

Tracing changes in teachers' professional learning network on Twitter: Comparison of teachers' social network structure and content of interaction before and during the COVID-19 pandemic

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Abstract

Background: The COVID-19 pandemic has affected teaching and professional learning activities. Teachers may have to rely on online spaces, such as Twitter, to interact with their professional learning networks and get enough support.

Objectives: This study aims to investigate the structure and the content of teachers' network interactions on Twitter both before and during the COVID19 pandemic.

Methods: Data were analysed for 103 teachers using multiple methods, including social network analysis (SNA) and content and thematic analysis.

Results and Conclusions: Content analysis revealed that teachers' cognitive and affective posts increased significantly during COVID-19. Thematic analysis showed that, during COVID-19, teachers' post sfocused on issues around digital transformation. SNA showed that the sizes of teachers' networks and in/out-ties grew during COVID-19. Although the study finds that teachers interacted with individuals both within and outside their discipline and their country, most teachers' interactions were with teachers from similar disciplines and same country. Teachers used Twitter to share information and support each other.

Implications: This study provides recommendations for stimulating professional interactions among teachers. This work shows the potential of SNA and content analysis to analyse teachers' professional learning networks.

KEYWORDS

content analysis, pandemic, professional learning network, SNA, teachers, twitter

1 | INTRODUCTION

The COVID-19 pandemic has created a worldwide education crisis. In response to this pandemic, many governments have imposed lockdowns and social distancing, including closing schools and suspending all face-to-face activities, which has affected teachers. For example, teachers are facing many new challenges, such as remote and distance learning, which have required them to redesign all teaching activities to be compatible with the distance learning. Azorin (2020) emphasize

providing teachers with effective, professional learning opportunities during this difficult time. Several researchers have argued that teachers' professional support networks can be strengthened with technology (Trust et al., 2016). A recent report from UNESCO (2020) on education response to COVID-19 highlighted the importance of reinforcing teachers' professional learning communities and peer learning to facilitate information sharing and find solutions.

Social media platforms, such as Twitter, can provide learning spaces that allow teachers to interact and network with each other,

enhance their teaching practices, and deal with any difficulties they face. Studies show that Twitter can help teachers to seek help and get emotional support (Xing & Gao, 2018). Due to social distancing mandates, teachers may have to rely on online spaces to get enough support. Hence, the question arises as to whether Twitter can provide social and professional learning opportunities during the COVID-19 pandemic. Therefore, this study employs a longitudinal design to investigate the effects of COVID-19 on teachers' network structures and the content of their interactions on Twitter by examining teachers' PLN before and during the pandemic.

2 | LITERATURE REVIEW

2.1 | Theoretical foundation of teachers' professional learning networks

A professional learning network (PLN) can be defined as a 'teacher-driven, global support networks that decreases isolation and promotes independence' (Flanigan, 2011 as cited in Trust, 2012, p. 133). Couros (2010, p. 125) describes a PLN as 'the sum of all social capital and connections that result in the development and facilitation of a personal learning environment'. Both of these definitions highlight the importance of the social elements of teachers' professional learning, which is not seen as an isolated process but one that is socially embedded. These definitions also point to a social-network perspective of teachers' professional learning. A number of studies on PLNs have used social capital and social network theory as theoretical foundations to examine teachers' professional learning (Rehm & Notten, 2016; Rienties & Kinchin, 2014).

Social capital regards the information and resources available to individuals through social network relationships (Lin, 2001). Such resources and information can contribute to the cognitive aspects of teachers' professional learning and effective sources of encouragement and emotional support (Fox & Wilson, 2015). Studies on PLNs show that social capital can play a significant role in facilitating teachers' acquisition and sharing of information and knowledge.

Whereas social capital focuses on the content of an interaction, social network theory focuses on social network structures. Teachers' networks comprise nodes (actors) and ties among actors. Social network theory provides an effective perspective for capturing teachers' professional interactions (Moolenaar, 2012). The assumption of this theory is that network composition and teachers' positions in a network can affect their professional learning experiences (Rienties & Kinchin, 2014; Van Waes et al., 2015).

