

A social network analysis of teaching and research collaboration in a teachers' virtual learning community

Xiaofan Lin, Xiaoyong Hu, Qintai Hu and Zhichun Liu

Xiaofan Lin is a PhD candidate in the School of Education Information Technology at South China Normal University. His interests fall into ICT-supported Teachers' Professional Development, collaborative e-learning. Dr Xiaoyong Hu is an ICT-supported pedagogy researcher from South China Normal University. Dr Qintai Hu is a professor of the academic leader for the School of Education Information Technology at South China Normal University. Zhichun Liu is a postgraduate at South China Normal University. Address for correspondence: Mr Lin Xiaofan, School of Education Information Technology, South China Normal University, #55 Zhongshan Dadao Xi, 510631, Guangzhou, China. Email: fancy7j@gmail.com

Abstract

Analysing the structure of a social network can help us understand the key factors influencing interaction and collaboration in a virtual learning community (VLC). Here, we describe the mechanisms used in social network analysis (SNA) to analyse the social network structure of a VLC for teachers and discuss the relationship between face-to-face and online collaborations. In contrast to previous research applying SNA to analyse measuring indexes alone, we emphasise the mechanisms combining SNA, questionnaires, content analysis and focus group interviews—the key methodology to analyse complex interaction in a VLC. On this basis, we present an analysis model for teachers' VLC and apply it to a teachers' VLC known as 'IRIS'. The study participants comprised 172 K12 teachers aged between 25 and 55 years. This study collected collaboration data from 2006 to 2012 and analysed the social network structure using sociograms, centrality, cohesive subgroups, clique phenomenon, and matrix correlation of SNA. These findings suggest that face-to-face and online collaborations are both indispensable in teaching and in research and continuously supplement and remedy each other in professional development. Moreover, the model succeeded in accessing, describing and analysing the social network structure of a VLC.

Introduction

Teacher communities are believed to contribute to improvements in the practices of teaching and research as well as to the collective capacity of schools (Admiraal, Akkerman & de Graaff, 2012). The majority of studies focus on teacher communities in real-world environments (eg, Brouwer, Brekelmans, Nieuwenhuis & Simons, 2012), although some researchers have already examined the phenomenon of teachers' engagement in online social network (eg, Duncan-Howell, 2010). Despite recognising the benefit of blended learning in teachers' communities (Khine & Lourdasamy, 2003; Stubbs, Martin & Endlar, 2006), few researchers have comprehensively analysed teachers' virtual learning communities (VLCs) from the perspective of both the virtual and real worlds. Thus, the relationship between face-to-face (FTF) and online collaborations remains unclear.

To study the functioning of a VLC, researchers draw from a variety of methods, such as content analysis, quantitative analysis, qualitative interviews and questionnaires (eg, Anderson, Rourke, Garrison & Archer, 2001; Gunawardena, Lowe & Anderson, 1997; Pilkington & Walker, 2003;

Practitioner Notes

What is already known about this topic

- Many researchers show that social network analysis (SNA) is an effective technique to analyse interactions in a virtual learning community (VLC) (eg, De Laat, Lally, Lipponen & Simons, 2007).
- Analysing social network structures can illuminate key factors influencing interaction and collaboration in a VLC.
- Many studies adopting SNA are simplistic. They ignore important relational information, such as email or face-to-face (FTF) communication and consider only one tool.

What this paper adds

- A teachers' VLC model combining SNA, questionnaires, content analysis and interviews.
- The model blends FTF and online collaborations to reflect the key factors of the interaction.

Implications for practice and/or policy

- The study offers guidance to help teachers obtain the necessary support and resources and evolve as leadership members in a community.
- The findings in this study could serve as a basis for the future educational policies revision or training strategy development focusing on the aspect of improving teachers' effectiveness through both online and FTF collaborations.

Vandyck, de Graaff, Pilot & Beishuizen, 2012). These methods can provide useful insights to understand teachers' VLCs and their associated professional development. However, such methods may fail to help us interpret the relationship of collaboration between teachers in VLCs, as they do not employ data of the relationship.

Previous research shows that social network analysis (SNA) may be an effective technique to illuminate the key factors influencing interaction and collaboration (De Laat *et al.*, 2007). SNA seeks to describe patterns of relationships among actors, analyse the structure of such patterns and identify their effects on people and organisations (Wasserman & Faust, 1997). SNA allows a better understanding of the relationship governing learners' participation and collaboration in VLCs (Russo & Koesten, 2005). However, an analysis of this complex interaction poses a methodological challenge (Bottino, 2007), as there remains an imperative need to develop a framework to shed light on the key factors influencing interaction and collaboration in a teachers' VLC. In other fields of research analysing student community behaviour, Martinez, Dimitriadis, Rubia, Gómez and De La Fuente (2003) combined quantitative statistics, qualitative data analysis and SNA to study the experiences that promote collaborative learning. Furthermore, Jimoyiannis and Angelaina (2012) proposed an analysis framework for evaluating blog-based learning activities based on SNA, which was extended using content analysis and the model of community of inquiry. These studies can thus serve as a basis for our research on teacher communities. Nevertheless, there remains insufficient research evidence on the efficacy and applicability of a multi-method approach in studies on teachers' VLCs. This study therefore aims to analyse the interaction network structure of a teachers' VLC while considering the mechanisms of SNA and the relationship between FTF and online collaborations.

Literature review

The learning process does not simply entail receiving fragmented knowledge, but rather constructing knowledge through social interaction and collaboration (Cohen & Prusak, 2001). Regarding previous methods that assessed interaction and collaboration in VLCs, Gunawardena *et al* (1997) used a fivefold model defining the interconnected construction of new knowledge. However, few studies have integrated qualitative data and methods using SNA. Nevertheless, to support computer-supported collaborative learning, Martinez *et al* (2003) presented a mixed evaluation method combining traditional data sources with computer logs by integrating quantitative statistics, qualitative data analysis and SNA. Following the approaches used by Martinez *et al* (2003) and Jimoyiannis and Angelaina (2012), our study attempts to understand the particular situations and attitudes affecting teachers' collaboration in VLC by using various methods, such as SNA, qualitative data analysis, questionnaires, and content analysis, to analyse the interaction data.

SNA

SNA has been shown to be an appropriate method when studying these social and participatory aspects of learning (Wasserman & Faust, 1997). SNA may evaluate critical items such as graphs, properties and the relationships among them (Dawson, 2010). Aviv, Erlich and Ravid (2003) have empirically supported the assertion that structured design allows high-level knowledge construction and that knowledge construction is related to cohesion and equivalence network structures by using SNA. The network supports democratic knowledge-building when numerous direct links exist between participants (Sha & van Aalst, 2003). Using SNA, Cho, Gay, Davidson and Infraffea (2007) highlighted the relationship between learning quality in discussions and the dynamics of the network. Learners remained active in the VLCs even after the original tasks were completed (Dunlap & Lowenthal, 2009). Koula, Canan, Eileen and Ann (2012) examined interactions between online peers, in particular through mobile phones and Twitter, to interpret VLC experiences. In this study, the relationship mode was analysed using UCINET, a type of SNA desktop application (http://www.analytictech.com/download_products.htm) that can generate sociograms from messages logs and visualise reciprocity and provides an indication of intimacy in social networks as the proportion of arcs that are mutual.

