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Exploring primary school teachers' technological pedagogical content knowledge (TPACK) in online collaborative discourse: An epistemic network analysis

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Abstract

The contextual influences on technological pedagogical content knowledge (TPACK) enactment and the method of TPACK assessment remain to be important research topics. Discourse data of 81 teachers in an online professional learning community were collected and analyzed based on the framework of TPACK. Frequency distribution and time series characteristics of teachers' knowledge domains were analyzed. In addition, epistemic network analysis was used to compare the epistemic network characteristics of teachers in the higher-score and the lower-score groups, different age groups, and post and reply groups. Results showed that teachers' knowledge domains enacted in the context of online discourse were mainly pedagogical content knowledge and general pedagogical knowledge. The teachers in the higher-score group had a rich, organized and flexible knowledge structure of TPACK. Younger teachers had more connections between pedagogical knowledge and pedagogical content knowledge, while senior teachers had more connections between technological knowledge and pedagogical knowledge. The teachers in the reply group had more connections among the different categories of knowledge as compared to the post group. Finally, implications, limitations and future research were discussed.

Introduction

Teacher training is critical to improve teachers' teaching ability and students' academic performance (Spear & da Costa, 2018; Tsiotakis & Jimoyiannis, 2016). The UNESCO and countries around the world all put great effort to teacher training and adopt various ways to promote professional development of teachers (Ariffin, Bush, & Nordin, 2018; Barnes, Zuilkowski, Mekonnen, & Ramos-Mattoussi, 2018; Kim, Jung, & Lee, 2008). Closely related to the influence of information technology on education are changes in the content, methods, resources and environments of teacher training programs (Lin, Hu, Hu, & Liu, 2016). Web-based training that is available anytime and anywhere has become the main way of teacher training in recent years (Jiménez & O'Shanahan, 2016; Kao & Tsai, 2009). Teacher training institutions have made use of web 2.0

Practitioner Notes

What is already known about this topic

- The TPACK framework is used to analyze teachers' knowledge in technology integration practices.
- Most studies use self-report instruments, open-ended questionnaires, and interviews to measure and investigate teachers' TPACK.

What this paper adds

- Teachers' TPACK enactment in online discourse was investigated.
- Epistemic network analysis (ENA) was used to compare the salient properties of knowledge networks generated by different groups of teachers.

Implications for practice

- In the middle stage of the online discourse, some support should be delivered to trainee teachers before they stop participating in the activity.
- Research related to TPACK should pay attention to both the frequency distribution and interplay of the knowledge domains.
- Analyzing the network structure of TPACK formed in online discourse is helpful for understanding the nature and key factors affecting the development of TPACK.

tools, such as social media, learning management systems and course management systems, to provide teachers with online learning environments. Such environments allow teachers discuss teaching problems and share education resources and experience online (Beach, 2017; Ching & Hursh, 2014). Teacher training institutions actively build the online professional learning community (OPLC) according to the theories of social constructivism and practice of community (Cho, 2016; Patton & Parker, 2017; Tsiotakis & Jimoyiannis, 2016). During the process of online collaborative discourse in OPLC, teachers constantly reflect on technology integration practices (Tseng, Cheng, & Yeh, 2019). Online discourse is an important source of measuring and evaluating teachers' technological pedagogical content knowledge (TPACK) (Koehler, Mishra, & Yahya, 2007). Some evidence suggests a positive correlation between teachers' TPACK and their technology integrated teaching plans (Akyuz, 2018) and discourse (Koehler *et al.*, 2007). Teachers' TPACK enactment is often context-specific, and can be affected by teaching levels, delivery formats and assessment methods. So far, only a few studies analyze teachers' discourse about technology integration from the perspective of TPACK. Our understanding about the relationship between the knowledge domains of TPACK is still far from conclusive (Cheng & Xie, 2018; Tseng *et al.*, 2019). Epistemic network analysis (ENA) treats domain expertise not as a set of isolated knowledge, skills and processes, but as a network of connections among knowledge, skills and decision-making processes (Csanadi, Eagan, Kollar, Shaffer, & Fischer, 2018). ENA is well suitable for modeling patterns of association in any domain expertise characterized by complex, dynamic relationships among a group of elements (Andrist, Ruis, & Shaffer, 2018). ENA can help us to take an integrated view of TPACK, rather than seeing its components as isolated ones.

Based on the TPACK framework, this study analyzed the frequency distribution and time series characteristics of teachers' knowledge domains in the online discourse. In addition, ENA was used to compare the salient properties of knowledge networks generated by different groups of teachers.

Literature review

Teachers' discourse in the online professional learning community

The teacher training mode has experienced several development stages, from the face-to-face training, the workplace-based training, to the current web-based training (Jonker, März, & Voogt, 2018). The development of information technology has provided many kinds of convenient ways for teachers to participate in online training. Teachers can communicate with subject experts without time and space limitation (Chen, Chen, & Tsai, 2009; Duncan-Howell, 2010; Lin *et al.*, 2016). Web-based training cannot only ensure the connection between teachers and subject experts, but also promote teachers to apply the knowledge they learned into their classroom teaching (Trust, Krutka, & Carpenter, 2016). Teacher training institutions use social software, such as blogs and WeChat, and specially developed online learning platforms to support teacher training activities, which include watching video online, participating in online discourse and writing reflection diaries (Burhan-Horasanlı & Ortaçtepe, 2016; Koc, Peker, & Osmanoglu, 2009). In the OPLC, teachers' reflection often exists in three different contexts: self-reflection based on video cases (Christ, Arya, & Chiu, 2017), collaborative reflection based on online discourse (Yuan & Mak, 2018) and reflection based on writing teaching diaries (Killeavy & Moloney, 2010). Teachers' online discourse is predominantly used for connecting teachers with each other, providing and seeking suggestions about teaching practices (Kelly & Antonio,

