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Interactive networks and social knowledge construction behavioral patterns in primary school teachers' online collaborative learning activities

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Abstract: A four-stage online collaborative learning approach to supporting teachers' professional development was proposed and described in this paper. This study investigated primary school teachers' interactive networks and social knowledge construction behavioral patterns in online collaborative learning activities. The subject of this study was 83 primary school Chinese teachers who were participating in a structured online professional development program that was 6 months in duration. By combining social network analysis, content analysis and lag sequential analysis, results showed that interactive networks generated in two rounds of online collaborative learning activities were low reciprocal, and loosely connected with a low cohesiveness. There was no significant difference of behavior distributions between core and peripheral members. Moreover, teachers' social knowledge construction behavioral patterns presented different characteristics in different rounds of activities. In addition, this study identified certain problems in teachers' online learning. Finally, some implications for the design of teacher education programs, limitations and further research plans are proposed.

Keywords: computer-mediated communication; cooperative/collaborative learning; learning communities; teaching/learning strategies

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1. Introduction

With the deepening application of Information and Communication Technologies (ICT) in classroom practices, teachers are faced with increasing demands due to educational reforms, changes in the curriculum, and new pedagogical approaches (Tsiotakis & Jimoyiannis, 2016; van den Bergh, Ros, & Beijaard, 2015). Teachers' professional development has been considered as a critical factor for their growth and educational reforms (Chen, Chen, & Tsai, 2009; Matzat, 2013). Teacher professional development programs have provided multiple opportunities for teachers to improve their instructional design knowledge and skills (Chen, 2012; Liu, Zhang, & Wang, 2015). The most traditional and popular approach is that teachers attend a training course and listen passively to experts. Yet, these approaches come out to have low impacts on teachers' faith to put innovative teaching methods into practice (Duncan-Howell, 2010). As a result of the increased demands and the complexity of instructional activities, collaboration and interaction among teachers have become increasingly important.

With the development of internet technology, online learning becomes an important method for teachers' professional development in addition to face-to-face approaches. Online learning offers authentic, flexible, and personalized opportunities for teachers to interact and communicate with each other (Chieu & Herbst, 2016; Duncan-Howell, 2010). Teachers can online discuss evidence of how successful an approach is in the classroom with their colleagues and then decide whether to try the suggested approaches or strategies themselves (Chen et al., 2009; Kent, Laslo, & Rafaeli, 2016). Online learning supports the sharing of educational experiences and co-construction of knowledge by means of fostering effective social interactions (Chen et al., 2009; Hou, 2015). In recent years, Web 2.0 tools, course management systems (CMS) and virtual learning environments

(VLE) such as Moodle are commonly used to build teachers' online learning communities. Teachers have the opportunities to share resources and develop their pedagogical skills and strategies in an online learning community (Chen et al., 2009). While online learning has been one useful strategy to enhance teachers' thinking and practice (Cherrington & Loveridge, 2014), nonetheless, it would be too simple to assume that the implementation of online professional development programs automatically promotes teachers' collaboration and knowledge construction (Vanblaere & Devos, 2016). Collaborative relationship means teachers act on an ongoing basis to develop their knowledge by sharing resources and engaging in critical dialogue (Wenger, McDermott, Snyder, 2002). Majority of teachers in online learning activities exhibit moderate or even low collaborative relationships (Pavo & Rodrigo, 2015; Tsiotakis et al., 2016). Pedagogy and social interaction are key factors of an online learning environment and these factors can be used to facilitate collaboration (Wang, 2008). Many researchers have proposed content analysis schemes to evaluate learner's levels of social knowledge construction during online discussion (Gunawardena, Lowe, & Anderson, 1997; Hou, 2012; Hou, 2015). Social knowledge construction behavioral patterns which mean sequential relationships between each type of coded discussion content can help to understand the whole sequential pattern of discussion in online learning activities. Compared to the research on behavioral patterns in students' online discussions activities, the issue of exploring the behavioral patterns of teachers' online discussion activities has attracted relatively little attention. Teachers' collaborative relationships and social knowledge construction behavioral patterns in an online learning activity are vital because such relationships and patterns can provide insight into the characteristics and limitations of teachers' online learning activities (Lee & Bonk, 2016).

In this study, on the basis of constructivist learning theories and the interactivity design theory, we propose a four-stage online collaborative learning approach, which consisted of two times of discussing lesson plans and two times of discussing classroom teaching. The objective of this study is to investigate collaborative relationships and social knowledge construction behavioral patterns in primary school teachers' online collaborative learning activities.

2. Theoretical framework

In this section, theoretical foundations that support the design of the four-stage online collaborative learning approach are introduced, followed by a detailed description of the four-stage online collaborative learning approach.

2.1 Theoretical foundations

2.1.1 Constructivist learning theories

Constructivist learning theories provide theoretical support for the design and development of the four-stage online collaborative learning approach. Cognitive constructivists argue that knowledge is actively constructed by individual learners rather than transmitted by others, and learners construct meaningful and conceptually functional representations based on their prior experience and new information (Jonassen, 1991; Wang, 2008). Social constructivists, however, argue that

learners construct knowledge collaboratively in processes of information sharing, negotiation, and discussion (Jonassen, Davison, Collins, Campbell, & Haag, 1995; Wenger, 1998). According to cognitive constructivism, online professional development programs must satisfy the learning intention of individual teachers and should be able to provide various leaning activities and opportunities for teachers to reflect and articulate on the content under study and to apply the knowledge learned to teaching practice. In addition, the design of the online learning environment must enable the mentor to scaffold teachers during their learning process. On the other hand, social constructivists suggest a culture of collaboration among teachers be cultivated to support long-term professional development. Teachers' theoretical knowledge and practical knowledge could be effectively coupled when they collaborated with more experienced and knowledgeable colleagues (Krutka, Bergman, Flores, Mason, & Jack, 2014).

2.1.2 Interactivity design

Among the factors in designing an effective online professional development program, interactivity remains a central concern. Educational researchers believe that interaction must be deliberately incorporated into an online learning design (Chou, 2003; Tang & Lam, 2014). Interactivity refers to real-time dynamics and mutual give-and-take between the learner and an instructional system, and his or her technology-enhanced peers (Merrill, Li, & Jones, 1990; Peng, Chou, & Chang, 2008). Interactivity plays an important role in learners' social knowledge construction and the development of cognitive skills. In an online learning environment, there are three interactive relationships, including learner-interface, learner-content, and learner-people interaction (Hillman, Willis, & Gunawardena, 1994; Liaw & Huang, 2000; Wang, 2008). Learner-people interaction refers to the interaction of learner-instructor and the interaction of learner-learner. Sound design of the interactivity of an online learning environment should be able to promote these three types of interaction. With regard to the learner-interface interaction, the online learning environment must grant learners easy access to functions and desired information with a user-friendly interface. A technically interactive online learning environment is essential, for the interaction with the interface serves as the foundation for both interaction with content and interaction with people. In terms of the learner-content interaction, learners should be able to access meaningful and authentic learning contents. Moreover, the online learning environment must allow the learners to add extra materials and resources to share in addition to those provided by moderators. The last but the most important, learners should be able to interact with other members and moderators in an online learning environment. Therefore, the design of the online learning environment should involve authentic tasks and group work to promote learners' interaction with other members and moderators.

2.2 A four-stage online collaborative learning approach

On the basis of constructivist learning theories and the interactivity design theory discussed above, we propose a four-stage online collaborative learning approach which is designed to support teachers' online professional development. This approach consists of two times of discussing lesson plans and two times of discussing classroom teaching (see Fig 1). A study group which consists of a chief teacher and some teachers is a basic unit to complete independently the

four-stage online collaborative learning activity. The chief teacher was selected based on three criteria: 1) teaching experience; 2) subject matter knowledge; and 3) proficiency of using the online learning platform. The chief teacher's duties include: 1) initiating questions and assigning roles, 2) creating and maintaining a friendly, interactive learning environment, and 3) summarizing key points for teachers.

At the beginning of the online collaborative learning activity, the chief teacher makes a plan, selects an authentic topic for discussion and then the plan and topic are posted onto an online learning platform. One teacher (hereafter referred to as Teacher A) is assigned by the chief teacher to submit the lesson plan and the video-recorded classroom teaching process. In addition, the chief teacher selects and uploads three to five reading materials related to the topic. All teachers are also encouraged to upload extra reading materials and resources to share with others.