Moreover, we have identified a set of SNA indicators for this study: centrality, cohesive subgroups. Centrality reveals the extent to which an individual interacts with other members in the network (Wasserman & Faust, 1997). The different actors may be determined by analysing the degree, betweenness and closeness centrality. Degree centrality is an index of the actor's prestige (Martinez *et al*, 2003). It reflects the activity of the actors. Betweenness centrality measures the extent of brokers' importance located paths between other actors (Badar, Hite & Badir, 2013). A higher betweenness centrality indicates that there would be information brokers hold powerful social positions or information monopoly in the network (Liu, Shih & Tsai, 2011). The closeness centrality of a node is defined as the sum of the distances of its shortest path to all other nodes (Lambropoulos, Faulkner & Culwin, 2012). Finally, to observe the cohesive subgroups in the community in depth, the various cliques should be examined (Aviv *et al*, 2003). If the number of cliques is larger, the interaction among participants is dense. This is propitious to knowledge construction. All of these indicators provide basic information about the activity of the actors in the network and about the global structure of the network according to different relationships.

Research objectives

After a review of the pertinent research and a description of our methodology, we present an analysis model for the teachers' VLC that combines SNA, questionnaires, content analysis and focus group interviews. The model blends FTF and online collaborations, thus reflecting the key

factors of VLC interaction. The blended network (BN) comprises both a social network of online collaborations—the virtual network (VN)—and a social network of FTF collaborations—the real network (RN). Data were obtained by applying the model to a teachers' VLC known as 'IRIS', involving 172 K12 teachers in China. On the one hand, the study analyses the teachers' learning community from the perspective of the SNA of BNs; on the other hand, it develops a mechanism model combining different methodologies for the analysis of community relationships.

To summarise, the objectives of the study is twofold:

- Identifying the features of collaboration and interaction in a teachers' VLC from the perspective of a multi-method analysis model.
- What is the relationship between FTF and online collaborations in a teachers' VLC? And how does it facilitate collaboration and interaction?

Research methodology

Participants

Since 2005, we have tracked online activity on the 'Tianhe Blog' (<http://www.thjy.org/>), an online platform based on blog technology that combines education and research with communication. This study selected a case named 'IRIS community' from the Tianhe Blog, which was established in 2006 by a K12 teacher from Guangzhou using the pseudonym 'Science', focusing on the creation and development of educational projects. IRIS developed around a cross-regional and interdisciplinary team that covers the Chinese, Mathematics, Geography, English, Information Technology, Comprehensive Practice, as well as other subjects. Since the creation of IRIS, there have been notable FTF and online collaborations between teachers from the Guangzhou city. The IRIS social network included teacher members from the Tianhe Blog (16 in total) as the core part of the sample. Educational projects involved much online interactive collaboration between teachers with similar interests, even though they may not have known each other in real life; later on, more teachers spontaneously joined the community. Given the radial diffusion situation, 172 K12 teachers who related to the core part through collaboration in the Tianhe Blog were chosen as the exterior sample for data collection. The 172 teachers included in this research project comprised 67 men and 105 women. The age of participants ranged from 25 to 55 years, with an average age of 33 years and standard deviation of 3.42. All teachers were college educated.

Research framework

This study developed a mixed model to investigate teaching and research relationships using SNA, content analysis, questionnaires and focus group interviews (Figure 1). Content analysis of the plentiful data on interactive communication taken from the Tianhe Blog aimed to discover the pattern of hierarchical interaction. Focus group interviews discussed the critical events and any particularities, thus helping to uncover any patterns. Community members, seen as research subjects, explained the environment and helped us clarify their behaviours and the reasons motivating them (Lally & Scaefe, 1995). The model blended FTF and online collaborations, reflecting the key factors of VLC interaction. In this way, we determined the analysis object and network border; clarified the different relationships; collected, encoded and analysed data; and finally formulated the conclusion. Data collection, analysis and the associated conclusions all interacted with each other, allowing us to approach our research target in a spiral manner.

Determining the units of analysis and the network boundary

In this study, the network boundary of the VN was the IRIS community in which the online collaboration occurred. Membership of the RN is based on participation in teaching and research activities. The units of analysis in SNA thus comprised the interaction that occurred between the teachers on the network.

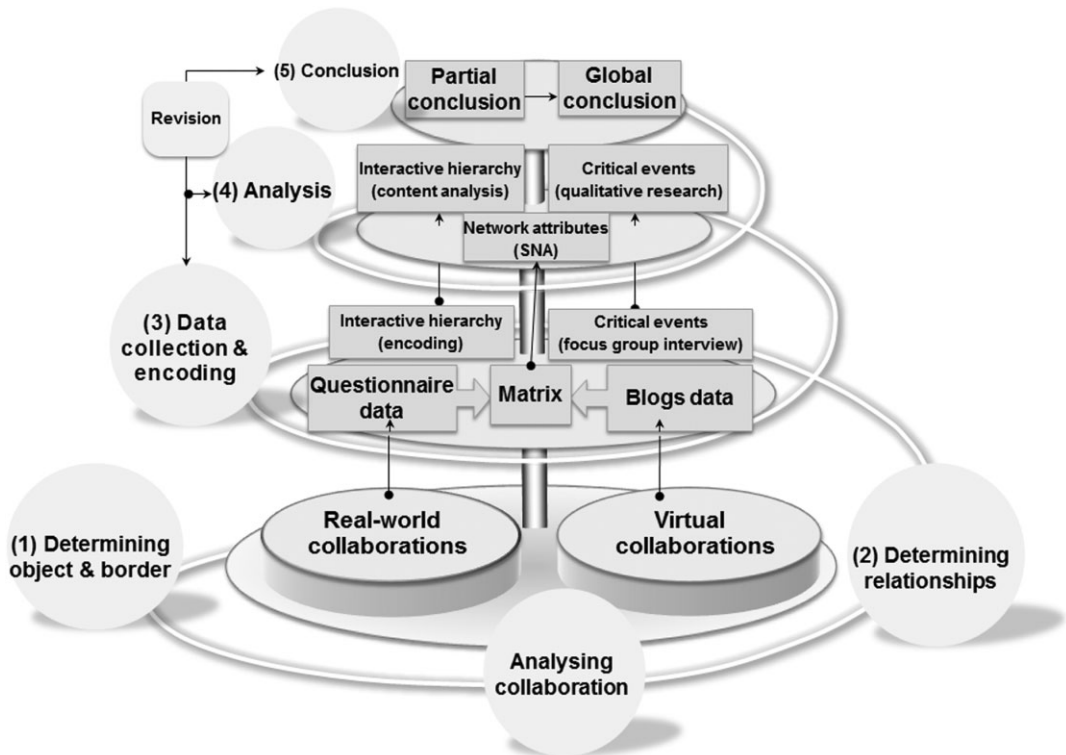


Figure 1: Analysing the model of collaborative relationships in the teachers' VLC for teaching and research

Determining the relational perspectives through collaborative activities

One of the important aspects in determining the relational perspectives was to clarify the main communication relationship in terms of the teaching and research activity in the social network. The following methods were used to classify the types of teaching and research activities and the extent of the interaction as well as to determine the extent of the interactivity between community members. Krackhardt and Hanson (1993) analysed numerous cases of informal networks and pointed out the effects of social networks on different kinds of management behaviour. The authors classified these cases into three types: consultant, informational and trust networks. Krackhardt and Kilduff (1990) showed that different behaviours might be classified into three networks, such as informal power and personal influence deriving from the trust network. Information exchanges are related to information networks, and relationships can thus be categorised into two types comprising weak and strong ties that require emotional support (Granovetter, 1973). Furthermore, Krackhardt and Kilduff (1990) identified a strong correlation between trust and friendship networks, whereas Krackhardt (1992) showed that friendship patterns could provide a convincing explanation for informal power struggles.