Teachers' network compositions are useful for examining whether teachers can access valuable resources or are too isolated to access them (Baker-Doyle, 2015). Two network composition properties have been extensively used in studies related to teachers' PLNs: size and diversity (Alwafi, Downey & Kinchin, 2020; Bokhove & Downey, 2018; Van Waes et al., 2018; Rienties & Hosein, 2020; Rienties & Kinchin, 2014). Network size concerns the number of individuals with whom a teacher is in contact. Studies on teachers' networks show that those who are connected to large numbers of individuals have

access to a large number of resources (Van Waes et al., 2018). The diversity of a network can be examined in terms of alters' attributes, such as their academic discipline. Diversity in teachers' networks can provide them with new perspectives on teaching and innovative ideas (Mehra et al., 2001). Studies have found that teachers with large, diverse networks can engage more effectively in teaching practice than those with smaller, less diverse networks (Van Waes et al., 2015).

Teachers' social capital and social networks have been affected by the COVID-19 pandemic. The social distancing and lockdowns that followed the outbreak have isolated teachers from school communities and their professional learning networks. Therefore, several researchers have emphasized teachers' PLNs to overcome any difficulties they may face during this pandemic. Azorín (2020) argues that teachers' networks and social capital can be strengths during COVID-19 by using technology as a media to engage teachers with professional learning community.

2.2 | Twitter as a teachers' professional learning space

With the rapid development of information and communications technology, teachers can use the online learning environment as a space in which to build relationships. Twitter is a platform that teachers can use to interact with other teachers and professionals, anytime and anywhere. Previous studies have shown that Twitter can help teachers seek advice and emotional support (Carpenter et al., 2020). Risser (2014) observed that teachers used Twitter to share resources and keep themselves up to date with news and ideas related to teaching practices. Rodesiler (2015) found that teachers used Twitter to reduce their isolation, network with others, and enhance their teaching practices. Carpenter and Krutka (2015) found that teachers see Twitter as a space that helps them to form relationships with people who share their interests and to learn from diverse people with different perspectives. Currently, studies on PLNs focus on examining the patterns of teachers' social interactions through the lenses of social network analysis (SNA) and content analysis. For example, Risser (2014) found that teachers primarily connected with people from their own academic disciplines. Choudhury (2011) found that teachers' tie formation on Twitter is usually predicated on shared interests. Risser (2014) and Stepanyan et al. (2010) found that the sizes of teachers' networks on Twitter decreased over time. In contrast, Rehm and Notten (2016) found that teachers' professional networks on Twitter increased over time. This contradiction might be explained by the time periods of teachers' participation on Twitter. According to Risser (2014), high frequencies of teacher interactions occur during school holidays and at the start of school semesters. Therefore, teachers seem to be using Twitter to fill a gap due to social disconnectedness from their professional networks at school.

A review of the literature revealed that the majority of the previous studies were conducted with teachers in Western countries and that no studies identified the use of Twitter for teachers' professional learning activities in the Arab Gulf context in general and Saudi Arabia

in particular. Religion and culture in Saudi Arabia are considered to be two aspects that influence people lives. Saudi people are Muslim, and the official language in Saudi Arabia is Arabic. Accordingly, religion and culture impact and inform teachers' practice, conversations and interactions (Alarfaj, 2015). For example, Islamic morals and values encourage people to collaborate and support each other. Moreover, collaborations with people in need are seen as work that pursues the blessings of Allah (God) and gains reward from God. These are reflected in Saudi teachers' professional practice. According to several studies (Alharbi & Kinchin, 2012; Mansour et al., 2014), Saudi teachers prefer collaborative professional learning activities. Another Islamic moral is that people tend to express prayer to others through their conversation. This moral reflects the religion of the individual, where people believe they are equal in reward in the prayer for each other. Prayer is used to express a sense of pursuing relief, success and good conduct for others. Teachers usually express these values in their conversations with students and other teachers. There are several benefits of such Islamic morals, such as a united society and the spread of love and peace. Teachers' practices in Saudi Arabia need to be characterized by Islamic values through their interactions with others. Studies (Abokhodair & Vieweg, 2016; Al-Saggaf, 2004) on the use of social media among Arab Gulf people observed that people follow Islamic teachings and morals in online and social media interactions and activities.