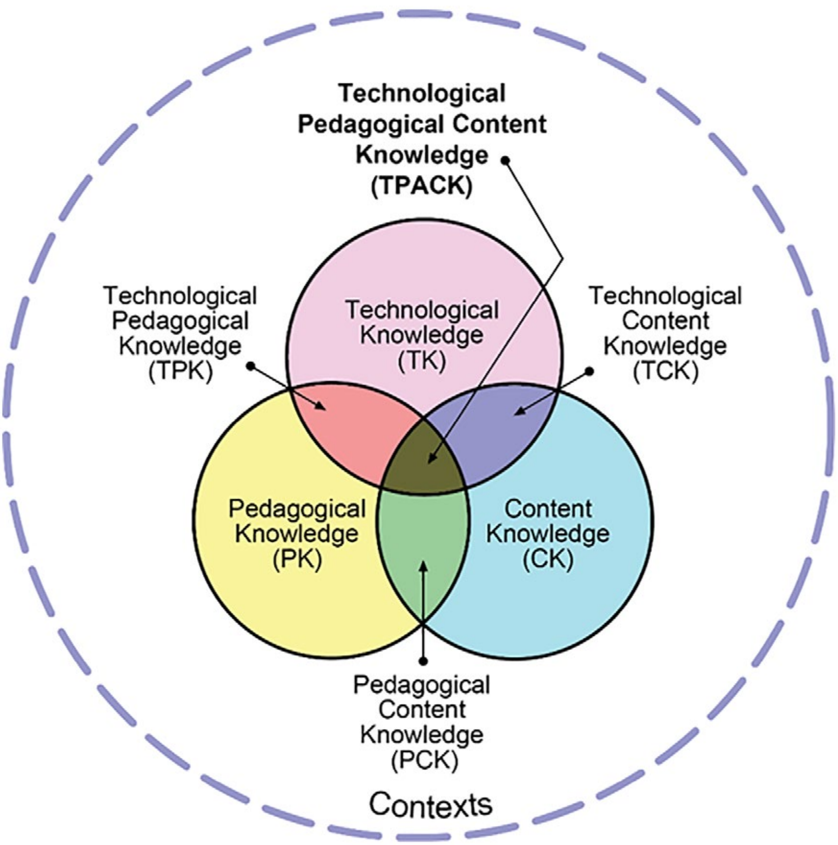

Figure 1: The TPACK framework Source: http://tpack.org

2016). Since teachers' discourse reflects the process of collaborative knowledge building, it has always been a focus of researchers in the field of the computer-supported collaborative learning and knowledge building (Lin & Chan, 2018; Wise & Schwarz, 2017).

TPACK enactment in online discourse

Developed from the notion of pedagogical content knowledge (PCK) proposed by Shulman (1987), a TPACK framework has emerged for envisioning the knowledge that teachers must rely on to design and implement instruction with digital technologies (Koehler & Mishra, 2005; Niess, 2005). TPACK is viewed as the interplay of three knowledge elements: technology, pedagogy, and content and many forms have been used to represent the complex nature of TPACK. For instance, Niess (2005) used a visual image to describe the intersection of three knowledge domains: technology, subject matter (content), and teaching and learning (pedagogy). Koehler and Mishra (2005) used a representation to highlight the seven knowledge domains in the TPACK framework, as shown in Figure 1.

Most of earlier studies on teachers' TPACK use self-report instruments, open-ended questionnaires and interviews (Chai, Koh, & Tsai, 2013). Performance assessment of teachers' lesson plans and content analysis of teachers' discussions have been used in recent studies to investigate teachers' TPACK (Akyuz, 2018; Tseng *et al*., 2019). More studies related to TPACK enactment in real-life practice are needed to understand the nature of TPACK (Rosenberg & Koehler, 2015). In the present study, the TPACK enactment was grounded in the context of discussing how to use technology via certain pedagogy to support the teaching of Chinese phonetic. The content of online discourse could shed light on how teachers enact TPACK while addressing authentic teaching problems arising in their classroom.

Research studies have shown that teachers' personal characteristics may relate to their TPACK (Cheng & Xie, 2018; Koh, Chai, & Tay, 2014; Scherer, Tondeur, Siddiq, & Baran, 2018). For example, teachers' age is negatively correlated with their technology-related knowledge domains, such as TK, TPK, TCK and TPACK (Cheng & Xie, 2018; Koh et al., 2014). Compared with secondary school teachers, primary school teachers have a lower perception of TPACK (Koh, Chai, & Tsai, 2014). In addition, TPACK is also closely related to teachers' academic performance in teacher education and professional development programs (Cheng & Xie, 2018; Erdogan & Sahin, 2010).