A special issue in *Learning Environment Research* published in 2012 discussed how to determine, analyse, evaluate and support collaborations in teachers' community. Among the five papers included in the issue, Dobber, Akkerman, Verloop, Admiraal and Vermunt (2012), Vandyck *et al* (2012) and Admiraal, Lockhorst, & van der Pol (2012) designed a model with three-dimensional principles involving group identity, interactional repertoire and shared domain to describe the activities in a community. We therefore suggest a typology for the three types of interaction contents—developing trust, consulting research and exchanging research information. Table 1

Table 1: Relation perspectives of research collaboration in the teachers' virtual learning community

Category	Subclasses	Description
Trust relationship	Coauthors	Being the coauthor of papers, books, research reports
	Coworks in teamwork	Working together in a team
	Partners of curriculum designs	Designing an open or research class
	Join in meetings	Attending conferences together (academic, project or discussion)
	Comment on each other	Commenting on others' cyberspace information (articles, pictures, videos and audios)
	Leaving recent messages	Leaving messages (articles, pictures, videos and audios) recently on others' cyberspace
	Friends' links	Adding online friends' links in their personal electronic devices
Consultant relationship	Recent visitors	Being recent visitors in the personal cyberspace
	Offline support	Ask for help if they have difficulties in research
	Online support	Ask for help on the Internet (via email, QQ, blogs, etc)
	Online help	Providing research help online (via email, QQ, blogs, etc)
Exchanging Informational relationship	Offline help	Providing initiatively help in the real world
	Diffuse information in the real world	Transmission of research information in the real world (face-to-face or on the telephone, etc)
	Diffuse information online	Transmission of research information online (via email, QQ, blogs, etc)

outlines the blended structure of these three indicators, which combine FTF activities and blogging activities.

Teachers' collaborative activities in the RN were classified according to various types of collaboration, namely coauthors of papers, colleagues in projects, partners in curriculum design and participants in the same conference.

Online collaborative activities mainly concerned discussions and comments pertaining to educational projects. For instance, the teachers developed numerous webinars on instructional design. The host would decide the time and rules for the webinar and post the draft version on the platform. Teachers made comments, and the design would subsequently be revised for further discussion a few days later. After several rounds of discussion and collaboration, an improved version of the design would be recorded as the result of teachers' collaborative activities. We collected the data on these comments and discussions in order to observe the VN. Thus, collaborative activities online were classified according to teachers' involvement in commenting on blogs, recent visitors, recent comments, friend links and senders and receivers of information about teaching and research.

Data collection and encoding

Three types of data were collected in the collaborative teaching and research activity: direction and strength of the relationship, content of the relationship and critical events.

Direction and strength of relationships

Both FTF and online data were considered to be forms of collaborative activities between units. Questionnaires were mainly adopted in this research to collect collaborative RN data, including personal information about the teachers and data measuring the relationship between teaching and research collaborations.

Referring to several questionnaires used in other relevant SNA studies on collaborative learning (eg, Luo, 2011), the questionnaire used in our research was modified in consideration of the

Table 2: Questionnaire of teaching and research collaboration

	1	2	3	4	...
Who was a coauthor with you?					
With whom did you participate in the same project?					
With whom did you design a research class?					
Who attended the same conference (academic, project-based or discussion) as you?					
With whom do you speak the most about teaching and research in the real world?					

research environment. Sample questions from the questionnaire given to teachers are listed in Table 2. Furthermore, online data relating to collaboration in teaching and research, such as comments, friend links, visits and messages, were collected using the Tianhe Blog platform. Information obtained through instant messages or emails, which would not be recorded by the platform, was completed in the questionnaire.

The social network relationship matrix was built according to the statistics of data coding, with the aim of encoding the relationship according to sender, receiver, frequency, direction and weight so as to obtain the interaction between teachers. In the relationship matrix, strength was determined by interaction frequency; thus, values in the matrix were used to determine the strength of collaboration. A BN was then constructed using the following steps. First, the relationship matrices were encoded and built. Second, nodes of the same type in the VN and RN were weighted and combined to have the same weight value. As members in both the real and virtual worlds were the same, data from both the RN and VN were encoded in a uniform manner. In this way, the new network matrix—that is, the BN—was built in order to reveal the relationship in teaching and research from the perspective of both the virtual and real worlds.

Collection and encoding of relationships

The collection and encoding of relationships mainly refer to the hierarchical model of interactive knowledge construction developed by Gunawardena *et al* (1997). After a series of theoretical studies on the characteristics of blogging, interactive features of blogs, existing interaction model and preliminary exploratory coding, the authors designed an encoding table to analyse the contents of teachers' interaction in blogger groups. This table could thus be used help to analyse the interactive behaviour of blogging and commenting in the VLC of the Tianhe Blog. The relationships data were directly exported from the Tianhe Blog platform, and then encoded according to the interactive hierarchy (Table 3).

Collecting and processing data from the critical event recall interview

The critical events of this study were included in the collection of data for each phase. The researchers focused on the interactive situation and environment, which the community has participated in since determining the relationship and designing the questionnaire. Meanwhile, it was combined with the SNA of VLC and content analysis. In the research process, eight members with different roles in the community were chosen to participate in the critical event recall and focus group interviews. The roles of these members in the RN, VN and BN are summarised in Table 4. They are presented in Result section and Discussion section.

Analysing the data on collaboration in teaching and research

There exists direct coupling between the data analysis and data collection steps. As shown by the arrows linking two steps in Figure 1, when analysing the data, we performed SNA on the network data for collaboration in teaching and research based on data collection and processing. We also conducted an analysis of the interactive level of the relationship after encoding and a qualitative analysis of the critical event recall interview.

