similarity. For instance, Castro and Neira's (2005) empirical results from M&A cases do not confirm the impact of cultural similarity on

knowledge sharing. Luo and Deng (2009) find that the similarity between strategic alliance partners accompanies many shortcomings such as cannibalization and low diversity among the partners. Bartunek (2007) studies integration in an academic–practitioner collaboration and discovers that the similarity between the two parties is not clear to predict their collaborative performance. Based on the empirical results, among the four elements, knowledge interdependency perform the best explanations, but expertise similarity has the worse effect on knowledge sharing. Thus, the dyads may prefer high complementary knowledge from colleagues to the expertise similarity. The previous results are quite particular to the past studies. Past literature indicated that IC factors, including similarity on expertise and knowledge fields, have generally positive effects on knowledge sharing (Tsai and Ghoshal, 1998; Cheng *et al.*, 2014; Makela *et al.*, 2007; Echajari and Thomas, 2015). This study, which concentrates on DIR, found that mutual trust and knowledge interdependency may have relative higher impacts on knowledge sharing than IC similarities between the parties. Such findings may signify that the critical factor for effective DIR is whether the IC from the dyads can be well synthesized, rather than just their similarities and aggregation.

Fourth and finally, the empirical evidence supports *H5* in that dyadic learning plays a mediating role in the relationship of DIC and knowledge sharing; in which exploratory learning has a stronger impact than exploitative learning. Such result is identical to the viewpoint of the existing learning-related studies. Past literature tended to treat exploration-exploitation as a conditional factor which highly relies on tasks or the contexts the organizations encounter (Mom, Van Den Bosch, and Volberda, 2007; Matzler and Mueller, 2011; Liao *et al.*, 2012). As what we mentioned previously, one major motivation for individuals/firms to participate in a DIR is due to the insufficiency of closer expertise of the individuals and the firms, so that they need to collect heterogeneous and diversified resources from external sources (Tenkasi and Boland, 1996; Rodan and Galunic, 2002; Bonner and Walker, 2004). The empirical evidences of this study can support the findings of past studies that exploratory learning is more effective than exploitative learning under interdisciplinary, cross-boundary contexts.

6.2 Limitations

This study still has some limitations that need to be improved. First, as the past literature still lacks sufficient architecture and measurement for IC under interdisciplinary dyadic contexts, this study thus follows the past literature, an in-depth interview and empirical surveys to circumscribe the DIC scope and to construct its architecture; hence, we construct a three-dimension, four-element DIC architecture with a scale. However, the previous effort is still exploratory a study with two surveys. The future efforts can be made by further replication to validate the architecture and to re-examine the scale, such as the statistical techniques like confirmatory factor analysis and test-retest reliability. It would be necessary to confirm the DIC architecture.

Second, to circumscribe the new DIC architecture, this study selects the most frequently cited three elements in the literature, i.e. human, structural and relational capitals. Thus, we may limit DIC scope in these perspectives only. IC perspectives in the literature, however, are quite multifarious. Alternative elements, such as external, process and social capitals (Molyneux, 1998; Habersam and Piber, 2003; Chen *et al.*, 2006), may be potential factors that generate DIC as well. The future studies can be conducted to compare the impacts of the human, structural and relational capitals on knowledge sharing to these potential elements to clarify the relative effects of the DIC elements.

Besides, this study targets R&D researchers as the samples. The DIR in R&D activities tends to be research-based; their mutual relationship is in a horizontal direction and relative simplex to the counterparts in business-based contexts, so that their DIC may be quite different. Future studies could target on alternative DIR in business contexts or in a vertical

direction, such as those in supplier-producer-distributor relationship, to raise managerial generality. In addition, another direction is to use the dyadic perspective to reexamine the existing studies on country, region and industry, such as the contexts of country-to-country and inter-organizational collaboration to raise external validity and extend the generalization of the DIC architecture.

Another limitation goes to the target of the empirical survey. This study selects individual R&D researchers in industry-academic cooperation projects as the target samples. In business and academic practices, the parties of the dyads are frequently teams or groups such as partners in a strategic alliance, rather than just individuals. Backgrounds of members under teams and groups contexts are much diversified and more complicated than that of two individuals. It is more difficult to build mutual trust and knowledge interdependency during the collaboration. Studies that target team- or group-based contexts may be a potential direction for the future efforts.

6.3 Future directions for research and practices

This study provides some directions for further academic efforts and practical implications. First, the empirical results signified that, among the four DIC elements, mutual trust and knowledge interdependency perform the best explanations on knowledge sharing, whereas expertise similarity has the weakest effect on knowledge sharing. Such results imply a significant meaning for the KM practices. In search of DIR parties, those who are trustable and have good relationship with our organizations would be proper partners for the collaboration. To keep a good mutual trust during the collaboration, the parties under a DIR context need more intensive connections and frequent interactions to build mutual trust, such as holding regular or non-regular meetings to keep contact or building on-line communities of practices to exchange ideas and information about the collaborations. It is also essential to raise knowledge interdisciplinary by seeking colleagues and coworkers with supplementary expertise and essential experiences, by attending cross-industry activities and participating cross-boundary communities, rather than those just having similar background and heterogeneous expertise.