Epistemic network analysis

ENA is an evidence-based assessment approach in digital learning environments (Shaffer, 2017). There are three core concepts in the ENA: codes, unit of analysis and stanza. The codes represent a set of conceptual elements, and the purpose of the ENA is to understand the interaction among these elements. The unit of analysis represents the objects of ENA, such as gender grouping or age grouping. Stanza represents the scope of the co-occurrence of the codes. Taking the teachers' online discourse as an example, when the stanza is set to four, ENA will calculate the co-occurrence of epistemic elements in every four comments. ENA has been successfully applied to analyze collaborative learning and scientific reasoning of preservice teachers (Csanadi *et al.*, 2018), and the design thinking of the engineering students (Arastoopour, Shaffer, Swiecki, Ruis, & Chesler, 2016). In this study, TPACK was treated as a network of connections among seven components, and ENA was used to investigate the relationships between the components and compare the salient properties of epistemic networks generated by different groups of teachers.

The main research questions of this study were:

1. What are the categories, frequency distribution and time series characteristics of teachers' knowledge domains in online discourse?

2 What are the differences between the epistemic network characteristics of teachers in the higher-score and lower-score groups?
3 What are the differences among the epistemic network characteristics of teachers with different ages?
4 What are the differences between the epistemic network characteristics of teachers in the post and reply groups?

Methodology

Research design

The research process consisted of three stages, as shown in Figure 2. In the first stage, teachers' trace data were collected and preprocessed, including the discourse data, log data and training course data. The second stage was data analysis. Qualitative content analysis was used to analyze teachers' discourse data. Statistical analysis was used to calculate teachers' course data. Time series analysis was carried out on the log data. Based on the results of qualitative content analysis, ENA was conducted to explore the epistemic network characteristics of different groups of teachers. Finally, the results were sorted out and saved.

Online collaborative discourse

The online collaborative discourse went through three phases (see Figures 3 and 4).Phase 1: A chief teacher posted a problem for discussion and uploaded relevant materials onto the OPLC.

Phase 2: All teachers discussed the problem and uploaded teaching materials, such as lesson plans, teaching slides or teaching videos.

Phase 3: At the end of the online discourse, each teacher reflected on the application of information technology in his/her classroom teaching and submitted a lesson plan.

A round of online discourse lasted for a month, and if necessary, the chief teacher might organize multiple rounds of online discourse activities.

Participants

In 2013, the Ministry of Education of China launched a five-year teacher training program called the information technology application ability enhancement project for primary and secondary

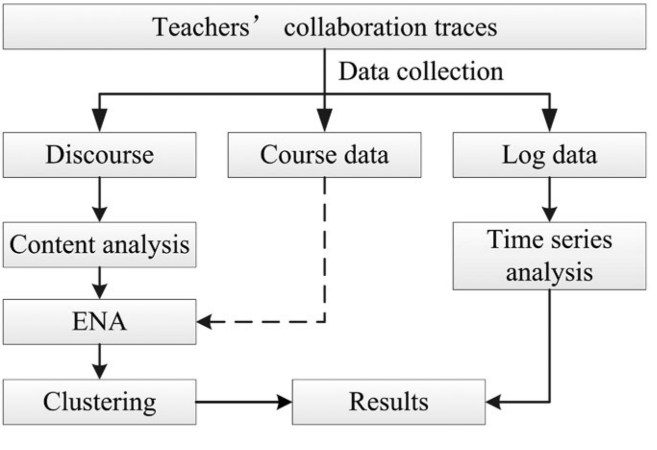

Figure 2: Research design of this study

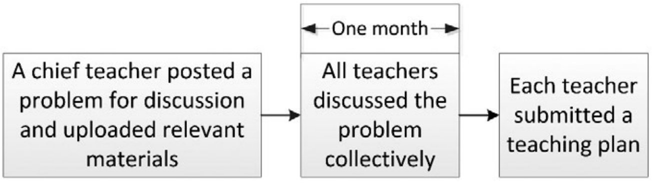

Figure 3: The workflow of the online collaborative discourse

Figure 4: The interface of the online collaborative discourse

school teachers. All primary and secondary school teachers in China were required to participate in this program in batches and the length of training for each teacher was 120 hours. Teacher training institutions were required to establish online professional learning communities based on subjects and implemented web-based teacher training. In this program, the trainee teachers needed to complete three tasks: watching video cases online, participating in online discourse and submitting lesson plans. The video cases were about how to use information technology tools to support classroom teaching. After watching the video cases, the trainee teachers in each community discussed the application of information technology in classroom teaching. The process of online discourse lasted for one month. Finally, each teacher submitted a lesson plan reflecting the application of information technology in his or her classroom.

A total of 934 primary teachers from a province in eastern China participated in the teacher training program. All the teachers were assigned to 12 online professional learning communities by subjects, with an average of 77.8 teachers per community. Of the 12 communities, four were Chinese language communities, three were mathematics communities and one was for each

Table 1: The coding scheme of TPACK

Code	*Description*	*Example*
TK	Knowledge of using emerging technologies	Teachers can use special functions in electronic whiteboards, such as the spotlights, to highlight important teaching content
PK	Knowledge of general pedagogical activities	In classroom teaching, teachers need to explore the teaching methods suitable for students, such as the collaborative learning, inquiry learning or problem-based learning
CK	Knowledge of topic-specific representations	Chinese pronunciation is the first difficulty in primary school Chinese teaching
PCK	Knowledge of subject-specific and content-specific activities or topic-specific representations	In Chinese pronunciation teaching, once teachers use children's eyes, ears, mouth, hands and heart, the boring and monotonous Chinese pronunciation teaching will become vivid and interesting
TPK	Knowledge of using emerging technologies to support general pedagogical activities	The special functions of electronic whiteboard, such as spotlight, or searchlight, are suitable for the implementation of interactive teaching
TCK	Knowledge of topic-specific representations that utilize emerging technologies	The animation function in the electronic whiteboard can be used to display the characters of Chinese phonetic alphabet
TPACK	Knowledge of using emerging technologies to coordinate the use of subject-specific or topic-specific activities with topic-specific representations	The animation function of the electronic whiteboard is used to display the Chinese phonetic alphabet, and this is combined with the game teaching method to improve students' learning interest