Table 3: Encoding table for the interactive degree of hierarchical content analysis levels

Category	Subclasses	Description
Shallow Interaction (S)	Short response S1	Simple words in reply, for example, "Got it," "Agreed"
	Reviewing the point S2	Agreeing to sentences or points made in reference to them, or simply replying to comments or the main theme
Moderate Interaction (M)	Shallow thoughts S3	Giving their personal reasons when commenting, or simply describing personal behaviour or ideas
	Comparison and sharing M1	Asking and answering each other and comparing the differences
	Summarising and integration M2	Using experience and literature to analyse and summarise, give personal opinions or suggestions
Deep Interaction (D)	Analysis and question D1	Reflecting deeply on the passages in blogs or comments, asking questions
	Profound thoughts D2	Thinking in depth and sharing unique personal insights or ideas
	Internalisation and transfer D3	Using critical thinking to discuss topics and other viewpoints

Table 4: Members participating in the critical event recall and focus group interviews

The participant ID	Role of the member
4	Former core member whose blogs are frequently shared and commented on
5	Founder of the group and leader in the social network
8	New core member whose blogs are frequently commented on
12	Core member in the later stages
15	Sub-core member in the VN while with a low value of centrality in the RN
16	Periphery actor in the RN, VN and BN
87	Top 10 value of the centrality in the VN but low in the RN
96	Top 15 value of the centrality in the VN but low in the RN

Analysis and construction of social network structure features as a whole

To reflect the comprehensive research cooperation, a comparative study of VN, RN and BN was systematically conducted. This paper thus reveals the general characteristics of the regional research cooperation and discusses the interaction and relationship between VN and RN.

Results

Features of the community (sociogram): qualitative analysis of the research cooperation network structure

The RN, VN and BN sociograms were drawn using UCINET 6.0 (Analytic Technologies Company, Lexington, Kentucky, USA) (Figures 2–4). From these figures, we may conclude that there were many connections in RN without the existence of any isolated node, which explains the frequency of collaborative nodes and the formed links of the research cooperation. The VN structure, however, is relatively loose, with fewer connections between nodes. The core nodes in the BN structure interconnect with strong links, whereas the peripheral nodes are distributed around the centre. A more detailed analysis of the features of the network structure and nodes is provided below.

Quantitative analysis of the individual attributes in teachers' collaboration

The actors in the core, periphery and isolated positions may be determined by analysing the degree, betweenness and closeness centrality.

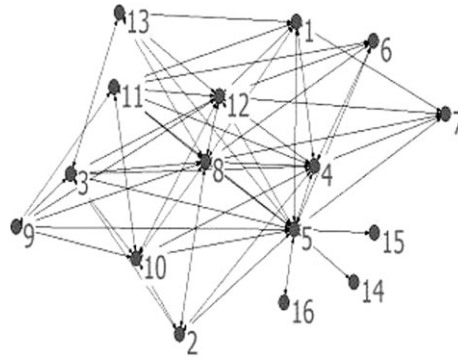


Figure 2: Real network sociogram

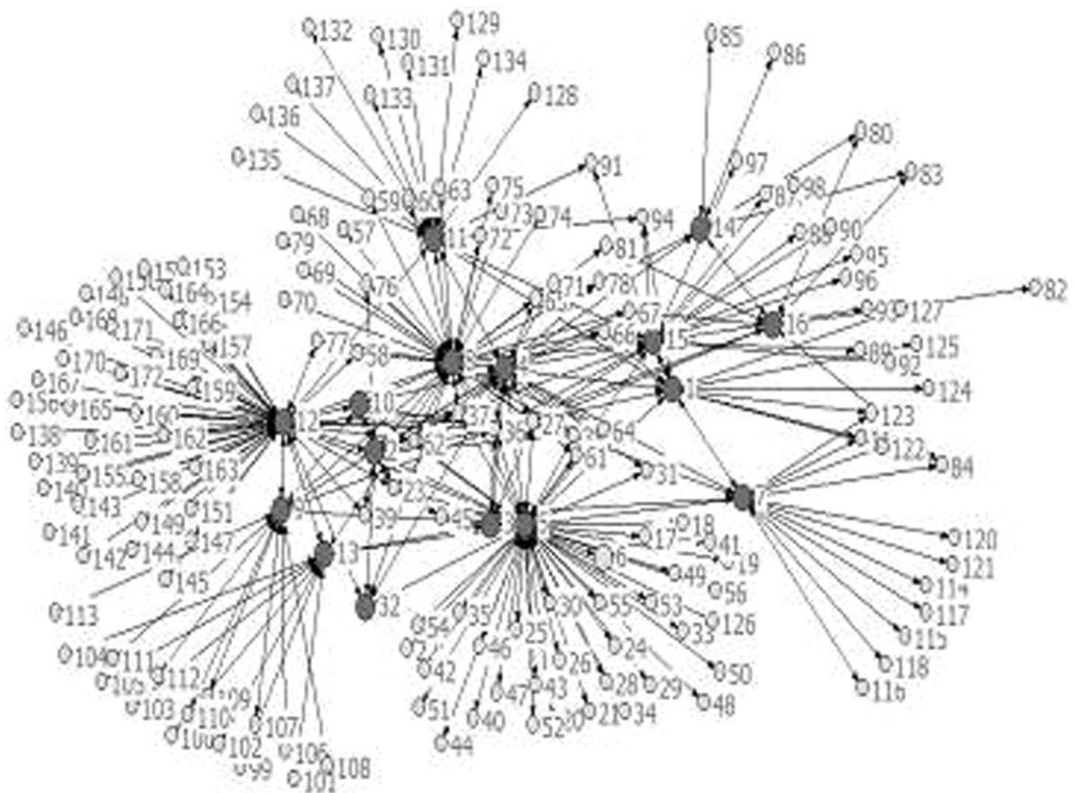


Figure 3: Virtual network sociogram

Degree centrality is defined as the number of links incident upon a node (ie, the number of ties that a node has). It thus indicates the strength of the collaboration among teachers. The following can be concluded from Table 5 below:

- Node 5 has the greatest strength in terms of the RN, VN and BN, which indicates that the individual has an upper hand in the collaborative network and a leadership role in the community, in effect controlling the entire collaboration.