After the preparation has been completed, Teacher A submits an initial lesson plan based on the topic discussed and his/her teaching experience to the online learning platform. The whole collaborative learning activity is divided into four stages, as described below:

In the first stage, the rest of teachers read online the initial lesson plan submitted by Teacher A. Then, Teacher A explains his/her design of the initial lesson plan, including the teaching objectives, content, organization form, and process. All teachers online discuss the initial lesson plan and propose revision suggestions based on their teaching experience and knowledge. The process of online discussion lasts for one week. At the end of this stage, teacher A refines the lesson plan for the first time based on the revision suggestions and conclusions of the online discussion.

In the second stage, teacher A implements classroom teaching for the first time based on the lesson plan revised in the first stage and video records the classroom teaching process. Next, Teacher A submits the video-recorded classroom teaching process (video episode 1) to the online learning platform. Teacher A can also upload extra materials such as teaching notes, teaching journal, and students' performance by using text and photos. All teachers view the video episode 1 online and reflect on the effects of teaching. Then, each teacher puts forward revision suggestions according to their teaching experience and online discuss with group members for one week. The chief teacher monitors the whole learning process regularly, gives information feedback and summarizes key points of online discussion. At the end of this stage, Teacher A refines the lesson plan for the second time based on the revision suggestions and key points of online discussion.

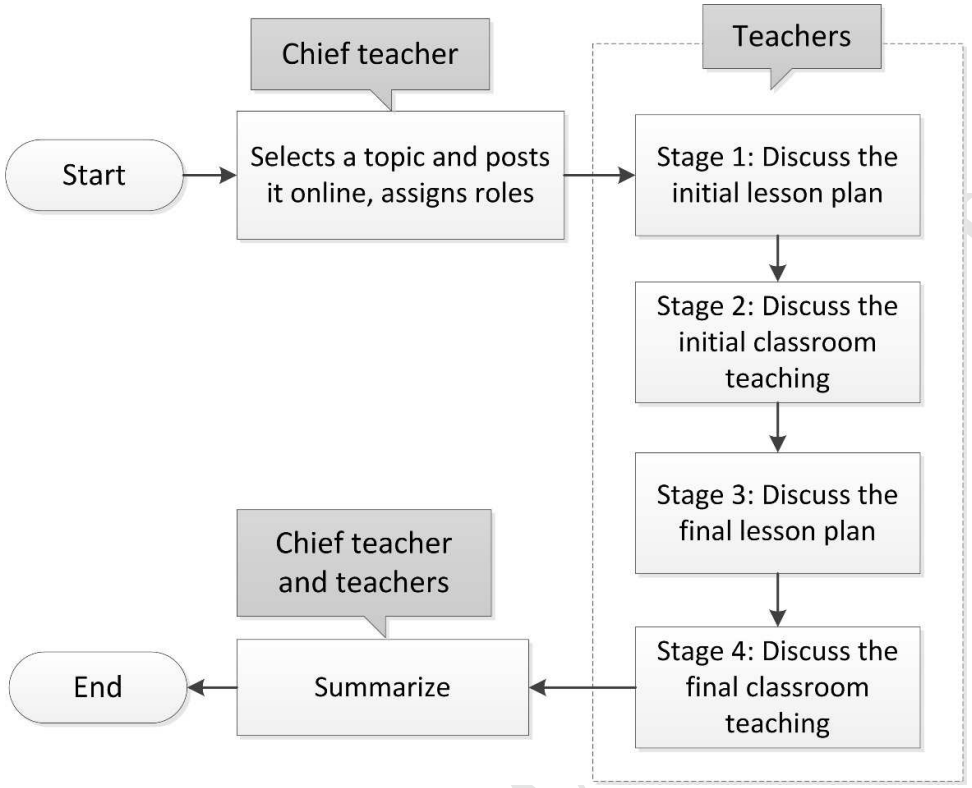

Fig. 1. Procedure of the four-stage online collaborative learning approach

In the third stage, Teacher A submits the revised lesson plan (the final lesson plan) to the online learning platform. All teachers online discuss the final lesson plan and propose suggestions for the implementation of the lesson plan.

In the final stage, Teacher A implements a classroom teaching for the second time based on the final lesson plan submitted in the third stage and video records the classroom teaching process. Next, teacher A submits the video-recorded classroom teaching process (video episode 2) to the online learning platform. All teachers view the video episode 2 online for the second time, discuss the effect of the classroom teaching, and reflect on the final lesson plan. If different opinions about the final lesson plan still existed, teachers can continue the discussion process in the second round of online collaborative learning activities.

This four-stage process takes about one month. After all the stages are completed, the chief teacher and other teachers summarize the result and every teacher submits a journal to the online learning platform.

2.3 Related literature

2.3.1 Collaborative relationships

Online collaborative learning has become more popular as it permits teachers to learn from each

other when they encounter classroom management problems (Cohen-Sayag & Fischl, 2012; Rigelman & Ruben, 2012). Social Network Analysis (SNA) is a major analytical method in educational research to explore collaborative relationships between individuals, groups and communities (Stepanyan, Mather, & Dalrymple, 2014). The basic constructs of SNA are nodes and links. The nodes are social entities such as discrete individuals, collective social units within the network, whereas the links represent relationships among social entities. SNA has been used to investigate the dynamics of the community and group development, the diffusion of information through social networks, and the structure of interrelated Web resources (Stepanyan et al., 2014). SNA studies the structure of the social network by using visual mapping and quantitative techniques for describing network characteristics. The SNA results report five groups of nodes and relationship characteristics: cohesion, role-groups, power of actors, range of influence and brokerage (Yang, Li, Guo, & Li, 2015). Among these characteristics, cohesion and power of actors (centrality) are most commonly used. Cohesiveness indicates the presence of strong socializing relationships in the whole network and the extent to which all members interact with others (Haythornthwaite, 1996). Power of actors (centrality) defines the position of an actor in the network in purely relational terms and indicates which actor or actors are "more or less in demand" in the network (Lee et al, 2016; Pavo et al., 2015). Centrality is a fundamental concept in social network analysis and is used to explain differential performance of communication networks and network members (Borgatti & Everett, 2006). A core is defined as a group of densely connected actors and is characterized by a high density of interrelations in contrast to a more loosely connected class of actors forming the periphery of the network (Borgatti & Everett, 1999). Core members who have a high degree of centrality are the most active and powerful members in the whole network with regard to spreading ideas and influencing others. Peripheral members are less powerful community members and they have marginal contribution to the learning activity. A three-dimensional analytical model was proposed to analyze the structural features of collaborative networks (Lin, Hu, Hu, & Liu, 2016), and results revealed that deep interactions between teachers need to be further strengthened. By using SNA to reveal teachers' interaction structures in an online learning community and exploring the factors of teachers' presence, Tsiotakis et al. (2016) suggested that a more critical understanding of collaborative relationships and information flow would be crucial.

2.3.2 Social knowledge construction behavioral patterns

Content analysis is a research technique for the systematic, objective, and quantitative description of the manifest content of communication and has been used to determine the effect of computer-supported collaborative learning (Rourke & Anderson, 2004). Communication has been segmented into analysis units, codes and their frequencies and percentage used for investigating and analyzing the process of the social knowledge construction (Lan, Tsai, Yang, and Hung, 2012). Many researchers have proposed coding schemes for online discussion content analysis (Chai & Khine, 2006; Gunawardena et al., 1997; Jeong, 2003). Gunawardena et al. (1997) proposed an interaction analysis model (IAM) which consists of five phases of social knowledge construction: 1) sharing or comparing of information of a problem; 2) discovery and exploration of dissonance or inconsistency among ideas, concepts or statements; 3) negotiation of meaning or co-construction of knowledge; 4) testing and modification of proposed synthesis or

co-construction; and 5) agreement statement(s) or applications of newly constructed meaning. The knowledge construction coding items had been widely used in previous research (Hou, Chang, & Sung, 2009; Lan et al., 2012; Lucas, Gunawardena, & Moreira, 2014) and it helped to increase the validity of the content analysis (Hou & Wu, 2011). Content analysis helps to understand the online discussion content by providing data of frequency and percentage. This method, however, provides limited information for us to understand the whole behavioral patterns of community members' social knowledge construction.