Table 2: The ENA data format

Time	*Name*	*Age*	*Post*	*Score*	*TK*	*PK*	*CK*	*PCK*	*TPK*	*TCK*	*TPACK*
19/11	T1	30–39	0	1	0	0	0	0	0	1	0
19/11	T2	50–59	1	0	0	0	0	0	0	0	1
20/11	T3	50–59	0	1	1	0	0	0	0	0	0
…	…	…	…		…	…	…	…	…	…	…

Note. The value of the post-column represented if the comment was a post or a reply, where 0 represented a post and 1 represented a reply. In the score column, 1 represented a higher-score and 0 represented a lower-score.

other subject. The purposive sampling method (Denzin & Lincoln, 1994) was used in this study to select one of the 12 communities to analyze teachers' TPACK enactment and the teachers of the selected Chinese language community were representative in terms of gender, years of service and training score. There were 81 teachers in this community, including 32 male teachers (39.5%) and 49 female teachers (60.5%). The average years of service of these teachers was 18.25 years. Before participating in the online training activities, these teachers experienced a technical training session and had sufficient skills to use the online learning platform. The online

Table 3: Rubrics for teachers' training score

	Description	*Score*
Watching video cases	Number and length of video cases watched, or number of questions embedded in the video cases answered	30
Participating in online discourse	Number of times participated in online discourse, number of posts contributed or length of posts	30
Lesson plans	Correct teaching content, appropriate teaching methods, reasonable use of information technology	40

discourse period of the Chinese language community was from November 19 to December 21, 2015. All online discourse data were collected and teachers were anonymized.

Data analysis instrument

Before the ENA, it was necessary to convert the qualitative text data of teachers' online discourse into the quantitative data. Referring to the definition of the TPACK proposed by Koehler and Mishra (2005) as well as the boundaries of seven factors in the TPACK framework proposed by Cox and Graham (2009), a TPACK coding scheme was developed for analyzing teachers' online discourse in this study, as shown in Table 1.

After the qualitative content analysis, each comment was labeled with a code. Then, teachers' online discourse data were sorted out according to the ENA data format, as shown in Table 2.

Data collection and analysis

A total of 561 comments were collected, of which 395 were replies (70.41%). These comments were sorted in a chronological order and saved in an excel documents for later data encoding and analysis. In this teacher training program, each teacher's training score consisted of three parts, as shown in Table 3. The score of the first part (watching video cases) and the second part (participating in online discourse) were calculated automatically by the training platform. The score of the third part were given by two subject experts with more than 20 years of Chinese teaching experience based on three key evaluation indicators: teaching content, teaching methods and information technology application. Although the three evaluation indicators were not very specific, they were ultimately adopted by considering practical operability and relevance to the object of the training program. All submitted lesson plans were assessed separately by two subject experts. The two subject experts firstly negotiated the scoring rubrics in detail to guarantee a high consistency. The scoring reliability (Spearman's correlation coefficient) between the two subject experts was 0.84 ($p < .01$). Due to the high scoring consistency, we used the average score of the two subject experts as the final score of each teacher's lesson plan. Those who scored above average were assigned to the higher-score group and the rest assigned to the lower-score group.

The first research question was answered by the methods of qualitative content analysis and time series analysis. Two researchers who were familiar with both the TPACK framework and content analysis encoded the online discourse data based on the TPACK coding scheme. The inter-coder reliability coefficient was calculated and the value was 0.81 (Cohen's Kappa), which showed a good reliability (Fleiss, 1981). After the completion of the qualitative content analysis, the

Table 4: Categories and frequency distributions of teachers' knowledge domains

Category	*TK*	*PK*	*CK*	*TPK*	*TCK*	*PCK*	*TPACK*
Numbers	13	87	35	27	13	300	86
Ratio	2.3%	15.5%	6.3%	4.8%	2.3%	53.5%	15.3%