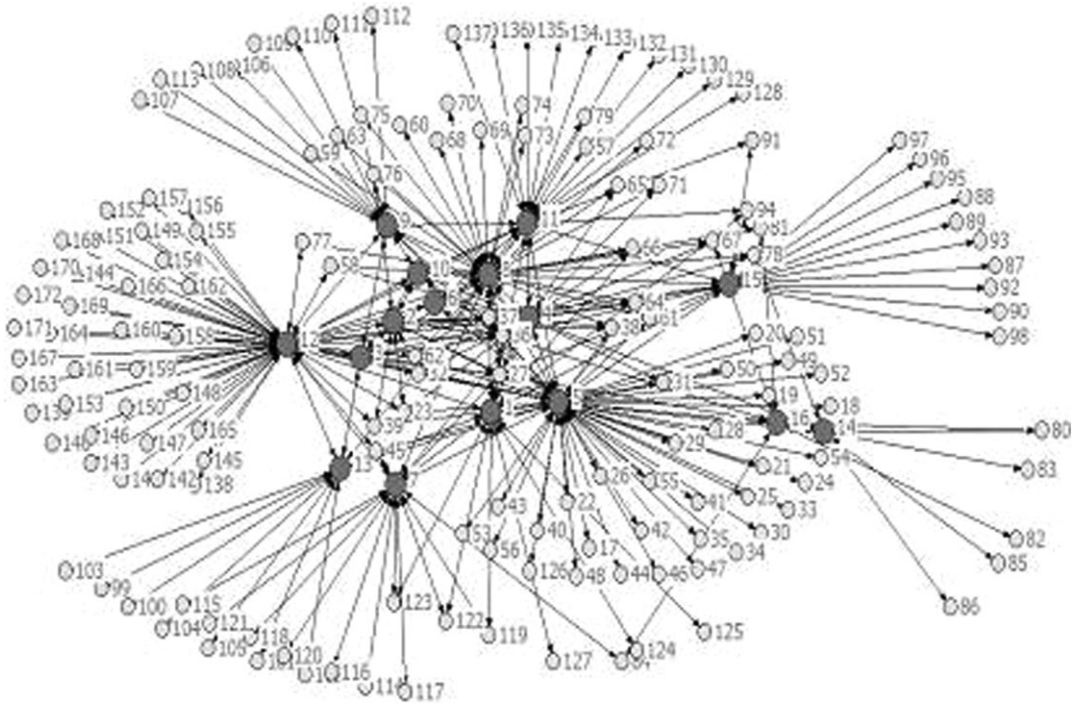


Figure 4: Blended network sociogram

Table 5: Centrality analysis of IRIS

Centrality	Degree			Betweenness			Closeness			
	Node number	VN	RN	BN	VN	RN	BN	VN	RN	BN
Ranking	1	5	5	5	5	5	5	5	5	5
	2	8	12	12	8	12	12	8	8	12
	3	12	8	8	12	8	8	12	12	8
	4	4	4	4	4	11	11	4	4	4
	5	10	15	11	3	15	15	10	96	1
	6	3	11	15	11	4	7	3	87	11
	7	11	7	7	10	7	9	11	9	96
	8	1	9	1	1	9	13	1	37	9
	9	9	1	9	13	13	1	9	15	87
	10	2	2	2	9	1	4	2	2	7

BN, blended network; RN, real network; VN, virtual network.

- The values of Nodes 4, 8 and 12 are somewhat higher, indicating that they are very active in the network, collaborating with others in various forms.
- The value of a node in the BN is greater than in the RN or VN, which indicates that the relationship is stronger in the BN. In other words, the combined collaboration in both real and virtual worlds can promote communication and interaction among teachers.

Betweenness centrality is a centrality measure of a vertex within a graph. By analysing it, the 'gatekeeper' and the 'bridge' in the collaboration can be identified. The following can be observed from Table 5:

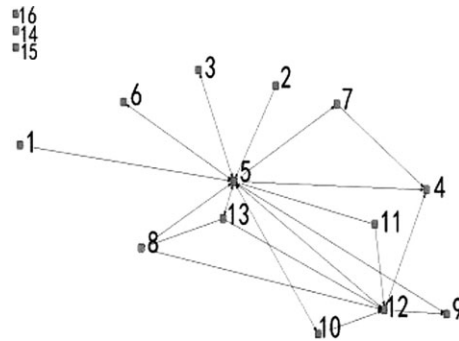


Figure 5: Real network sociogram

- The top 10 betweenness centrality of a node was fundamentally the same in all three networks, indicating that they map to each other.
- Nodes 5, 8 and 12 were the top three nodes from the perspective of betweenness centrality in all three networks, which indicates that they are the 'bridge' in the VN, RN and BN to a large extent. They affect the flow of information and distribution of educational resources.
- Node 15 was not in the top 10 in the RN but was medium level in the VN and BN. After the interview, it was shown that Node 15 is an administrative staff member in his school. He often undertakes collaborative work in teaching and research with other teachers in the online community. For this reason, his control of information and educational resources in the VN and BN was greater than in the RN.

The closeness centrality of a node is defined as the sum of the distances of its shortest path to all other nodes. Thus, the lower the total distance to all other nodes, the more central a node is. The following can be observed from Table 5, and the results of closeness are from the top 10:

- Node 5 has the lowest closeness in all three networks, which indicates it to be the centre of the network and able to collaborate with other teachers in the shortest path. The other top four nodes are 8, 4 and 12, which are the sub-core of the network.
- The closeness value of Nodes 96 and 87 is low level in the RN while in the top 10 in both the VN and BN. Following the interviews, these two teachers were found to often write teaching and researching articles online and actively collaborate with other teachers, which leads to a good collaboration and makes up for the shortage in the real world.

Quantitative analysis of integrity attributes in teaching and research collaboration

Analysis of cohesive subgroups

To observe the cohesive subgroups in the community in depth, the various cliques should be examined (Aviv *et al.*, 2003). To simplify the networks by screening the nodes with a greater strength of collaboration, three matrices were binarised (Figures 5–7). From these figures, the following can be concluded:

- Nodes 5, 1, 6, 3, 87, 13 and 8 form a cohesive subgroup in the RN with Node 5 being the core, whereas Nodes 13, 9, 10, 11 and 4 form another cohesive subgroup in the RN with Node 12 being the core. In the VN, Nodes 12, 9, 10, 11 and 4 form a subgroup, whereas the BN subgroup includes Nodes 12, 3, 8, and 5.
- The interview revealed that Nodes 5 and 8 were the core actors for advice on teaching and research. They provided professional advice on research methods.
- The effect of the cohesive subgroups in the BN is inconspicuous because all of the community members participated in both online and real-world collaborations (Figure 7).