Behavioral patterns refer to the sequential relationships between each types of coded discussion content and can be determined by calculating the statistical significance of a behavioral sequence of one certain behavior followed immediately by another. Lag sequential analysis (LSA) helps researchers to examine the statistical significance of a certain behavior being followed by another and a visualized diagram of behavioral patterns can be inferred by using this method (Bakeman & Gottman, 1997). More details of learners' online learning processes and behavioral transition patterns can be revealed through the use of lag sequential analysis of online discussion behavioral. By combining content analysis and LSA to compare and contrast students' social knowledge construction behavioral patterns in a mobile devices-based online asynchronous discussion environment, results showed that students are more engaged in sharing information and reflecting thinking (Lan et al., 2012). Compared to research on behavioral patterns in students' online discussions activities, the issue of exploring the behavioral patterns of teachers' online discussion has attracted relatively little attention. Therefore, it is necessary to further investigate teachers' social knowledge construction behavioral patterns in an online learning environment.

2.3.3 Teachers' perceptions of experiences

Teachers' perceptions of experiences can provide an important perspective on the design features that help support outcomes such as interaction. By interviewing some teachers to understand their perceptions towards an online synchronous discussion environment which was developed to support in-service teachers' web-based professional development, Chen et al. (2009) revealed that the way to use online synchronous interaction tools, the quality of discussion topic, the opportunity for teachers to reflect upon knowledge construction, and the role of online moderators and tutors all affect teachers' interaction and the development of a sense of online learning communities. A specific questionnaire was used to depict teachers' perceptions and views of an online learning community which was developed to support primary and secondary public school teachers' professional development. The results showed that the functionality of a community platform, the stages of teachers' engagement, and the community activities constitute critical design factors for an effective online learning community (Tsiotakis et al., 2016).

In accordance with the research objectives, three research questions to be addressed are as follows:

(1) What are the collaborative relationships in the online collaborative learning activities?
(2) What social knowledge construction behavioral patterns exist in the online collaborative learning activities?
(3) What are the participating teachers' perceptions of experiences in the online collaborative

learning activities?

3. Methodology

3.1 Research design

In order to understand teachers' collaborative relationships, social knowledge construction behavioral patterns, and their perceptions of experiences in online collaborative learning activities, this study went through four main phases (see Fig 2):

1. Phase 1: The design of a four-stage online collaborative learning approach, the development of an Online Professional Development Platform (OPDP);
2. Phase 2: The implementation of two rounds of online collaborative learning activities;
3. Phase 3: Data collection and analysis. All the data, such as posts, interactions and logs were collected according to certain formats. Two analytical approaches, social network analysis and content analysis were used to explore and visualize collaborative relationships, social knowledge construction behavioral patterns of teachers.
4. Phase 4: a questionnaire and in-depth interviews were conducted immediately with teachers to obtain more in-depth information after the two rounds of online collaborative learning activities were finished,. Finally, some conclusions and implications for activity design were proposed.

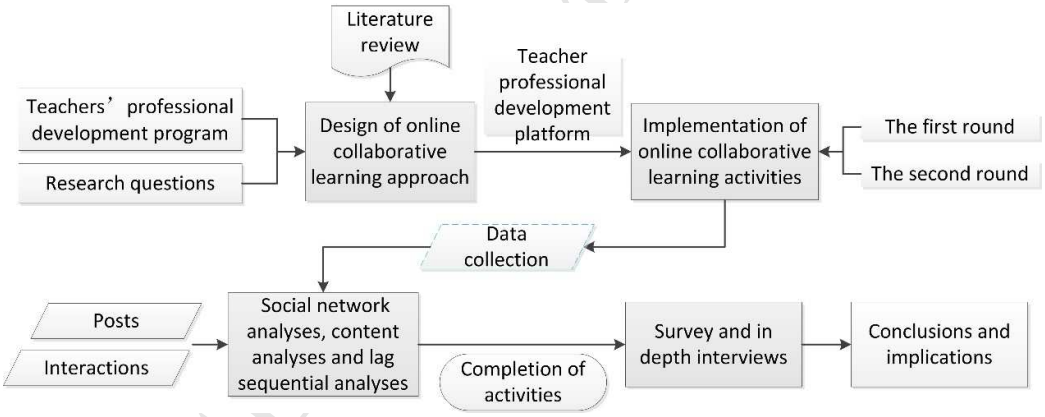

Fig. 2. The research design of this study

3.2 Participants

12000 primary school teachers from a county of China had participated in an online professional development program that was 6 months in duration. The online professional development program was divided into three continuous parts: 1) watching ICT-integrated courses individually (for 2 months), 2) two rounds of online collaborative learning (for 2 months), and 3) submitting an ICT lesson plan or a video-recorded classroom teaching process (for 2 months). These teachers came from different towns of this county. The same as another study (Liu et al., 2015), these teachers were mainly composed of female participants (n=6963, 58%) and had an average of 18.52 years of teaching experience. In order to better manage and provide services, teacher

educators had divided all these teachers into 150 study groups with 70-100 teachers per study group according to teachers' discipline and the towns where these teachers came from. In the 150 study groups, the proportions of study groups with 70-80 teachers was 14% (n=21), with 80-90 teachers was 62% (n=93), and the rest is the study groups with 90-100 teachers (n=36). These study groups were mainly composed of major disciplines (81%), such as Chinese, Math, and English in China. Each study group had to complete independently the two rounds of online collaborative learning activities. A study group was selected for this study. In order to control the possible factors that might influence the result of this study, the study group was selected based on the following three criteria: 1) belonging to major disciplines; 2) having an average size of the study groups; and 3) take into account the two important factors: gender and years of teaching experience. The selected study group consisted of 83 Chinese teachers who had an average of 18.48 years of teaching experience and female teachers were the majority (n=51, 61%). All teachers had accepted online professional development platform's operation training and could complete their learning task smoothly. In addition, schools where these teachers came from had often organized off-line lesson study activities, and these teachers were familiar with the process of the activities.

3.3 Instruments

3.3.1 In-service teachers' online professional development platform

An Online Professional Development Platform (OPDP) for the in-service teachers was developed to support the whole online professional development program (http://guopei.crtvu.edu.cn/cms). Educational courses, resources, asynchronous communication and collaboration tools, such as asynchronous text chat, file uploading and downloading tools were provided in the OPDP. Two rounds of online collaborative learning activities that lasted for two months were an important part of the whole online professional development program. Figure 3 showed the interface of the four-stage online collaborative learning activity in the OPDP. At the beginning, the teachers were trained to view information, post messages, respond to others' postings, upload and download learning materials. And one teacher was recommended as the chief teacher to organize and coordinate the activities. Afterward, all teachers participated in two rounds of online collaborative learning activities and each activity lasted for one month. All interaction data and comments were recorded automatically into the back-end database of OPDP. The chief teacher could publish information and monitor the whole online learning activities. All teachers could online discuss with group members, upload and download files via the interface.

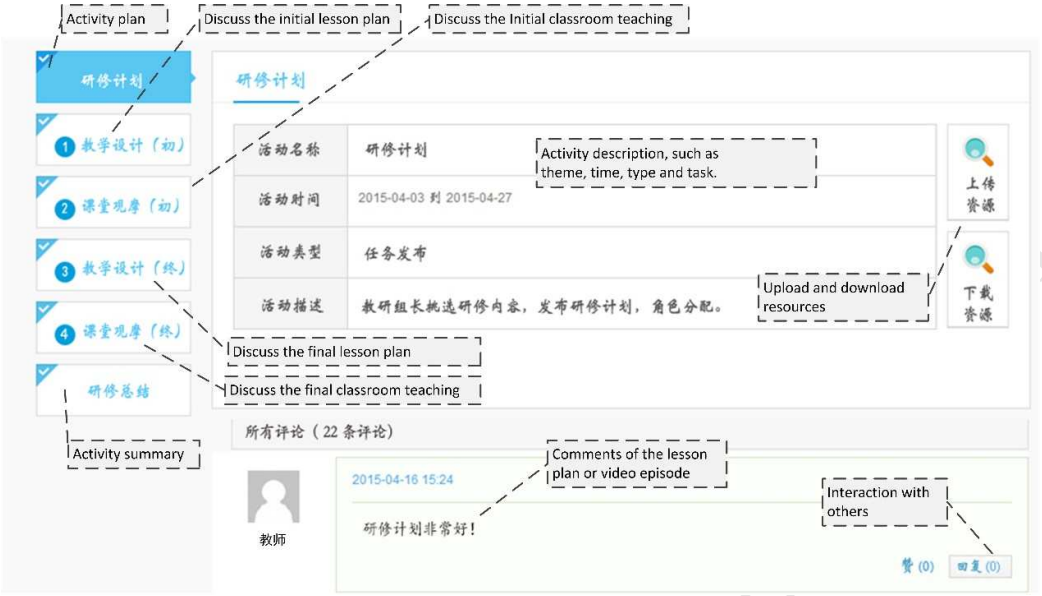

Fig. 3. The interface of the four-stage online collaborative learning activity in the OPDP

3.3.2 Coding Scheme

All interaction data of this group of teachers in the OPDP were collected and coded. The interaction analysis model (IAM), which was developed by Gunawardena et al. (1997), was used to code the online discussion content. In addition to the five phases in IAM, we added a new phase KC6 to represent the contents irrelevant to the learning task (See Table 1). In order to guarantee the validity of this coding scheme, two experts who were proficient in online collaborative learning and learning behavior analysis were invited to check and verify the feasibility of the coding scheme and the corresponding definitions and examples.