Hence, the question arises as to whether Twitter can provide teachers with social capital and network opportunities whereby teachers' professional learning can be fostered. This study employs a longitudinal design to investigate the differences between teachers' network structures and the content of interactions on Twitter before and during the COVID-19 pandemic to determine the benefits that Twitter can confer on teachers amid social distancing mandates. Therefore, this study aims to examine the following research questions:

- RQ1: How does the content of teachers' professional learning vary before and during pandemic?
- RQ2: How does teachers' network structures on Twitter vary before and during pandemic?

3 | METHODOLOGY

3.1 | Research design

This study employs a longitudinal design. This design is considered to be a useful approach for studying developmental trends over time (Cohen et al., 2011) and therefore can facilitate the analysis of teachers' PLN over time (before and during COVID-19). In this study, two periods are analysed: a 3-month period before any cases of COVID-19 were reported in Saudi Arabia (from 1 December 2019 to 1 March 2020) and a 3-month period during the pandemic. The second period starts from the second semester when the Saudi Ministry of Education announced the lockdown and school closures (10 March 2020 to 10 June 2020). The content of teachers' posts and their social network relations is examined for the two periods.

3.2 | Participants

Since the aim of this study was to analyse teachers' Twitter posts and professional networks, a random sample of teachers who use Twitter would have been difficult to collect. Therefore, a convenience sample was used. In this study, Twitter was used to invite and recruit participants. This technique has been used in many studies on teachers' use of Twitter (Veletsianos, 2012; Visser et al., 2014; Trust et al., 2016) and other social media platforms (Baltar & Brunet, 2012; Fewkes & McCabe, 2012). The researcher reached the participants via education-related hashtags and by checking users' profiles and accounts. Twitter accounts were examined to determine whether teachers had started using Twitter more than 3 months before the COVID-19 pandemic. Then, the researcher sent invitation links to the participants via private messages on Twitter. This link included information related to the study, requested their participation, and collected demographic data, such as age, teaching experience, discipline and Twitter username. Snowball sampling was used by asking the participants to send the invitation to other friends who use Twitter.

A total of 103 Saudi teachers who agreed to have their Twitter accounts analysed participated in the study. Around 63.10% of the participants were male and 36.89% were female. Participants were between 26 and 46 years old, and their teaching experience ranged from 3 to 21 years. Thirty-one per cent of the participants were primary school teachers, 28.15% were middle school teachers and 43.68% were secondary school teachers.

3.3 | Data collection methods

The data used in this study were collected from Twitter and included teachers' posts and social network relations. Data were collected using multiple methods, including a demographic survey, content analysis, thematic analysis and SNA. Researchers in the area of computer-supported learning (Eynon et al., 2016; Rienties et al., 2012) recommend the use of multiple methods, such as content analysis and SNA, in order to understand the complexity of learning that takes place in this environment. The demographic survey collected data about the participants' ages, teaching experience and academic disciplines. The content analysis focused on the frequency and nature of the tweets. In this study, both single tweets and tweets in a thread are considered. The SNA focused on the teachers' relationships.

3.3.1 | Teacher contribution in Twitter using content analysis

Content analysis can provide insight into the types and frequency of content in teachers' Twitter posts (tweets). In this study, the coding schema was developed via a thematic analysis of the teachers' tweets. There were two main themes: cognitive and affective (positive and negative affective) posts. Table 1 presents the coding schema that was used in this study. The complete message (tweet) was chosen as

the unit of analysis. However, if the message involved multiple elements, the message was divided. To ensure the objectivity of the analysis, inter-rater reliability was assessed with two independent coders. Coders independently coded samples of teachers' posts. The level of agreement between the coders was examined by using Cohen's kappa. The levels of agreement between Coders 1 and 2, 2 and 3 and 1 and 3 were 0.81, 0.85 and 0.83, respectively. These results represent excellent agreement (De Wever et al., 2006).