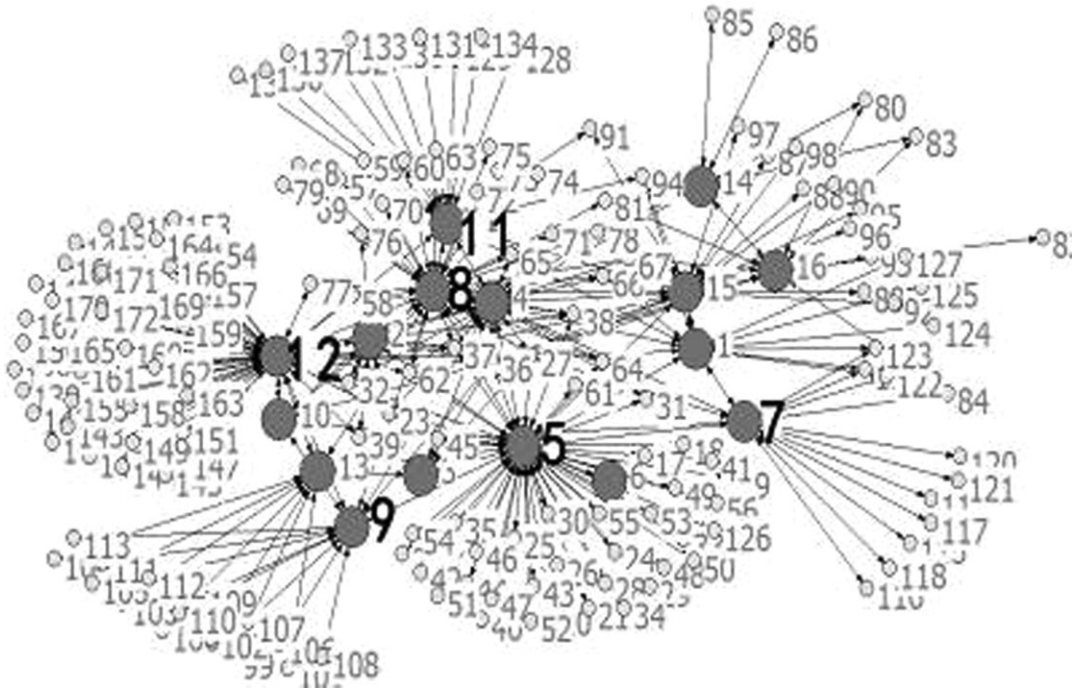


Figure 6: Virtual network sociogram

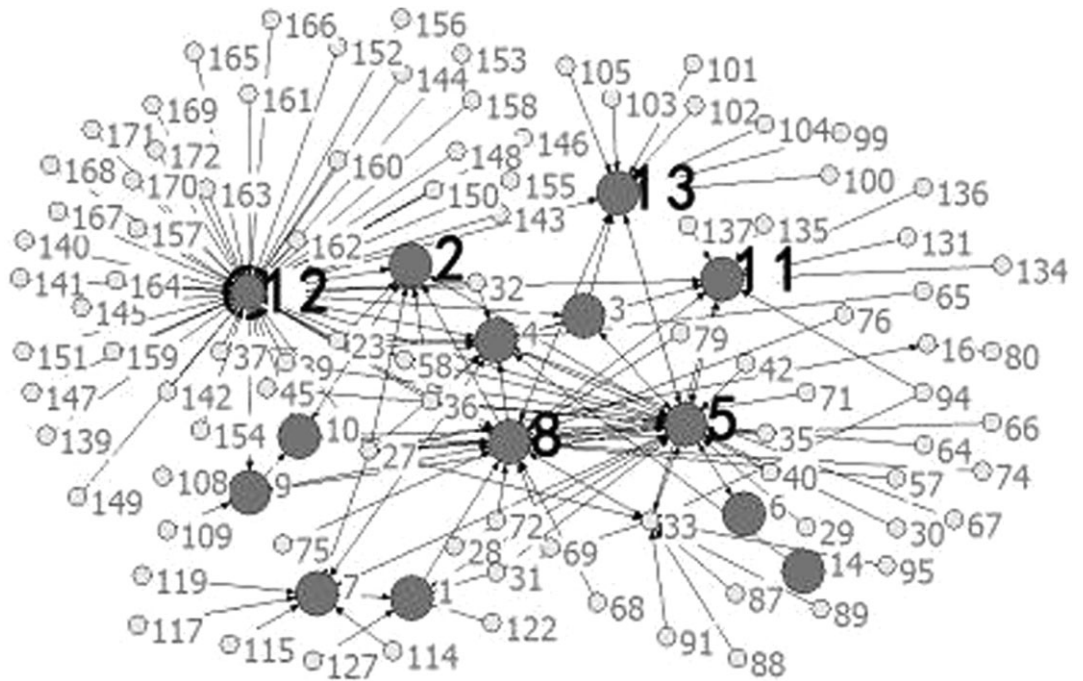


Figure 7: Blended network sociogram

Table 6: Correlation between the various matrices (significance 0.000)

	RN	VN	BN
RN	1.000	0.530	0.875
VN	0.530	1.000	0.710
BN	0.875	0.710	1.000

BN, blended network; RN, real network; VN, virtual network.

Analysis of the matrix correlation

The RN, VN and BN separately represent the different aspects of teachers' collaboration in teaching and research. In this study, further attention was paid to the relationship between the VN and RN—namely whether the VN was able to replace real-world teaching and research collaborations and how the RN exerted itself in terms of the VN interactions.

Therefore, the Quadratic Assignment Procedure (QAP), provided by the UCINET6.0, was adopted to analyse the matrix correlation and explore the relationship between the three types of networks. First, the matrix correlation of RN and VN was compared. The significance level was 0.000 with a Pearson's correlation coefficient of 0.53. Thus, the RN and VN matrices showed an obvious correlation. This study suggests that the mapping of real-world collaboration relationships in teaching and research was extended to the VN in online collaborations, which the latter transformed into RN relationships of collaboration. The correlations between the three matrices were then analysed as shown in Table 6.

The correlations between the two matrices were positive (Table 6), and the Pearson's correlation coefficients for the BN, RN and VN were high. Thus, both the VN and RN are indispensable for collaboration in teaching and research in this community. However, online teaching and research cannot replace FTF communication. It nevertheless plays an effective role in complementing real-world teaching and research and expanding the coverage range of collaboration, and in this way, a blended world is formed by combining the virtual and real worlds.

Discussion

The results show that teaching and research collaboration in IRIS was competitive, with a stable network structure and key network nodes being formed (Nodes 5, 4, 8 and 12). According to our study, there were several reasons for the success of the IRIS community.

First, there was a core actor in the community, who played an important leadership role. The critical event recall and focus group interviews showed that Node 5 was a teacher and researcher in this community, who could effectively organise all kinds of collaboration activities and provide support and guidance for teaching methods. Node 4 was a director in the research office in this community, who provided many academic resources for research and projects, thus playing a leading role from the research perspective. Under the leadership of the original core members, Nodes 4 and 5, a number of new collaborative groups formed. Nodes 8 and 12 became the team's new core members and developed a number of projects, creating a good collaborative relationship. They both had a strong academic background and abundant educational resources, which played an important role in terms of the guidance given, communication between members and the sharing of resources. This conclusion is in line with the previous results of other teacher bloggers using SNA. Some network positions have a particular influence on individual and group achievements due to the structure of social interactions that promote or strengthen individual approaches by offering invaluable resources, such as suggestions, strategies and social support.

Second, the centrality and QAP correlation analysis revealed that the community found a balanced coexistence between online and real-world collaboration. At the same time, the VN and RN

were both indispensable for collaboration in this community in terms of extending and forming relationships. On the one hand, real-world collaboration played an active role as a bridge or it was located at the core of the node, whereas the virtual collaborative networks reflected a similar trend. On the other hand, online collaboration both extended and complemented weak collaborations in the real world, increasing the extent of the collaboration through the characteristics of the Internet. The interviews show that real-world teaching and research played an important role in integrating collaborative networks and achieving outcomes, such as in research collaborations and coauthored academic papers. Previous studies showed that although an individual's role varies in the different Internet realms, this online role more or less reflects the personality in the real world (Argyle & Shields, 1996). Similarly, Wellman (1997) considered that social ties on the Internet represent an extension of the real-world relationship network. Based on this belief, Yeh and Luo (2001) found that it was highly possible for people with a high degree of centrality in the real world to have the same characteristic online. Our findings develop these ideas even further, as they showed that with the mutually supported networks, online teaching and research can surpass the constraints of time and space by expanding the breadth of interaction and dissemination, particularly in terms of promoting the professional growth of novice teachers. For example, Nodes 15, 87 and 96 carried out online teaching and research, which greatly compensated for their lack of real-world teaching and research. These teachers formed collaborative relationships across different institutions through the network, thus revealing the fast, efficient and cross-boundary nature of online networking activities as well as their ability to enhance the efficiency and expand the coverage.