Table 1. The coding schemes for online discussion content analysis

Code	Phase	Description	Examples
KC1	Sharing/comparing of information	Presenting new information to other teachers; a statement of agreement between teachers	I think the key points and difficult points of this lesson are “”. I agree with you.
KC2	The discovery and exploration of dissonance or inconsistency	Identifying areas of disagreement; asking and answering questions to clarify disagreement	The analysis of key points of this lesson is problematic. I think teaching methods should be adjusted.
KC3	Negotiation of meaning or co-construction of knowledge	Negotiation or clarification of the meaning of terms; identification of areas of agreement or overlap among conflicting concepts	I have accepted your opinion and revised my lesson plan. I agree with your opinion, and let more students participate in classroom activities.
KC4	Testing and modification of proposed synthesis or co-construction	Testing the proposed new knowledge against existing cognitive schema or personal experience	According to the curriculum standard, the content of this lesson should contain “”. Therefore, I revise the lesson plan.

KC5	Agreement statement(s) / applications of newly-constructed meaning	Summarization of agreements or metacognitive statements that illustrating their understanding	By discussing the lesson plan and classroom teaching, I realize the importance of knowledge in life to Chinese teaching.
KC6	Contents irrelevant to the learning task	A comment that is completely irrelevant to the learning task	This activity is very meaningful. I will actively participate in this activity.

3.4 Data collection and analysis

Two rounds of online collaborative learning activities yielded 763 comments. These comments were exported to a Word document for further content analysis and lag sequential analysis. In order to give a complete picture of collaborative relations of teachers, the interaction data from the comments that teachers had posted and received in the process of collaborative learning were gathered and converted into an adjacency matrix for further SNA. The total number of learner-people interactions in the first round were 109 (57.7% of the total number of comments), while the number of interactions were 405 in the second round (70.6% of the total number of comments).

For the first research question, SNA was used to investigate teachers' collaborative relationships in the two rounds of online collaborative learning activities by using UCINET 6.0. Two indicators, namely, the cohesion and power of actors, were selected to analyze the relationships between nodes in the two rounds of activities. Density was a major statistical descriptor used to represent the level of cohesion in this study. The density of a network refers to the level of linkages among nodes and can be calculated as the ratio of the number of actual links to the number of possible links in a population (Haythornthwaite, 1996). Distance is a commonly used concept in SNA and measures the efficiency of information diffusion. Distance is calculated by the number of links in the shortest possible pathway from one node to another (Han, McCubbins, & Paulsen, 2016). Reciprocity is an index for measuring the tendency of actors to reciprocate. Centrality defines the position of an actor in the network. In a directed network, in-degree centrality means the number of ties coming in, and out-degree centrality means the number of ties going out. The actor with most lines into or out, the core member, is most central. Actors with a few lines into or out, the peripheral members, exhibit a marginal presence. The method of content analysis was combined to explore the difference of behavior distributions between core and peripheral members.

For the second research question, content analysis and LSA were used to explore and visualize the social knowledge construction behavioral pattern. Due to the fact that teachers' posts in the online collaborative learning activities mainly consisted of one sentence, the basic unit of content analysis was a sentence, and every sentence was coded based on its temporal order. In order to ensure the reliability of the behavioral sequence analysis in this study, two researchers skilled at content analysis participated in the two-stage coding process. In the first stage, two coders received coding training and grasped the definitions and examples of items in the coding scheme. Then 200 messages (about one fourth of the total number of messages) were chosen at random for

recording by them. Coding results showed that the inter-rater reliability Kappa was 0.626 ($p<0.01$), which demonstrates fair to good reliability (Fleiss, 1981).

For the third research question, a questionnaire survey and interviews were conducted to investigate teachers' perceptions of their experiences in the online collaborative learning activities. The questionnaire survey consisting of six items (see Table. 2) was implemented online (https://sojump.com/jq/9929155.aspx) after 83 teachers finished the two rounds of online collaborative learning activities. Each questionnaire item adapted from Yang and Lin's (2010) survey and used a 5-point Likert scale ranging from 1 as strongly disagree to 5 as strongly agree. A total of 78 teachers participated in the survey, and the response rate was 94%. Results of the questionnaire were analyzed by using the SPSS statistic software and the reliability of the questionnaire was 0.797 (using Cronbach's alpha), indicating that the internal reliability was sufficient. The Shapiro-Wilk test was used for checking the normality of distributions of six measured items' values and the test results were significant ($p<0.05$), showing six measured items of this questionnaire did not have normal distributions of data.

Table 2. The items of the questionnaire survey.

Question	Shapiro-Wilk test	
	W	P
1. I knew how to get to the next stage by reading the activity plan.	0.781	0.000
2. I carefully read other members' comments on the OPDP.	0.816	0.000
3. I collaborated with other members by actively commenting on their messages.	0.767	0.000
4. I could share teaching materials conveniently with other members on the OPDP.	0.824	0.000
5. I referred to lesson plan or video episode submitted by Teacher A for proof of my explanation to other members.	0.805	0.000
6. I am willing to use the OPDP again to discuss lesson plan with other members.	0.807	0.000

As the questionnaire survey was completed first, its results were used to formulate interview questions. Interview questions probed for perceptions of their experiences in online collaborative learning activities, and main impediments they encountered. Online interviews (each lasting between 20 and 30 min) were conducted with one chief teacher (N=1, female) and ten teachers (female=6, male=4) of the study group using purposeful sampling (Maxwell, 2013) when the two rounds of online collaborative learning activities were finished. The information about the purposefully sampled teachers were provided in Table 3. All participant names were replaced with pseudonyms. The results of questionnaire survey and interviews were combined in the results section organized around the third research question.

Table 3. Demographics of interview participants

Participant	Gender	Grade Level	Years of teaching experience
Chief teacher	Female	6	25+
1	Male	3	16-20
2	Male	5	11-15
3	Female	4	6-10
4	Female	6	21-25

5	Female	2	6-10
6	Female	1	16-20
7	Male	2	11-15
8	Male	4	25+
9	Female	5	16-20
10	Female	3	21-25

4. Results

4.1 What are the collaborative relationships in the online collaborative learning activities?

4.1.1 Network cohesion

The density of the interactive network of the first round of online collaborative learning activities was 0.016, and the value increased to 0.0595 in the next round of activities (see Table 4). The density of the two rounds of activities represented that teachers' collaborative relationships was a low-density network. The teachers in the low density network were in touch with a few members and information could not be distributed freely among all teachers. The mean distance of the network of the first round was 4.858, and the value decreased to 3.248 in the next round of activities which means one teacher could traverse fewer nodes to touch another teacher. The reciprocity of the interactive network in the first round was 0.06, and the value increased to 0.10 in the next round, which showed the network was low reciprocal.

Table 4. Network cohesion of two rounds of online collaborative learning activities

	Density	Mean Distance	Reciprocity
The first round	0.0160	4.858	0.060
The second round	0.0595	3.248	0.100

4.1.2 Network centrality

By applying the Shapiro-Wilk test for checking the normality of distributions (Shapiro & Wilk, 1965) of in-degree and out-degree centrality values, the p-value were 0.000 (1^{st} in-degree centrality), 0.000 (1^{st} out-degree centrality), 0.038 (2st in-degree centrality), 0.000 (2st out-degree centrality), respectively. That is, test results were significant ($p<0.05$), showing samples of this study did not have normal distributions of data. So, a Wilcoxon-Mann-Whitney test (Fay & Proschan, 2010) was used to analyze whether there was any statistically significant difference between the first and second round of online collaborative learning activities in terms of in-degree and our-degree centrality values. Significant differences were found in in-degree ($Z=-3.779$, $p<0.001$) values (see Table 5). In-degree centrality values of individual teachers in the second round significantly increased. The significant change of teachers' positions in the network meant they could receive more information from others.