Thematic analysis was used to gain a comprehensive understanding of the nature of teachers' tweets. This study followed the guidelines for thematic data analysis proposed by Braun and Clarke (2006) in order to better understand teachers' posts on Twitter. To ensure the trustworthiness of the qualitative analysis, the researcher and one

expert in the field of computer-assisted learning and qualitative analysis coded the sample of tweets independently, and the result was compared. Around 97% of coding was similar, and the differences were discussed to resolve any issues. Teachers posts were in Arabic language and it was translated to English. To ensure the accuracy of the translation, back-translation technique was applied.

3.3.2 | Teacher's network using social network analysis

SNA was used to map changes in teachers' social networks before, versus during, the COVID-19 pandemic. SNA is a useful method for

TABLE 1 The coding schema for teachers' posts

Category	Subcategory	Description	Example	# of posts before COVID-19	# of posts during COVID-19	Total
Cognitive posts	Share resource	Posts on sharing media such as articles and video related to profession	See this video. It describes the process of use MS Teams	458	767	1225
	Share practice	Posts on sharing information related to teachers' practice	I use inquiry-based learning as activity. It allows student to be critical	263	375	638
	Share professional learning event	Posts on sharing professional learning events such as workshops and training courses	The Education Directorate provides short course about the use interactive board	291	584	847
	Provide information	Posts on providing information related to profession such as provide solution and ideas	You can use One Drive to share your files with students	1029	1384	2413
	Ask question	Posts involving sort of questions such as ask for help or resources	Can anyone tell me how I can make online forum?	541	767	1308
Total of cognitive posts				2582	3877	6459
Affective: Positive affective posts	Appreciate	Posts includes some sort of thanks and appreciating other people's help	Thank you for sharing this experience with me. I really appreciate your supports	585	761	1346
	Prayer	Posts express a sense of pursuing relief, success and good conduct for others	I ask Allah to make the online teaching easy for you. May God bless your time	349	658	1007
	Giving encouragement/praises	Posts include sort of encouraging and praise to teachers	I know you can do it. You are a creative teacher and your teaching experience is wonderful	174	268	442
Affective: Negative affective posts	Sharing fear	Posts show feel of fear among teachers	I am afraid I cannot from the low speed of my internet during the use video conferencing with my students	135	219	354
	Sharing worries/stress	Posts show feel of worries and stress among teachers	I am worries of how I can move all my teaching materials online in this short time	227	344	571
Total of affective posts				1470	2250	3720

examining social interaction patterns of teachers' networks on Twitter. This study used an ego network approach to analyse social networks. The ego network focuses on mapping the network of an individual (ego). The people who communicate or connect with the ego are called alters, and any link between the ego and an alter is called a tie. Figure 1 provides a visualization of ego network of teacher K. The A44, A46, A47, A48 and A49 are alters.

This study employed four measurements: the size of the ego network, in-degree, out-degree and network homophily (E-I index). The size of the ego network measured how many alters an individual teacher directly communicates with. The out-degree is considered the number of ties that teachers created with alters. This reflects the teacher's activities, including sending posts, asking questions or sharing information with others. For example, Teacher K has an out-degree of 3, which is the number of links this teacher created with alters (see Figure 1). Teacher K established relations with A44, A47 and A48. The in-degree reflects the numbers of ties that teachers received; in other words, this indicates the number of posts teachers received from others (alters). As shown in Figure 1, Teacher K received two ties (relations with A46 and A49). Consequently, Teacher K has an in-degree of 2. Network homophily (the external-internal index) was used to measure the tendency to interact with people who are more similar to the focal participant in terms of a specific attribute such as discipline or country. In this study, the external-internal (E-I) index was used to examine the diversity of an alter's discipline and country. This study measured two network homophilies: discipline E-I index and country E-I index. In terms of discipline E-I index, internal ties (I) refer to the number of ties with alters from the same discipline, while external ties (E) refer to the number of ties for individual teachers with alters from different disciplines. The results show an E-I index range from 1 (all ties are to

people from different disciplines, or heterophily) to -1 (all ties are to people with the ego's own discipline, or homophily; Krackhardt & Stern, 1988). The E-I index takes the numbers of relations of people from different departments, subtracts the numbers of ties of members from the same department and divides this by the total number of ties. Regarding the calculation of a country's E-I index, the value of the country's E-I index indicates the degree of heterogeneity between teachers and their alters. A value of -1.0 indicates complete homogeneity (all teachers' ties are to alters with the ego's own country), and a value of $+1.0$ indicates complete heterogeneity (all ties are to alters from a different country). The following equation was used to calculate Krackhardt and Stern's (1988) E-I index:

$$E-I \text{ index} = \frac{E-I}{E+I}$$

3.4 | Statistical analysis

The distribution of the collected data was visually checked and seemed to be normally distributed. The skewness and kurtosis values were also examined, and the values were within an acceptable range of -1.96 to $+1.96$. A paired samples *t*-test was used to examine the difference within the variables before and during the COVID-19 pandemic. To calculate the effect size, Cohen's *d* was used. The interpretation of the effect size was $0.2 = \text{small}$, $0.6 = \text{medium}$ and $0.8 \geq \text{large}$ (Cohen, 1988). ANOVA was used to measure the differences among primary, middle and secondary teachers. The network analysis software package UCINET version 6.658 (Borgatti et al., 2002) was used to analyse both network sizes and E-I indexes.

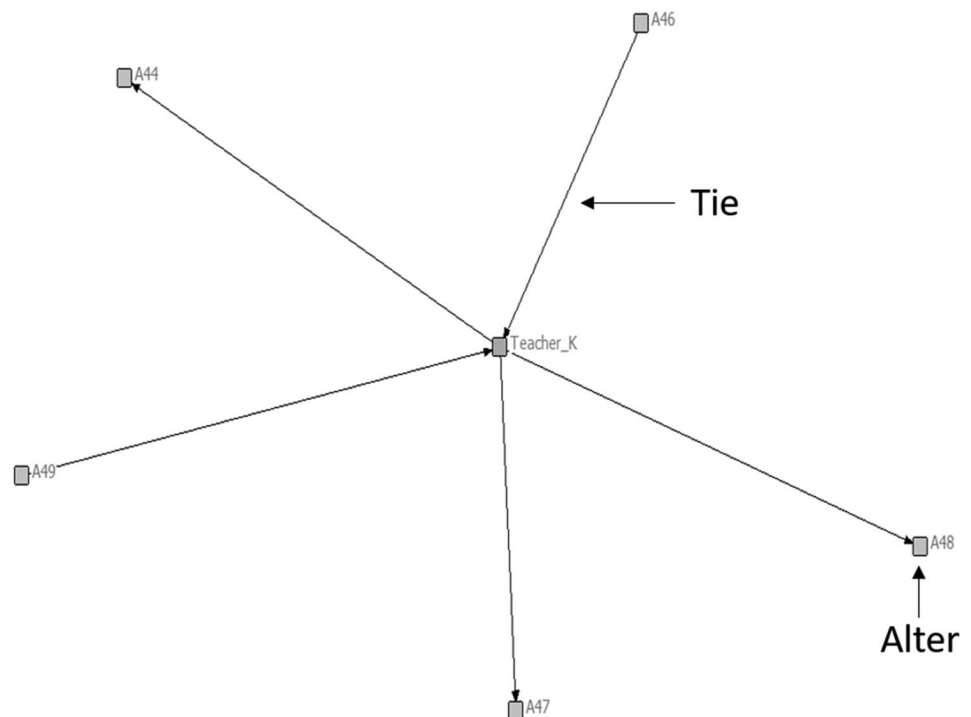


FIGURE 1 An example of network visualization

4 | RESULTS

4.1 | RQ1: Changes in the content of teachers' professional learning

The first research question considered the effects of the pandemic on the content of teachers' professional learning on Twitter. This section focuses on the level of teachers' tweets' type and the nature of the tweets. In terms of the level of teachers' tweets, as seen in Table 1, in total, teachers posted 10,255 tweets in both periods: 4025 before the pandemic and 6230 during the pandemic. The total number of cognitive posts was 6562. Teachers produced 2582 cognitive posts before the pandemic and 3980 during the pandemic. In terms of the total number of affective posts, teachers posted 2768 positive affective posts and 925 negative affective posts. Before the pandemic, teachers posted 1443 affective posts: 1081 posts were positive and 362 were negative. During the pandemic, the number of affective posts was 2250: 1687 of the posts were positive affective and 563 of them were negative. Table 2 shows that during the COVID-19 pandemic, there was a significant increase in the volume of teachers' cognitive and affective posts (both positive and negative affective posts).