Third, learners' shared knowledge remained at a rather basic level of construction. Further data analysis along with the focus group interviews revealed that although a higher quantity of shallow interaction was less directly related to the teachers' professional development, it still allowed trust to be built between community members. The trust relationship between members is an important foundation of deep interaction. At the same time, it was beneficial to transfer virtual collaborative relationships into the real world. Moreover, teachers' professional development and practical knowledge was shown to lead to deeper interactions through, for example, reflections on lessons, units and themes; lesson preparation; lesson study; and scientific research and training.

Of course, some weaknesses were identified in the analysis of the community. For example, some community members in a weak position in the network for real-world collaboration did not have much collaborative interaction. Thus, in order to guide the isolated nodes within collaborative networks, more attention should be paid to them. The study also shows that virtual teaching and research activities cannot replace the support gained from the exchanges in real-world activities. This suggests that collaborative activities should be carried out actively and more regularly in order to improve knowledge sharing and group exchanges and promote weak link nodes so that they obtain greater support and resources to evolve into core members and, ultimately, form new collaboration groups. Overall, in contrast to previous studies (Jimoyiannis & Angelaina, 2012; Martinez *et al*, 2003), we found that in the relationship between real-world and virtual collaborations are indispensable to the community. On the one hand, role in the network of nodes in real world usually may be found in the virtual world. Virtual collaboration nevertheless extends the range of collaboration and functions as a supplement to weak relationships in the real world.

Multi-method analysis

In order to assure the validity of the results, a 'methodological triangulation' was adopted (Elliott, 1991). The 'triangulation' process employs more than one approach to enhance confidence in research findings (Bryman, 2012). In this study, triangulation was conducted in several ways. First, the outcomes of several methods were integrated; for example, the notions of teacher

participation and teaching and research activities were used to select participants for the interviews (Table 4) with the aim of uncovering emergent patterns, such as participants with increasing or decreasing activity over time. Second, summary tables obtained from content analysis were used as stimulus during the critical events interviews to help the participants reflect on these patterns. Third, the results of one method helped interpret and contextualise the outcomes of another; for example, participants' positions in the sociograms were compared with the content analysis findings. In this respect, we employed both data triangulation (data collection over time) and methodological triangulation (multiple methods) (Denzin & Lincoln, 2005).

The combination of SNA with the critical event recall interviews and content analysis allowed us to understand the process and intentions of participants on a personal level. The framework presented in this study thus offers enhanced source data to investigate teachers' engagement and learning actions through educational blogs. Content analysis coding results were mapped against a participant's position in the group as identified by SNA. Furthermore, participants' statements about their own and others' engagement in group activities was contextualised from their own position in the network. Our work with SNA supports the idea that VLC participants have a good understanding of how the community interacts, as indicated during the interviews. They knew who was active and was not and understood the relationships between members. They were also aware of the visual figures who tried to develop the community's learning or teaching activities.

Implications

In the light of the practical implications, for the education authorities as well as teacher educators, the findings in this study could serve as a basis for the future educational policies revision or training strategy development focusing on the aspect of improving teachers' effectiveness through both online and FTF collaborations. Based on the results of this study, both FTF and online collaborations continuously supplement in teachers' professional development. For example, education authorities and schools should provide various opportunities to enhance collaboration and connections among teachers, rather than simply appraise teachers by students' test scores. Strong community connections are a promising indicator of a positive and collaborative teacher community (Admiraal *et al*, 2012). Teachers may be encouraged to familiarise themselves with the skills of interaction in online and FTF activities, find their own interest, and then apply the skills and knowledge to solve problems in the workplace. Accordingly, teachers may truly obtain the necessary support to solve practical teaching problems and evolve as leadership members in a community.

The methodological implications drawn from this study include that future research could use multi-method integrating quantitative analysis, qualitative data analysis and SNA for analysing the complex collaboration and interaction in teachers' activities. Our work with multi-method supports the idea that researchers and VLC participants gain deeper understandings of how the community interacts. More studies should be undertaken to explore how to identify the different social networking positions with multi-method analysis and try to facilitate the interaction to promote the professional development of teachers.

Limitations and future studies

This study did not suggest an optimal mechanism for analysing a teacher community. As a result, its conclusions and suggestions may only be applicable to a scenario similar to this environment. To evaluate the methodology of SNA in a VLC to greater extent and develop our conclusions pertaining to teaching and research collaboration, we would like to conduct similar research with a greater number of subjects or in different network environments in the future.

Finally, the teaching and researching collaboration data used in the research was mainly collected from the Tianhe Blog platform and participants. However, not all of the interactions occurred on

the platform. We would therefore like to focus on further data sources that would not be recorded by the platform, such as private instant messengers and email discussions. With permission of the subjects, those private communication data would be obtained from communication logs, part of that would be collected by a survey. Therefore, the intensity and betweenness of subjects would be further evidenced by reference to the private communication.

Conclusions

This study on a teachers' VLC focused on the process of their collaborative activities and interactive content based on the three-dimensional analytical model integrating the VN and RN using SNA. The study used a variety of methods, including SNA and quantitative and qualitative research, to analyse the overall structural features of collaborative networks in teaching and research, their main nodes as well as the status of participants. The conclusions may be summarised as follows.

Using SNA, content analysis and questionnaires, the results are mutually consistent. They reveal that the SNA model used in this study can obtain an effective access, description and analysis of the structural features used in teaching and research collaborative networks in a teachers' VLC.

Both the RN and VN are indispensable in stimulating the teachers' learning community as well as their collaborations. When used together, they draw from each other's advantages and compensate for the deficiencies. Collaboration is promoted by teaching and researching in the RN, whereas VN collaborative relationships can expand on and complement weak collaborations in the real world, thus expanding the range of coverage.

IRIS formed a stable social network structure with key nodes and achieved the coexistence of virtual and real-world collaborations, although deeper interactions need to be further strengthened. Therefore, in order to promote collaborations and the professional development of teachers to the greatest extent, the regional education authorities and schools should provide different opportunities to enhance the collaboration and communication among teachers through both virtual and FTF teaching and research activities. Both modes of collaboration are expected to play an important role so that, ultimately, virtual and real-world interactions may complement each other and coexist.

Acknowledgements

This study is supported by Key Project of Chinese Ministry of Education (No. MCM20121011) and the Scientific Research Foundation of Graduate School of South China Normal University (N O.2013kyjj030).