Table 5. Wilcoxon-Mann-Whitney test result of in-degree and our-degree centrality values

		Mean	Std. dev.	Std. error Mean	Z	P
In-degree	The first round	0.534	0.669	0.073	-3.779	0.000
	The second found	0.992	0.803	0.088		
0ut-degree	The first round	0.534	0.729	0.080	-1.695	0.090
	The second found	0.992	1.442	0.158		

4.1.3 Social network diagram generated in online collaborative learning activities

The social network diagram (see Fig. 4 and Fig. 5) clearly showed the structure and features of the network generated in the two rounds of online collaborative learning activities according to interaction data among teachers. In these figures, nodes represented individual teachers within interactive networks and links showed the relationships among nodes. The mean of the number of comments that individual teachers sent to others in the first round was 1.313, and the value increased to 4.88 in the second round. Thirty teachers had no connection to others in the first round, which means they only received information on the OPDP but had no opportunities to pass on that information. The number of teachers who had no connection with others decreased in the second round.

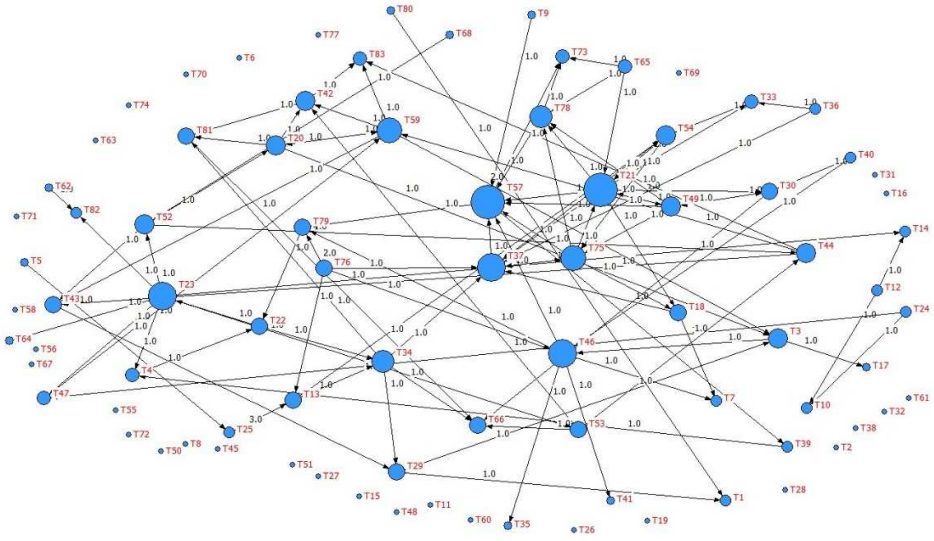

Fig 4. The social network diagram of the first round of activities

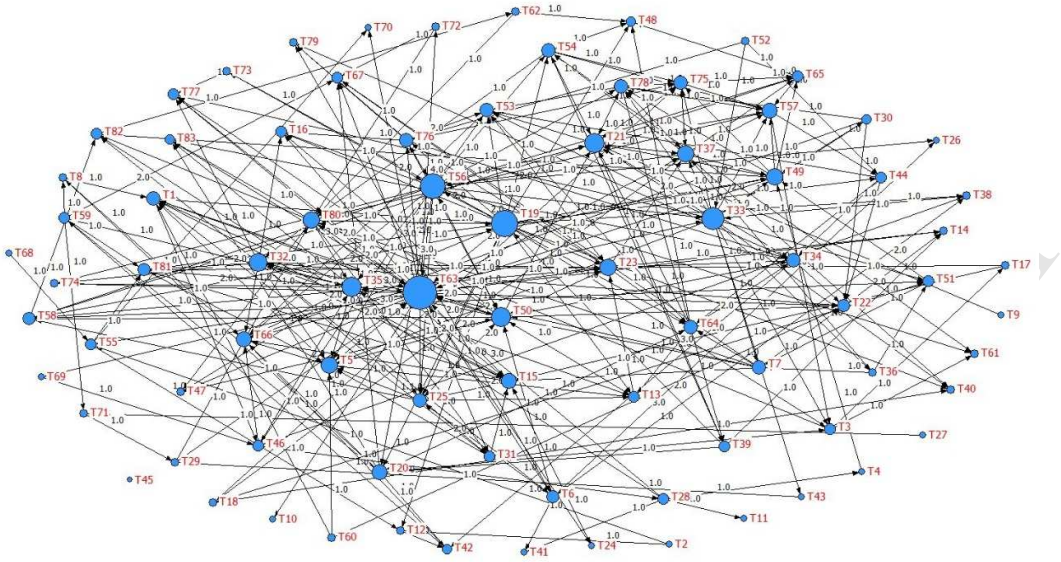

Fig 5. The social network diagram of the second round of activities

4.1.4 The behavior distributions between core and peripheral members

SNA and content analysis were applied to explore the difference of behavior distributions between core and peripheral members and results were shown in Table 6. C-1 to C-8 represented core members, while P-1 to P-8 represented peripheral members.

The total numbers of each behavioral category of core and peripheral members were calculated after content analysis. According to a Chi-Square test result ($X^2(3) = 3.044$, $P > 0.1$), there was no significant difference of behavior distributions between the core and peripheral members. "sharing/comparing of information" (KC1) appeared most frequently which suggests that both core and peripheral members were concerned with sharing and present information to others.

The in-degree centrality demotes the degree of closeness of one teacher perceived by others. The in-degree centrality values of core members (except C-3) were higher in the second round than in the first round. Similarly, the out-degree centrality values of core members were higher in the second round. The teacher (C-3) contributed more to other teachers and received less from others in the second round, which means C-3 became increasingly important. The in-degree centrality values of peripheral members (except P-7 and P-8) were higher in the second round than in the first round. Five peripheral teachers' in-degree centrality was 0 in the first round of activities, which means they did not interact with others but only posted new information. The out-degree centrality values of all 8 peripheral teachers were 0 in the two rounds of online collaborative activities, which indicates that their contribution to the development of interactive network was very little.

Table 6. Behavior distributions of core and peripheral members

Name	In-degree centrality			Out- degree centrality			KC1	KC2	KC3	KC4	KC5	KC6
	1st	2nd	differe	1st	2nd	differe						

	round	round	nce	round	round	nce						
C-1	1.62	3.86	-2.24	2.85	9.35	-6.5	41	0	4	0	0	0
C-2	0.40	0.81	-0.41	2.85	5.69	-2.84	16	4	7	0	0	0
C-3	1.22	0.81	0.41	2.44	4.68	-2.24	23	1	1	0	0	0
C-4	0.81	1.42	-0.61	2.03	4.68	-2.65	12	2	6	0	0	1
C-5	1.22	1.83	-0.61	2.03	3.46	-1.43	13	0	4	0	0	0
C-6	0.41	1.63	-1.22	2.03	2.85	-0.82	12	0	2	0	0	0
C-7	0.81	1.42	-0.61	2.03	2.85	-0.82	12	0	2	0	0	0
C-8	1.22	2.85	-1.63	2.03	2.64	-0.61	13	0	0	0	0	0
P-1	0.41	3.25	-2.84	0	0	0	5	0	0	0	0	0
P-2	0	1.22	-1.22	0	0	0	2	0	0	0	0	0
P-3	0	1.02	-1.02	0	0	0	2	0	0	0	0	0
P-4	0	0.81	-0.81	0	0	0	1	0	0	0	0	0
P-5	0	0.41	-0.41	0	0	0	1	0	0	0	0	0
P-6	0	1.02	-1.02	0	0	0	1	0	0	0	0	0
P-7	0.81	0.41	0.4	0	0	0	1	0	0	0	0	0
P-8	1.22	1.02	0.2	0	0	0	1	0	0	0	0	0

Note. "C-1" means the first core member of the network, and "P-1" means the first peripheral member of the network.

4.2 What social knowledge construction behavioral patterns exist in the online collaborative learning activities?

To answer the second question, we conducted LSA by using GSEQ 5.1 to analyze social knowledge construction behavioral patterns in different rounds of online collaborative learning activities (Hou, 2012; Lai & Hwang, 2015). Table 7 shows frequency and percentage of each behavioral category across the two rounds of activities. Results showed that "sharing/comparing of information" (KC1) was the most-frequent behavior (95%) in the first round, while "Testing and modification of proposed synthesis or co-construction" (KC4) and "Agreement statement(s) / applications of newly-constructed meaning" (KC5) were missing. Similarly, in the second round, "sharing/comparing of information" (KC1) was the most-frequent behavior (79%), while "Testing and modification of proposed synthesis or co-construction" (KC4) was least frequently used (1%).