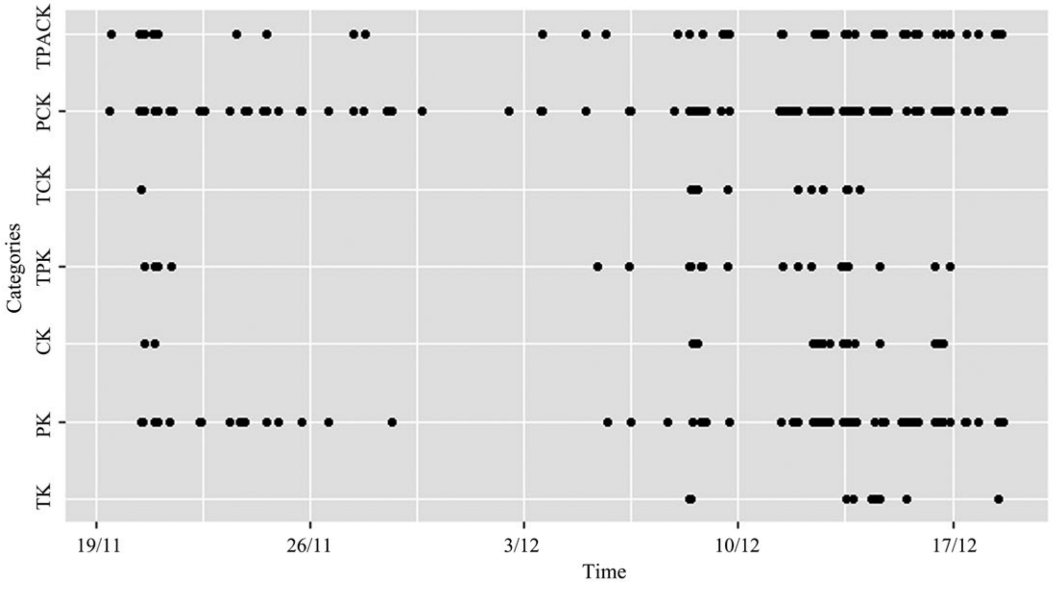

Figure 5: Time series characteristics of teachers' knowledge domains

distribution of the seven TPACK knowledge domains in teachers' online discourse was calculated by using the Excel software. Then, the "ggplot" package in the R software was used to analyze the time series characteristics of these knowledge domains.

The other three research questions were answered using the ENA. The seven factors in the TPACK framework were selected as the codes, the serial number of the comments was selected as the stanza and the size of the stanza was set to four. For research question 2, the training score and name were selected as the unit of analysis. For the third research question, teacher age and name were selected as the unit of analysis. For the fourth research question, the categories of the comments (post or reply) and teacher name were selected as the unit of analysis.

Result

What are the categories, frequency distribution and time series characteristics of teachers' knowledge domains in online discourse?

Categories and frequency distribution

The categories and frequency distribution of teachers' knowledge domains were shown in Table 4. All the seven knowledge domains of the TPACK framework appeared in teacher's online discourse, but with different proportions. The pedagogical content knowledge (PCK) appeared the most frequently (300, 53.5%), followed by the general pedagogical knowledge (PK, 87, 15.5%). The lowest were the technological knowledge (TK, 13, 2.3%) and the technological content knowledge (TCK, 13, 2.3%).

Time series characteristics

R software took the time as the horizontal axis and the categories of teachers' knowledge domains as the vertical axis to draw a time series diagram (see Figure 5). Teachers' comments mainly appeared in the early and late stages of the online discourse. At the late stage of the online discourse, there were many comments related to teachers' technological knowledge and TPACK.

What are the differences between the epistemic network characteristics of teachers in the higher-score and the lower-score groups?

The epistemic networks of teachers in the higher-score and the lower-score groups during the process of online discourse were shown in Figure 6. The connection coefficients of epistemic networks in the higher-score and lower-score groups were shown in Table 5. The value in the table represented the weight of the number of times that each connection appeared in the online discourse.

In the epistemic network of teachers in the higher-score group, there were more connections between PK and PCK, PK and TPACK, which indicated that these paired knowledge domains co-occurred more often in higher-score group teachers' online discourse. In addition, CK and PCK also occurred repeatedly over time in higher-score group teachers' online discourse. Some connection coefficients in the epistemic network of the lower-score group exceeded those of the higher-score group, but the difference was small.

What are the differences among the epistemic network characteristics of teachers with different ages?

The epistemic networks of teaches with different ages were shown in Figure 7. The connection coefficients of these epistemic networks were calculated, and the result is shown in Table 6.

Figure 7 showed that the discourse of teachers aged 20–29 was more towards the lower part of the ENA space. The discourses of teachers aged 30–39 was more towards the right side of the ENA space. While the discourses of teachers aged 40–49 was more towards the left side of the ENA space.

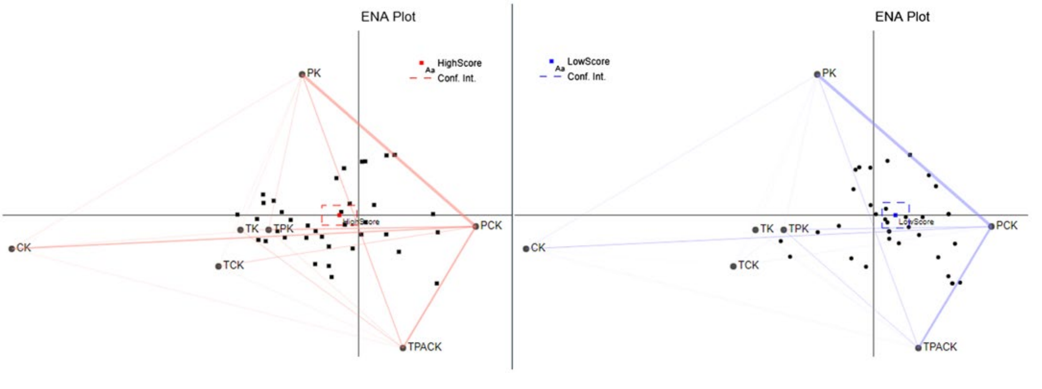

Figure 6: Epistemic networks of the higher- score and low-score groups

Table 5: *Connection coefficients of the higher- score and lower-score groups*

Connection	*Higher-score*	*Lower-score*	*Connection*	*Higher-score*	*Lower-score*	*Connection*	*Higher-score*	*Lower-score*
TK-PK	0.047	0.012	TK-CK	0.009	0	TK-TPK	0.021	0.046
TK-TCK	0.004	0.018	TK-PCK	0.119	0.038	TK-TPACK	0.127	0.022
PK-CK	0.063	0.036	PK-TPK	0.101	0.023	PK-TCK	0.034	0.01
PK-PCK	0.734	0.509	PK-TPACK	0.229	0.089	CK-TPK	0.061	0.006
CK-TCK	0	0.008	CK-PCK	0.337	0.122	CK-TPACK	0.046	0.018
TPK-TCK	0.010	0.022	TPK-PCK	0.228	0.079	TPK-TPACK	0.065	0.074
TCK-PCK	0.136	0.021	TCK-TPACK	0.037	0.002	PCK-TPACK	0.461	0.367

Note. The connection between TK and PK represents the co-occurrence of the TK and PK in a stanza.