Besides, the empirical results discover that exploitative learning does not induce the mediation on the relationship between DIC and knowledge sharing. Exploratory learning, however, is an essential factor leading to the association, and the mediating effects commonly occur in the four DIC elements. Such a result signifies that the selection of parties in collaborative relationship needs to consider the types of learning and tasks of the collaboration. Under the DIR contexts, the management has to improve exploratory learning by organizing interdisciplinary dyads and cross-boundary staffing, rather than just selecting those members who have similar background and expertise or those in related fields and industries. They can assign the dyads with unstructured and innovative tasks and encourage them to solve the uncertain problems with alternative, challenging ideas and experimental, risky methods, but not just with routine, incremental changes and conservative ways. They may induce exploitative learning by experiential refinement, reusing existing knowledge and technologies and continuous process improvement by focusing on the similar tasks and organizational environment. The result implies that collaboration in DIR should be beneficial to exploratory learning so as to improve the lowly structured, non-experienced tasks, while those routine and experienced ways are less effective for exploration. On the other hand, the features of exploitative learning may bring limitations and hinder works under DIR contexts; some extensive and stable solutions may work for the exploitative tasks. To respond the research questions of this study for managerial practices, the previous results are very expressive to practitioners: only two heads with interdisciplinary integration and exploratory learning can make the tasks better than that of one head. Based on the empirical evidence, the dyads/colleagues with

knowledge interdependency and mutual trust can in particular lead to better collaborative outcomes.

Finally, this study circumscribes DIC architecture with the most frequently cited elements in the literature, i.e. human, structural and relational capitals. The perspectives toward IC in the literature, however, are quite multifarious. Some alternative elements, such as external, process, and social capitals (Molyneux, 1998; Habersam and Piber, 2003; Chen *et al.*, 2006), may be potential factors that induce DIC. These factors may include the capability of acquiring necessary resource from outside of the organizations, the ability of generating expertise and knowledge from the internal process, and the social relationship with external critical professionals and stakeholders. Past studies indicate that these elements of IC are all beneficial for the knowledge generation and sharing of the organizations and the dyads. The future studies can work to clarify the relative effects of the human, structural and relational capitals on knowledge sharing to the potential elements.

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Appendix 1. The interview questions (the exploratory interview)

In this study, we attempt to understand how the next three factors influence the dyadic relationship between you and your colleague.

1. *Human factors*, which include the expertise, knowledge, skill, experiences, and attitudes of yourself and her/him.
2. *Structural factors*, which mean the routines and process in the collaboration between you and her/him.
3. *Relational factors*, which include the closeness, loyalty, partnership, and trust in the collaboration between you and her/him.

Please respond to the following three questions:

1. Please describe how human factors influence the dyadic relationship in the collaboration between you and your colleague.
2. Please describe how structural factors influence the dyadic relationship in the collaboration between you and your colleague.
3. Please describe how relational factors influence the dyadic relationship in the collaboration between you and your colleague.

Appendix 2

Table AI Measurement of the constructs (the empirical survey)

Constructs	Operational definitions	Item descriptors	Sources
Dyadic intellectual capital			
Knowledge interdependency	The extent to which the dyads interact and are interdependent on each other	We have supplementary expertise She/he has a professional background that is essential to me, but I do not possess She/he often provides me with creative viewpoints from an alternative perspective	Palazzolo and Clark (2007) Lee *et al.* (2008) Jackson *et al.* (1991) Van Vijfeijken *et al.* (2002) Kang *et al.* (2007)
Expertise similarity	The homogeneity of expertise background between the parties of the dyads	I have a similar expertise background with her/him We share a common language during the collaboration We have a tacit understanding during the collaboration	
Collaborative routines	The regulations, rules, and norms embedded in the process of collaboration	We have developed a particular cooperative mode during the collaboration We have formed some particular routines (such as norms, procedures, or regulations) that we follow	
Mutual trust	The extent of interpersonal confidence and commitment in the collaboration	We have mutual trust of each other We have formed a close bond during the collaboration We are very willing to exchange our expertise and knowledge	
Dyadic learning			
Exploitative learning	The degree of utilizing the existing experiences, routines, and practices to seek a more profound understanding to the existing knowledge	We pay more emphasis on getting the job done, rather than making it innovative We used to use routine ways to accomplish the tasks We use familiar methods to improve the outcomes of the tasks We used to follow experienced methods during the collaboration	Atuahene-Gima and Murray (2007)

(continued)

Table AI

Constructs	Operational definitions	Item descriptors	Sources
Exploratory learning	The degree of fundamentally pursuing new knowledge domains to create new values and improvement in performance	We used to look for something experimental and risky to accomplish the works We prefer to search for innovative information and methods to get the job done, even though they may be very different from what we are using now We work for collecting new knowledge from other expertise domains We enjoy collecting new information that we did not experience before We often push each other to gather and learn new knowledge to make the tasks better	Davenport and Prusak (1998) Lin (2007); Bartunek et al. (2001)
Knowledge sharing Knowledge sharing	The willingness of the dyads to share owned knowledge and expertise with each other	She/he often shares experiences about our tasks She/he is willing to provide her/his expertise and knowledge without sparing any details when I am in need of assistance She/he often expresses her/his opinions on the tasks	