Table 7. Frequencies of social knowledge construction behavior in two rounds of activities

	KC1	KC2	KC3	KC4	KC5	KC6	Total
The first round	180(95%)	2(1%)	6(3.5%)	0	0	1(0.5%)	189
The second round	453(79%)	34(6%)	43(7%)	5(1%)	27(5%)	12(2%)	574
Total	633	36	49	5	27	13	763

The frequency of each behavioral category immediately following another behavioral category was calculated (see Table. 8). The second column represents starting behaviors and the first row represents follow-up behaviors. The numbers in Table 8 represent the total number of times of one behavior followed by another. For example, in the first round, the frequency of starting behavior

KC1 followed by KC1 was 171 and the frequency of starting behavior KC2 followed by KC1 was 2.

Table 8. Frequency transition table in the two rounds of activities

	Frequency	KC1	KC2	KC3	KC4	KC5	KC6
The first round	**KC1**	171	2	5	0	0	1
	KC2	2	0	0	0	0	0
	KC3	5	0	1	0	0	0
	KC4	0	0	0	0	0	0
	KC5	0	0	0	0	0	0
	KC6	1	0	0	0	0	0
The second round	**KC1**	345	32	35	5	23	12
	KC2	31	0	1	0	2	0
	KC3	34	2	6	0	1	0
	KC4	4	0	0	0	1	0
	KC5	26	0	1	0	0	0
	KC6	12	0	0	0	0	0

We calculated adjusted residuals (Z-scores) among coded behaviors of teachers, and the significance level of each behavioral sequence indicated overall social knowledge construction behavioral patterns in online collaborative learning activities (Bakeman et al., 1997). Table 9 showed the adjusted residuals (Z-scores) of the two rounds of activities. The second column represented starting behaviors and the first row represented follow-up behaviors. The z-score value greater than +1.96 indicated a behavioral sequence reaches the level of significance ($p<0.05$), from which we can obtain the behavior transition diagrams (see Figure 6).

In Figure 6, nodes represented six behavioral categories (KC1 to KC6), the numerical value (Z-scores) represented the significance level, and the arrowhead represented the behavioral transitional direction. As shown in Figure 6, no remarkable behavioral sequence existed in the first round. Nevertheless, two behavioral sequences were obtained in the second round, that was, KC1-KC2 and KC5-KC1. In the second round the path KC1→KC2 (Z-score = 2.24) means that when one teacher proposed and shared information on the OPDP, the rest of teachers tended to discover and explore inconsistency. The behavioral path KC5→KC1 (Z-score = 2.27) meant that teachers would like to summarize the views of others and then generate new ideas. The results suggested that in the second round, teachers could focus on the subject of discussion, posted different views and obtained useful and meaningful information.

Table 9. Adjusted residuals table (Z-scores)

	Z-score	KC1	KC2	KC3	KC4	KC5	KC6
The first round	**KC1**	0.91	0.32	-1.39	0	0	0.22
	KC2	0.32	-0.15	-0.26	0	0	-0.10
	KC3	-1.39	-0.26	1.91	0	0	-0.18
	KC4	0	0	0	0	0	0
	KC5	0	0	0	0	0	0

	KC6	0.22	-0.10	-0.18	0	0	-0.07
The second round	**KC1**	-2.90	**2.24***	0.42	1.16	0.82	1.81
	KC2	1.81	-1.51	-1.04	-0.56	0.33	-0.88
	KC3	0.03	-0.37	1.67	-0.64	-0.77	-1.00
	KC4	0.06	-0.56	-0.64	-0.21	1.62	-0.33
	KC5	**2.27***	-1.34	-0.77	-0.50	-1.18	-0.78
	KC6	1.81	-0.88	-1.00	-0.33	-0.78	-0.51

*Note. * p<0.05.*

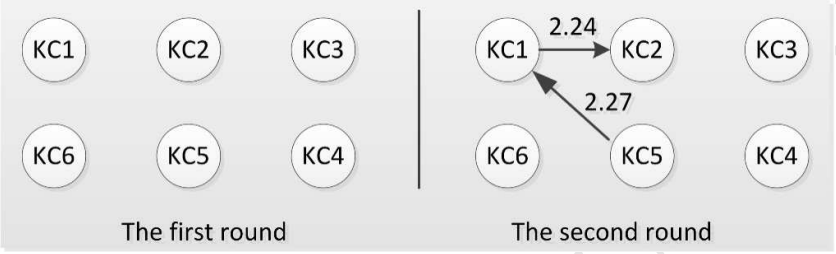

Fig 6. Behavioral transition diagrams in two rounds of activities

Note. KC1 : "Sharing/comparing of information". KC2 : "The discovery and exploration of dissonance or inconsistency". KC3 : "Negotiation of meaning or co-construction of knowledge". KC4 : "Testing and modification of proposed synthesis or co-construction". KC5 : "Agreement statement(s) / applications of newly-constructed meaning". KC6 : "Contents irrelevant to the learning task". Numerical values (Z-scores) represent the significance level, and the arrowhead represents the behavioral transitional direction.

4.3 What are the participating teachers' perceptions of experiences in the online collaborative learning activities?

Descriptive statistics were used to analyze the results of questionnaire survey regarding perceived experiences of online collaborative learning activities (see Table. 10). The sample means were higher than 3 which showed that these teachers took a positive attitude to the environment of the OPDP and the design of online discussion activities. Teachers of the sample had lowest perceptions on the learner-content interaction (Q5, Mean=3.75) and then the learner-learner interaction (Q3, Mean=3.85). In the meantime, the majority of teachers of the sample tended to have the strongest sense in terms of the plan of the online learning activities (Q1, Mean=4.32) and the usefulness of the online learning environment (Q6, Mean=4.20).

Table 10. The descriptive data of the questionnaire survey.

Question	Mean	Std. dev.	Point ≥ 4
1	4.32	0.730	88%
2	4.17	0.746	82%
3	3.85	0.605	75%
4	4.12	0.756	80%
5	3.75	0.706	71%
6	4.20	0.727	85%

Interviews were conducted to get a deeper understanding of problems teachers encountered, their experiences and feeling about online collaborative learning activities. Most of the interviewed teachers pointed out that the four-stage online collaborative learning approach was better than previous training methods and the online collaborative learning environment did provide them a way to share education resources, exchange information, and correlate theories with practices:

*Different from the previous training methods which paid more attention to operating skills and test score, the four-stage online collaborative learning approach lets me have more opportunities to discuss problems in teaching with colleagues and make practical use of knowledge. This will authentically improve my teaching skills and knowledge (*Teacher 1*).*

*The ODPD (Online Professional Development Platform) is new to me. It is a very good platform because I can find useful educational resources there (*Teacher 3*).*

*I can upload and download learning resources conveniently on the OPDP. I can log into the ODPD by using my mobile telephone and communicate with others anywhere and anytime (*Teacher 4*).*

*I have improved my teaching skills and knowledge by discussing with others and I am willing to test innovative teaching methods provided by others into practice (*Teacher 6*).*

*I have learned to look at the theories behind lesson plans, and see some connections between theories of learning and teaching practices in school (*Teacher 9*).*

Although the questionnaire survey showed that the majority of teachers of the sample took a positive attitude to the environment of the OPDP and the design of online discussion activities, some teachers admitted during the interviews that the main problem they encountered was how to solve the contradiction of teaching tasks and personal learning:

*I am teaching two classes. In addition to this, I am the head teacher of one of the two classes at the same time. I can only participate in the online collaborative learning activities in the evening of workday or in the weekend (*Teacher 2*).*

*Apart from completing the basic teaching task, I need to do some educational and scientific research to promote the development of Chinese education. I don't know how to combine my teaching task and this online professional development program (*Teacher 7*).*

Despite questionnaire survey data showing high scores in perceived experiences of online learning and platform operation, a majority of teachers pointed out that some aspects were helpful for online learning activities:

*If I can identify sections of the online discussion (threads and sub-threads) as coherent units and use such information to make decisions about which posts to give comments, I will be better to participate in the online discussion (*Teacher 5*).*

*If the topic of online discussion is related to teaching problems in my class, I will be more interested in this topic and actively participate in the online discussion (*Teacher 8*).*

*If the chief teacher can pay attention to me and provide help for me when I encounter problems during the online learning activities, I will actively participate in the activities (*Teacher 10*).*

These thoughts were echoed by the chief teacher who said, "The main problems I encountered were how to: 1) select an authentic topic which could arouse teachers' interest, 2) pay attention to the difference between teachers, 3) monitor the learning process regularly because of her busy schedule, and 4) summarize key points accurately and timely." This suggested that appropriate

skills were needed for the chief teacher.