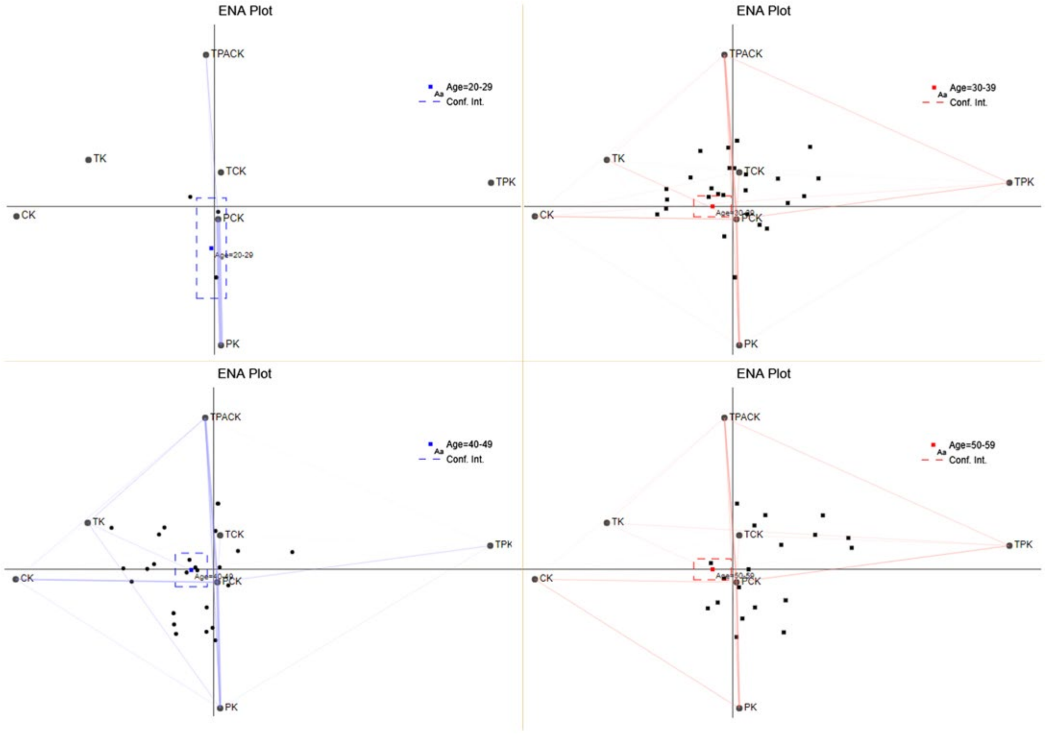

Figure 7: Epistemic network of teachers with different ages

The connection between PK and PCK meant that these two knowledge domains co-occurred more often in the online discourse. Compared to teachers in other age groups, the connection coefficient that was the strongest for teachers aged 20–29 was between PK and PCK. Teachers aged 30–39 had the lowest connection coefficient (0.317) between PK and PCK.

The connections between PK and TPACK, CK and PCK meant that these paired knowledge domains occurred repeatedly over time in the online discourse. Teachers aged 40–49 had the highest connection coefficient between PK and the TPACK (0.167), CK and PCK (0.236), while those aged 20–29 had the lowest connection coefficient between PK and the TPACK (0.046), CK and PCK.

The connection between TPK and PCK meant that these two paired knowledge domains occurred repeatedly over time in the online discourse. Teachers aged 30–39 had the highest connection coefficient (0.123) between TPK and PCK, while those aged 20–29 had the lowest connection coefficient between TPK and PCK.

The connection between the PCK and TPACK meant that these two knowledge domains co-occurred more often in the online discourse. Compared to teachers in other age groups, the connection coefficient that was the strongest for teachers aged 50–59 was between PCK and TPACK (0.409). Teachers aged 20–29 had the lowest connection coefficient (0.138).

Table 6: Connection coefficients of different age groups

Connection	*20–29*	*30–39*	*40–49*	*50–59*	*Connection*	*20–29*	*30–39*	*40–49*	*50–59*
TK-PK	0	0.011	0.071	0.008	TK-CK	0	0	0.007	0.02
TK-TPK	0	0.004	0	0.072	TK-TCK	0	0.013	0	0.009
TK-PCK	0	0.085	0.054	0.048	TK-TPACK	0	0.025	0.079	0.047
PK-CK	0	0.017	0.037	0.139	PK-TPK	0	0.024	0.027	0.007
PK-TCK	0	0.004	0.028	0.024	PK-PCK	0.738	0.317	0.416	0.443
PK-TPACK	0.046	0.114	0.167	0.123	CK-TPK	0	0.037	0.005	0.01
CK-TCK	0	002	0.006	0.012	CK-PCK	0	0.153	0.236	0.150
CK-TPACK	0	0.02	0.037	0.024	TPK-TCK	0	0.013	0.006	0.040
TPK-PCK	0	0.123	0.09	0.199	TPK-TPACK	0	0.087	0.010	0.117
TCK-PCK	0	0.086	0.062	0.072	TCK-TPACK	0	0.023	0.003	0.003
PCK-TPACK	0.138	0.372	0.379	0.409					