References

- Admiraal, W., Akkerman, S. F. & de Graaff, R. (2012). How to foster collaborative learning in communities of teachers and student teachers: introduction to a special issue. *Learning Environments Research*, 15, 3, 273–278.
- Admiraal, W., Lockhorst, D. & van der Pol, J. (2012). An expert study of a descriptive model of teacher communities. *Learning Environments Research*, 15, 3, 345–361.
- Anderson, T., Rourke, L., Garrison, D. R. & Archer, W. (2001). Assessing teaching presence in a computer conference context. *Journal of Asynchronous Learning Networks*, 5, 2, 1–17.
- Argyle, K. & Shields, R. (1996). Is there a Body in the Net? In R. M. Shields & R. Shields (Eds), *Cultures of Internet: Virtual spaces, real histories, living bodies* (pp. 58–69). Sage Publications. Sage.
- Aviv, R., Erlich, Z. & Ravid, G. (2003). Cohesion and roles: network analysis of CSCL communities. In *Advanced Learning Technologies, 2003. Proceedings. The 3rd IEEE International Conference on* (pp. 145–149). IEEE.
- Badar, K., Hite, J. M. & Badir, Y. F. (2013). Examining the relationship of co-authorship network centrality and gender on academic research performance: the case of chemistry researchers in Pakistan. *Scientometrics*, 94, 2, 755–775.

- Bottino, R. M. (2007). Online learning networks: framework and scenarios. *Education and Information Technologies*, 12, 2, 93–105.
- Brouwer, P., Brekelmans, M., Nieuwenhuis, L. & Simons, R. J. (2012). Fostering teacher community development: a review of design principles and a case study of an innovative interdisciplinary team. *Learning Environments Research*, 15, 3, 319–344.
- Bryman, A. (2012). *Social research methods*. Oxford: Oxford University Press.
- Cho, H., Gay, G., Davidson, B. & Infracchia, A. (2007). Social networks, communication styles, and learning performance in a CSCL community. *Computers & Education*, 49, 309–329.
- Cohen, D. & Prusak, L. (2001). *In good company: how social capital makes organizations work* Vol. 154. Boston: Harvard Business School Press.
- Dawson, S. (2010). 'Seeing' the learning community: an exploration of the development of a resource for monitoring online student networking. *British Journal of Educational Technology*, 41, 5, 736–752.
- De Laat, M., Lally, V., Lipponen, L. & Simons, R. J. (2007). Investigating patterns of interaction in networked learning and computer-supported collaborative learning: a role for Social Network Analysis. *International Journal of Computer-Supported Collaborative Learning*, 2, 1, 87–103.
- Denzin, K. & Lincoln, S. (2005). *Handbook of qualitative research* (3rd ed.). Beverly Hills, CA: Sage Publications.
- Dobber, M., Akkerman, S. F., Verloop, N., Admiraal, W. & Vermunt, J. D. (2012). Developing designs for community development in four types of student teacher groups. *Learning Environments Research*, 15, 3, 279–297.
- Duncan-Howell, J. (2010). Teachers making connections: online communities as a source of professional learning. *British Journal of Educational Technology*, 41, 2, 324–340.
- Dunlap, J. C. & Lowenthal, P. R. (2009). Tweeting the night away: using Twitter to enhance social presence. *Journal of Information Systems Education*, 20, 2, 129–155.
- Elliott, J. (1991). *Action research for educational change* Vol. 49. Buckingham: Open University Press.
- Granovetter, M. S. (1973). The Strength of Weak Ties. *American Journal of Sociology*, 78, 6, 1360–1380.
- Gunawardena, C. N., Lowe, C. A. & Anderson, T. (1997). Analysis of a global online debate and the development of an interaction analysis model for examining social construction of knowledge in computer conferencing. *Journal of Educational Computing Research*, 17, 4, 397–431.
- Jimoyiannis, A. & Angelaina, S. (2012). Towards an analysis framework for investigating students' engagement and learning in educational blogs. *Journal of Computer Assisted Learning*, 28, 3, 222–234.
- Khine, M. S. & Lourdasamy, A. (2003). Blended learning approach in teacher education: combining face-to-face instruction, multimedia viewing and online discussion. *British Journal of Educational Technology*, 34, 5, 671–675.
- Koula, C., Canan, B., Eileen, S. & Ann, J. (2012). Museum learning via social and mobile technologies: (how) can online interactions enhance the visitor experience? *British Journal of Educational Technology*, 43, 5, 802–819.
- Krackhardt, D. (1992). The Strength of Strong Ties: The Importance of Philos in Organizations. In N. Nohria & R. Eccles (Eds), *Networks and Organizations: Structure, Form, and Action* (pp. 216–239). Boston, MA: Harvard Business School Press.
- Krackhardt, D. & Hanson, J. R. (1993). Informal networks. *Harvard Business Review*, 71, 4, 104–111.
- Krackhardt, D. & Kilduff, M. (1990). Friendship patterns and culture: the control of organizational diversity. *American Anthropologist*, 92, 1, 142–154.
- Lally, V. & Scaefe, J. (1995). Towards a collaborative approach to teacher empowerment. *British Educational Research Journal*, 21, 3, 323–338.
- Lambropoulos, N., Faulkner, X. & Culwin, F. (2012). Supporting social awareness in collaborative e-learning. *British Journal of Educational Technology*, 43, 2, 295–306.
- Liu, E. Z. F., Shih, R. C. & Tsai, Y. L. (2011). Hyperlink network analysis of the educational blog. *British Journal of Educational Technology*, 42, 2, E25–E29.
- Luo, J. D. (2011). Guanxi revisited: an exploratory study of familiar ties in a Chinese workplace. *Management and Organization Review*, 7, 2, 329–351.
- Martinez, A., Dimitriadis, Y., Rubia, B., Gómez, E. & De La Fuente, P. (2003). Combining qualitative evaluation and social network analysis for the study of classroom social interactions. *Computers & Education*, 41, 4, 353–368.
- Pilkington, R. M. & Walker, S. A. (2003). Facilitating debate in networked learning: reflecting on online synchronous discussion in higher education. *Instructional Science*, 31, 1–2, 41–63.
- Russo, T. C. & Koesten, J. (2005). Prestige, centrality, and learning: a social network analysis of an online class. *Communication Education*, 54, 3, 254–261.

- Sha, L. & van Aalst, J. (2003). An application of social network analysis to knowledge building. In annual meeting of the American Educational Research Association, Chicago.
- Stubbs, M., Martin, I. & Endlar, L. (2006). The structuration of blended learning: putting holistic design principles into practice. *British Journal of Educational Technology*, 37, 2, 163–175.
- Vandyck, I., de Graaff, R., Pilot, A. & Beishuizen, J. (2012). Community building of (student) teachers and a teacher educator in a school–university partnership. *Learning Environments Research*, 15, 3, 299–318.
- Wasserman, S. & Faust, K. (1997). *Social network analysis: methods and applications*. Cambridge, UK: Cambridge University Press.
- Wellman, B. (1997). An electronic group is virtually a social network. *Culture of the Internet*, 4, 179–205.
- Yeh, Y. C. & Luo, J. D. (2001). Are Virtual Social Relationships independent from Reality? *Journal of Cyber Culture and Information Society*, 1, 33–55.