5. Discussion

The interactive networks generated in the two rounds of online collaborative learning activities were loosely connected and had very low reciprocity. Majority of teachers exhibited low rates of interaction (Hou et al., 2009; Wenger et al., 2002). Although the interaction was limited, the teachers of the sample agreed that the adoption of the four-stage online collaborative learning approach in OPDP expanded their learning experience and positively contributed to their professional development. At the beginning of the professional development program, the teachers were connected by the active task and their disciplinary major. Along with the participation of the online collaborative learning activities, the teachers became acquainted with each other and they posted and received more information. The in-degree centrality of each teacher significantly increased at the end of second round of activities compared to that at the beginning. The OPDP was designed and developed to support teachers' online collaboration, however, an effective online collaborative learning atmosphere was not established. Some teachers contributed no information, which adversely affected the collaboration willingness and attitude of others. Some teachers preferred to post initial messages (i.e., posts that did not have parent post) on the platform (Chieu et al, 2016). Beyond that, some similar comments appeared multiple times on the OPDP, e.g., "I agree with you." "You are so right that I couldn't agree more". These issues will prevent the formation of an online learning community which promotes teachers' collaboration and engagement. Based on the constructivist learning theories and interactivity design theory, we can conclude that a beneficial interaction depends on teachers' active interaction with content and with others. In order to achieve this, teachers firstly need to read comments posted by other teachers carefully and actively reflect on the meaning of these comments (proactive interaction with content). Then they need to elaborate on their ideas and experiences and actively interact with others. So, a beneficial interaction is a multiple, reciprocal and iterative process in which each iteration is essentially circular – each interaction receives input from, and provides output to, another interaction (Hou, 2015). In addition, the chief teacher is a key role and needs to possess appropriate skills (Wang, 2008), including initiating questions, keeping discussions focused, giving actively feedback, setting up norms, monitoring regularly, and providing technical assistance. Peripheral members only post new information on the online learning platform and rarely respond to the comments of others, so their contribution to the development of interactive network was limited. Besides stimulating the involvement of peripheral members in online learning activity, building a sense of community for peripheral members is a critical element (Tsiotakis et al., 2016). Peripheral members must feel obliged to reply, distribute knowledge and experience, and support each other.

Teachers' social knowledge construction behavioral patterns presented different characteristics in the two rounds of online collaborative learning activities. The behavioral sequences (e.g., KC1→KC2, KC5→KC1) were helpful for the teachers to construct knowledge. As for the high ratio of K1, this was in line with previous studies, which indicated that knowledge construction in the online collaborative learning process concentrated mostly in K1 (Gunawardena et al., 1997; Hou et al., 2012). KC6→KC6 did not appear indicated that teachers actively shared knowledge and

experience and seldom used the online platform for other social purposes (Rolando, Salvador, Souza, & Luz, 2014). Moreover, teachers attempted to provide more information about teaching plans and share information with other teachers to complete training tasks, rather than spend extra time to promote in-depth understanding of the comments posted by others. For the high level knowledge construction, behavioral sequences of KC1→KC3, KC2→KC3, KC3→KC4, KC3→KC5 should also be encouraged to occur. For example, after sharing or comparing information, teachers began to explore knowledge implications which was helpful for them to construct knowledge meaning. In this regard, we recommend the chief teacher and moderators to be aware of the appropriate interactive strategies such as peer coaching (Britton & Anderson, 2010; Lu, 2010) and peer assessment (Lynch, McNamara, & Seery, 2012). In addition, some intelligent agents, which can provide instant messages or hints through semantic and behavior analysis, should be integrated into the OPDP to promote knowledge construction.

6. Conclusion

This study proposed a four-stage online collaborative learning approach and investigated collaborative relationships and social knowledge construction behavioral patterns of primary school teachers in an online professional development program. By combining SNA, content analysis, and LSA, results showed that interactive networks generated in the two rounds of online collaborative learning activities were low reciprocal, and loosely connected with a low cohesiveness. There was no significant difference of behavior distributions between the core and peripheral members. In different rounds of online collaborative learning activities, teachers' social knowledge construction behavioral patterns presented different characteristics. Remarkable behavioral sequences were not found in the first round. Nevertheless, two behavioral sequences of social knowledge construction were obtained in the second round, that is, KC1-KC2 and KC5-KC1. Our findings contribute to the current understanding of teachers' online learning and the design and implementation of the online professional development program.

In this study, we discovered an obvious issue. The participating teachers took a positive attitude to the environment of the OPDP and the design of online collaborative learning activities, and they were also willing to positively comment. However, these teachers' in-depth interaction did not appear. Some possible factors, such as teachers' lack of personal learning time, weak online discussion skills, and the chief teacher's shortage of organizational ability, might be the main barriers affecting teachers' levels of interaction and social knowledge construction. An efficient and convenient ubiquitous learning environment which provides a variety of online synchronous and asynchronous discussion tools and support might be helpful for addressing this issue (Trust, Krutka, & Carpenter, 2016).

6.1 Limitations and future directions

Some limitations existed in this study. Firstly, there might have some face-to-face interaction during the 2-month online collaborative learning activities but this study was unable to capture the evidence of non-online interactions that were relevant to teachers' online learning behaviors. For example, some teachers in a study group might work in the same school and these teachers'

everyday non-online contact might influence their online interactions. In the future, we will synthesize online and non-online interactions to understand teachers' online learning behaviors. Secondly, because of the limited sample, we could not infer statistically that all the participants of the online professional development program took a positive attitude to the environment and the design of online collaborative learning activities. The fact that in-depth interaction did not appear was an important aspect need to be deeply explored and verified in future research. Thirdly, we did not analyze the relationships between interactive network characteristics, social knowledge construction behavioral patterns and learning performance. Future studies need expand the number of samples in order to make results more representative. A comparative study investigating relationships between teachers' collaborative relationships, social knowledge construction behavioral patterns and learning performance by setting up the control group will provide richer insights about teachers' online learning. We plan to divide the group into several sub-groups of 4-6 teachers per group. Fourthly, we did not distinguish whether a respondent was Teacher A who was responsible for submitting lesson plans and video episodes or the remaining teachers of the study group. Hence, we did not explore the relationship between the core and periphery membership and teachers' status. The relationship between the core and periphery membership and teachers' status is an important aspect, which will be further explored and verified in future research.

References

Bakeman, R., & Gottman, J. M. (1997). Observing interaction: An introduction to sequential analysis (2 edition). UK: Cambridge University Press.

Borgatti, S. P., & Everett, M. G. (1999). Models of core/periphery structures. Social Networks, 21, 375-395.

Borgatti, S. P., & Everett, M. G. (2006). A graph-theoretic perspective on centrality. Social Networks, 28, 466-484.

Britton, L.R., & Anderson, K. A. (2010). Peer coaching and pre-service teachers: Examining an underutilized concept. Teaching and Teacher Education, 26, 306-314.

Chai, C. S., & Khine, M. S. (2006). An analysis of interaction and participation patterns in online community. Educational Technology & Society, 9(1), 250-261.

Chen, W. C. (2012). Professional growth during cyber collaboration between pre-service and in-service teachers. Teaching and Teacher Education, 28, 218-228.

Chen, Y. H., Chen, N. S., & Tsai, C. C. (2009). The use of online synchronous discussion for web-based professional development for teachers. Computers & Education, 53(4), 1155-1166.

Cherrington, S., & Loveridge, J. (2014). Using video to promote early childhood teachers' thinking and learning. Teaching and Teacher Education, 41, 42-51.

Chieu, V. M., & Herbst, P. (2016). A study of the quality of interaction among participants in online animation-based conversations about mathematics teaching. Teaching and Teacher

Education, 57, 139-149.

Chou, C. (2003). Interactivity and interactive functions in web-based learning systems: a technical framework for designers. British Journal of Educational Technology, 34(3), 265-279.