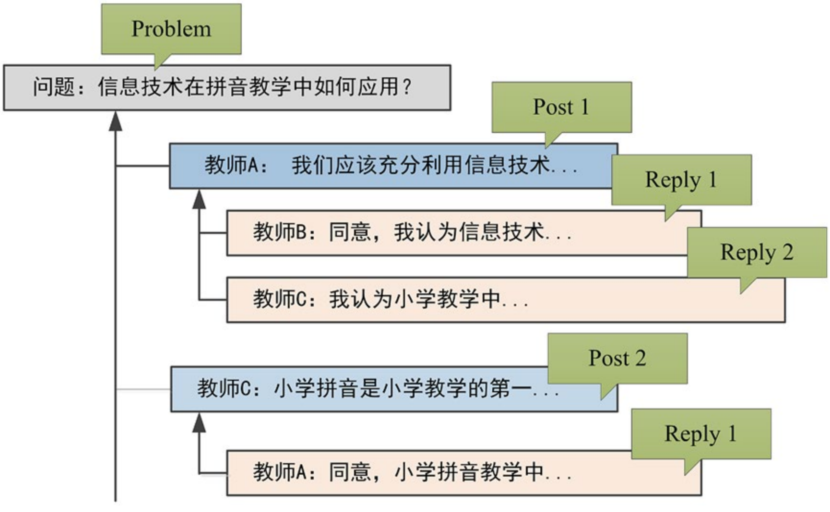

Figure 8: Relationship between post and reply

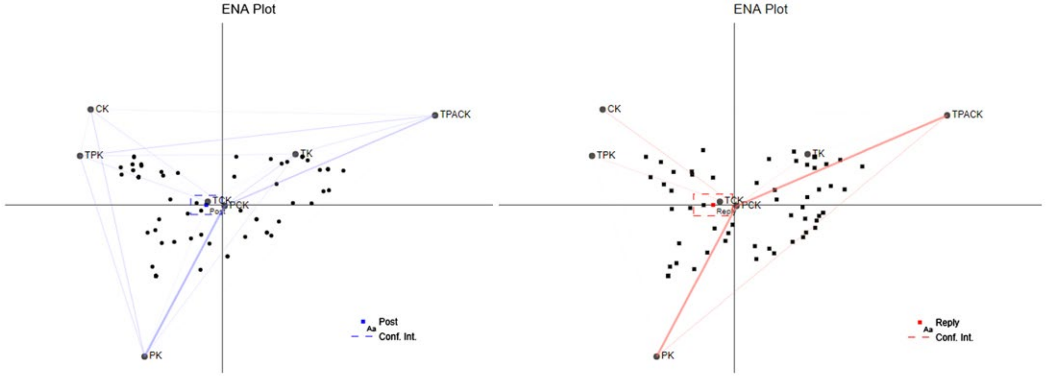

Figure 9: Epistemic network of teachers in the post and reply groups

What are the differences between the epistemic network characteristics of teachers in the post and reply groups?

As shown in Figure 8, a post was an answer to a problem, and a reply was a response to a post. In this study, the comments belonging to the post were divided into one group, while those belonging to the reply were divided into another group.

The epistemic networks of teachers in the post and reply groups during the process of online discourse were shown in Figure 9. The connection coefficients of the epistemic networks were calculated and presented in Table 7.

The connection between PCK and TPACK meant that these two knowledge domains co-occurred more often in the online discourse. The connection coefficient between PCK and TPACK in the epistemic networks of the reply group (0.378) exceeded that of the post group (0.274). Similarly, the connections between PK and CK (with a coefficient 0.29 in the reply group and 0.043 in the post group), PK and TPACK (0.149 vs. 0.083), TPK and PCK (0.122 vs. 0.107) meant that these paired knowledge domains co-occurred more often in the online discourse.

Figure 9 showed that the discourse of teachers in the post group was more towards the upper part of the ENA space, while the discourses of teachers in the reply group was more towards the lower part of the ENA space.

Discussion

Teachers' comments mainly appeared in the early and late stages of the online discourse. This finding was inconsistent with the previous studies. Chen *et al.* (2009) used an online synchronous discussion to support in-service teachers' professional development and found that the number of teachers' comments was quite consistent across the 6 weeks of online discussion. Redmond (2015) built online mentoring learning communities to support preservice teachers' professional development and found that teachers' comments appeared mainly in the middle stage of online discussions. Two factors might contribute to this results. First, the chief teacher did not participate in the process of online discourse after he posted the discussion topic. Second, many repetitive and irrelevant comments appeared, which affected teachers' enthusiasm to participate in the online discourse. In addition, teachers often stopped participating in the online discourse after they met the minimum training requirements. In order to change this situation, it is necessary to keep teachers' enthusiasm of continuous participation in online discourse (Tondeur, Aesaert, Prestridge, & Consuegra, 2018), or introduce intelligent technology to monitor teachers' online discourse.

It was found that the categories of teachers' knowledge domains reflected in the online discourse were mainly the pedagogical content knowledge and general pedagogical knowledge. This finding was consistent with the previous studies. One study examined the TPACK perceptions of Chinese in-service K12 teachers (Liu, Zhang, & Wang, 2015) found that in-service teachers had the higher perceptions on the PK, CK and the PCK variables. In another study, Cheng and Xie (2018) examined the TPACK perceptions of in-service teachers from elementary and high schools and found that teachers had the higher perceptions on the CK, PCK and PK. This finding may be related to the context of TPACK enactment. For the students in the lower grades of primary school, Chinese teachers seldom use technology to assist their teaching, and they more often use teaching methods such as storytelling and children's song.

On the whole, the connection coefficients in the epistemic network of the higher-score group teachers were higher than that of the lower-score group, especially the connection coefficients between PK and PCK, CK and PCK, PCK and TPK, PK and TPACK. This finding indicated that the higher-score group teachers had rich, organized and flexible knowledge to perform appropriate technology integration. This may also be related to the fact that teachers in the higher-score group posted more comments than those in the lower-score group. Teacher's training score was

Table 7: Epistemic network parameters of teachers in the post and reply groups

Connection	*Post*	*Reply*	*Connection*	*Post*	*Reply*	*Connection*	*Post*	*Reply*
TK-PK	0.019	0.016	TK-CK	0	0.005	TK-TPK	0.018	0.018
TK-TCK	0.008	0.006	TK-PCK	0.035	0.095	TK-TPACK	0.026	0.056
PK-CK	0.043	0.29	PK-TPK	0.035	0.041	PK-TCK	0.010	0.014
PK-PCK	0.370	0.380	PK-TPACK	0.083	0.149	CK-TPK	0.012	0.019
CK-TCK	0.004	0.003	CK-PCK	0.158	0.155	CK-TPACK	0.012	0.037
TPK-TCK	0.022	0.011	TPK-PCK	0.107	0.122	TPK-TPACK	0.043	0.031
TCK-PCK	0.030	0.070	TCK-TPACK	0	0.014	PCK-TPACK	0.274	0.378

proportional to the number of comments contributed by them. Therefore, high scores indicated that these teachers posted more comments and there were more co-occurrences between the knowledge domains.

In terms of the connection coefficient between PK and PCK, younger teachers were higher than those who were older, while in terms of the connection coefficients between PCK and TPACK, CK and PCK, TPK and PCK, senior teachers were higher than younger teachers. This finding contributed to a new understanding of the nature of TPACK. Liu, Zhang and Wang (2015) investigated the TPACK perception of primary and secondary school teachers in China and found that younger teachers had the higher perception on the TK, and the lower perceptions on the PK and PCK, while senior teachers had the higher perceptions on the PK and PCK, and the lower perceptions on the TK. Zhang, Liu, and Wang (2017) investigated the online peer coaching among primary and secondary school teachers in China and found that younger teachers provided more technical support, while senior teachers provided more academic support. A possible reason for this phenomenon was that although younger teachers thought they had more technical knowledge, they could not apply it well in their teaching practice. Senior teachers had rich knowledge of subject content and teaching methods, and they had a better foundation for technology integration in classroom.

The connection coefficients of epistemic network in the reply group were higher than those in the post group. This may be related to the different number of replies and posts. The more replies, the more knowledge domains co-occurred in the time window, and therefore, the higher the connection coefficient. In addition, since each post was an answer to the problem, and each reply was a response to a post, the relationship between multiple replies was closer and it is reasonable that there were more co-occurrences of knowledge domains in the replies.

The findings of this study have important implications for researchers, teacher educators and teacher training managers. Firstly, in the middle stage of the online discourse, some support should be delivered to trainee teachers before they stop participating in the activity. For instance, training organizers take the initiative to enhance teachers' perceived task value, or provide scaffolding for teachers' learning tasks. Secondly, although the frequency distribution of teachers' knowledge domains obtained from the online discourse analysis was similar to the results of TPACK questionnaire surveys, the research on the interplay between the knowledge domains contributed new understanding to TPACK. Teacher's TPACK is a whole, so researches related to TPACK should not only focus on analyzing the frequency distribution of teacher's knowledge domains, but also pay attention to the interplay of these knowledge domains. Finally, teachers of different roles in online discourse formed different network structures of TPACK, which illustrated the decision-making process of these teachers in solving the problems of technology integration. Analyzing the network structure of TPACK formed in online discourse is helpful to understand the nature and key factors affecting the development of TPACK.

Conclusion, limitations and future study

The contextual influences on TPACK enactment and the method of TPACK assessment remain to be important research topics. This research combined the qualitative content analysis and ENA to explore the characteristics of teachers' TPACK in the online discourse and the results showed that ENA had the unparalleled advantages in exploring the structure of TPACK. There are two main limitations associated with this study. First, the sample in this study is not representative enough. This study only analyzes the discourse data in an OPLC, and the research conclusion is difficult to be extended to all the online professional learning communities. Second, this study only analyzes the characteristics of teachers' epistemic network at a certain point and lacks the continuous and follow-up research on the characteristics of teachers' epistemic network. In the future study, the number of research samples will be further expanded, and the teachers' knowledge domains will be continuously measured and evaluated through multiple data collection and analysis. In addition, this study will combine the ENA and text mining to explore the automatic analysis and evaluation methods of teachers' knowledge domains in online professional learning communities.

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Statements on open data, ethics and conflict of interest
Data can be accessed by contacting the author (saved in a personal repository). Ethical approvals were gained from the hosting institution. This research has no conflicts of interest.

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