Cohen-Sayag, E., & Fischl, D. (2012). Reflective writing in pre-service teachers' teaching: what does it promote? Australian Journal of Teacher Education, 37(10), 20-36.

Duncan-Howell, J. (2010). Teachers making connections: online communities as a source of professional learning. British Journal of Educational Technology, 41(2), 324-340.

Fleiss, J. L. (1981). Statistical methods for rates and proportions (2 edition). New York: John Wiley.

Fay, M. P., & Proschan, M. A. (2010). Wilcoxon-Mann-Whitney or t-test? On assumptions for hypothesis tests and multiple interpretations of decision rules. Statistics Surveys, 4, 1-39.

Gunawardena, C. N., Lowe, C. A., & Anderson, T. (1997). Analysis of 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.

Han, G., McCubbins, O. P., & Paulsen, T. H. (2016). Using Social Network Analysis to Measure Student Collaboration in an Undergraduate Capstone Course. NACTA Journal, 60(2), 176-182.

Haythornthwaite, C. (1996). Social network analysis: an approach and technique for the study of information exchange. Library & Information Science Research, 18(4), 323-342.

Hillman, D. C. A., Willis, D. J., & Gunawardena, C. N. (1994). Learner-interface interaction in distance education: An extension of contemporary models and strategies for practitioners. The American Journal of Distance Education, 8(2), 30-42.

Hou, H. (2015). What makes an online community of practice work? A situated study of Chinese student teachers' perceptions of online professional learning. Teaching and Teacher Education, 46, 6-16.

Hou, H. T. (2012). Exploring the behavioral patterns of learners in an educational massively multiple online role-playing game (MMORPG). Computers & Education, 58, 1225-1233.

Hou, H. T., & Wu, S. Y. (2011). Analyzing the social social knowledge construction behavioral patterns of an online synchronous collaborative discussion instructional activity using an instant messaging tool: A case study. Computers & Education, 57(2), 1459-1468.

Hou, H. T., Chang, K. E., & Sung, Y. T. (2009). Using blogs as a professional development tool for teachers: analysis of interaction behavioral patterns. Interactive Learning Environments, 17(4), 325-340.

Jeong, A. C. (2003). The sequential analysis of grout interaction and critical thinking in online threaded discussions. The American Journal of Distance Education, 17(1), 25-43.

Jonassen, D. H. (1991). Objectivism versus Constructivism: Do we need a new philosophical paradigm? Educational Technology Research and Development, 39(3), 5-14.

Jonassen, D., Davidson, M., Collins, M., Campbell, J., & Haag, B. B. (1995). Constructivism and computer-mediated communication in distance education. The American Journal of Distance Education, 9(2), 7-26.

Kent, C., Laslo, E., & Rafaeli, S. (2016). Interactivity in online discussions and learning outcomes. Computers & Education, 97, 116-128.

Krutka, D. G., Bergman, D. J., Flores, R., Mason, K., & Jack, A. R. (2014). Microblogging about teaching: Nurturing participatory cultures through collaborative online learning with pre-service teachers. Teaching and Teacher Education, 40, 83-93.

Lai, C. L., & Hwang, G. J. (2015). A spreadsheet-based visualized Mindtool for improving students' learning performance in identifying relationships between numerical variables. Interactive Learning Environments, 23(20), 230-249.

Lan, Y. F., Tsai, P. W., Yang, S. H., & Hung, C. L. (2012). Comparing the social social knowledge construction behavioral patterns of problem-based online asynchronous discussion in e/m-learning environments. Computer & Education, 59, 1122-1135.

Lee, J., & Bonk, C. J. (2016). Social network analysis of peer relationships and online interactions in a blended class using blogs. Internet and Higher Education, 28, 35-44.

Liaw, S. S., & Huang, H. M. (2000). Enhancing interactivity in web-based instruction: A review of the literature. Educational Technology, 40(3), 41-45.

Lin, X. F., Hu, X. Y., Hu, Q. T., & Liu, Z. C. (2016). A social network analysis of teaching and research collaboration in a teachers' virtual learning community. British Journal of Educational Technology, 47(2), 302-319.

Liu, Q. T., Zhang, S., & Wang, Q. Y. (2015). Surveying Chinese In-Service K12 Teachers' Technology, Pedagogy, and Content Knowledge. Journal of Educational Computing Research, 53(1), 55-74.

Lu, H. L. (2010). Research on peer coaching in pre-service teacher education – A review of literature. Teaching and Teacher Education, 26, 748-753.

Lucas, M., Gunawardena, C., & Moreira, A. (2014). Assessing social construction of knowledge online: A critique of the interaction analysis model. Computers in Human Behavior, 30, 574-582.

Lynch, R., McNamara, P. M., & Seery, N. (2012). Promoting deep learning in a teacher education programme through self- and peer-assessment and feedback. European Journal of Teacher Education, 35(2), 179-197.

Matzat, U. (2013). Do blended virtual learning communities enhance teachers' professional

development more than purely virtual ones? A large scale empirical comparison. Computers & Education, 60(1), 40–51.

Maxwell, J. A. (2013). Qualitative research design: An interactive approach (3 ed.). Los Angeles, CA: Sage.

Merrill, D., Li, Z., & Jones, M. (1990). Second generation instructional design. Educational Technology, 30(2), 7-15.

Pavo, M. Á. H., & Rodrigo, J. C. (2015). Interaction analysis of a blog/journal of teaching practice. Internet and Higher Education, 27, 32-43.

Peng, H. Y., Chou, C., & Chang, C.-Y. (2008). From virtual environments to physical environments: exploring interactivity in ubiquitous-learning systems. Educational Technology & Society, 11(2), 54-66.

Rigelman, N. M., & Ruben, B. (2012). Creating foundations for collaboration in schools: Utilizing professional learning communities to support teacher candidate learning and visions of teaching. Teaching and Teacher Education, 28, 979-989.

Rolando, L. G. R., Salvador, D. F., Souza, A. H. S., & Luz, M. R.M. P. (2014). Learning with their peers: Using a virtual learning community to improve an in-service Biology teacher education program in Brazil. Teaching and Teacher Education, 44, 44-55.

Rourke, L., & Anderson, T. (2004). Validity in quantitative content analysis. Educational Technology Research and Development, 52(1), 5-18.

Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). Biometrika, 52(3/4), 591-611.

Stepanyan, K., Mather, R., & Dalrymple, R. (2014). Culture, role and group work: A social network analysis perspective on an online collaborative course. British Journal of Educational Technology, 45(4), 676-693.

Tang, E., & Lam, C. (2014). Building an effective online learning community (OLC) in blog-based teaching portfolios. Internet and Higher Education, 20, 79-85.

Trust, T., Krutka, D. G., & Carpenter, J. P. (2016). “Together we are better”: Professional learning networks for teachers. Computers & Education, 102, 15-34.

Tsiotakis, P., & Jimoyiannis, A. (2016). Critical factors towards analyzing teachers’ presence in on-line learning communities. Internet and Higher Education. 28, 45-58.

Vanblaere, B., & Devos, G. (2016). Relating school leadership to perceived professional leaning community characteristics: A multilevel analysis. Teaching and Teacher Education, 57, 26-38.

van den Bergh, Ros, A., & Beijaard, D. (2015). Teacher learning in the context of a continuing professional development program: A case study. Teaching and Teacher Education. 47, 142-150.

Wang, Q. Y. (2008). A generic model for guiding the integration of ICT into teaching and learning. Innovations in Education and Teaching International, 45(4), 411-419.

Wenger, E. (1998). Communities of practice: Learning, meaning and identity. New York: Cambridge University Press.

Wenger, E., McDermott, R., & Snyder, W. (2002). Cultivating communities of practice: A guide to managing knowledge. Boston: Harvard Business School Press.

Yang, X. M., Li, J. H., Guo, X. S. & Li, X. J. (2015). Group interactive network and behavioral patterns in online English-to-Chinese cooperative translation activity. Internet and Higher Education, 25, 28-36.

Yang, J. C., & Lin, Y. L. (2010). Development and evaluation of an interactive mobile learning environment with shared display groupware. Educational Technology & Society, 13(1), 195-207.

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Hightlights:

(1) A four-stage online collaborative learning approach to supporting in-service teachers' professional development was proposed.

(2) Interactive networks were low reciprocal and loosely connected with a low cohesiveness.

(3) There was no significant difference of behavior distributions between core and peripheral members.

(4) Social knowledge construction behavioral patterns presented different characteristics in different rounds of activities.