By examining the number of cognitive posts in each time period, the results show that before the pandemic, teachers' posts could be broken down as follows: 39.85% provided information, 20.95% asked questions, 17.74% shared resources, 11.27% shared professional events and 10.19% shared practices. In terms of the second period (during COVID-19), around 34.77% of cognitive posts were related to providing information, 21.85% asked question, 19.27% shared resources, 14.85% shared professional learning events and 9.40%

shared practices. The analysis shows that the teachers posted in the same pattern in each time period. For illustration, the most common type of cognitive post provided information, followed by asking questions; the lowest number of posts shared practices. Table 2 shows a significant large growth in the volume of posts providing information, asking questions, sharing resources and sharing information about a professional learning event. There was a modest but significant growth in the volume of posts related to sharing practices.

In terms of the volume of affective post categories in each time period, the analysis shows that before the COVID-19 pandemic, around 74.91% of affective posts were positive affective and 25.09% were negative affective. Around 40.54% of affective posts were related to appreciative posts, 24.18% were prayer, 15.73% shared worries, 10.18% gave encouragement and 9.35% shared fears. During the pandemic, 74.98% of posts were positive and 25.02% were negative affective posts. 33.82% of affective posts were related to appreciative posts, 29.24% were prayer, 15.28% shared worries, 11.91% gave encouragement and 9.73% were shared fear. The analysis shows that both teachers' positive and negative posts increased through time, but positive affective posts were higher than negative affective posts before and during the pandemic. Differences in the average number of positive affective posts show that there was a modest increase in the level of appreciative messages, and both prayer and encouragement posts saw a significant increase during the pandemic. In terms of negative affective posts, both sharing fears and worries showed a significant increased during the pandemic.

In terms of the nature of the teachers' cognitive posts on Twitter, the thematic analysis reveals that before COVID-19, teachers shared information and practices related to how to deal with face-to-face

TABLE 2 The level of teachers' posts

		Before COVID-19			During COVID-19			T-test	Cohen-d value
		% of posts	Mean	SD	% of posts	Mean	SD		
Cognitive posts	Sharing resource	17.73	4.49	2.25	19.27	7.52	3.49	-14.18**	1.40
	Sharing practice	10.18	2.57	1.55	9.42	3.67	2.39	-7.06**	0.69
	Sharing professional learning event	11.27	2.85	1.48	14.67	5.72	2.67	-10.70**	1.06
	Provide information	39.85	10.09	4.37	34.77	13.57	4.79	-15.77**	1.57
	Ask question	20.95	5.30	2.43	21.85	8.53	2.34	-10.90**	1.08
	Total	100	25.31	7.75	100	39.02	8.40	-25.59**	1.69
Affective posts: Positive sentiment	Appreciate	40.54	5.73	2.61	33.82	7.46	2.69	-17.14**	0.79
	Prayer	24.18	3.42	2.40	29.24	6.45	2.53	-32.24**	3.21
	Giving encouragement/praises	12.05	1.71	0.87	11.91	2.63	1.08	-16.70**	0.92
	Total of positive posts	74.91	10.86	4.68	74.97	16.54	4.83	-36.27**	1.193
Affective posts: Negative sentiment	Sharing fear	9.35	1.32	0.78	9.73	2.15	0.99	-16.70**	0.93
	Sharing worries/stress	15.73	2.22	0.82	15.28	2.39	1.01	-9.54**	1.15
	Total of negative posts	25.08	3.55	1.25	25.02	5.52	1.54	-16.41**	1.41
	Total of affective posts	100	14.41	4.80	100	22.06	5.03	-39.40**	1.55

* $p < 0.05$; ** $p < 0.01$.

classroom interactions, technologies used inside classrooms and some information on teachers' subject knowledge. However, during COVID-19, most teachers' tweets were related to issues of the digital transformation to learning. Teachers' discussion focused on the use of digital tools, but most tweets were related to the discussion of national platforms and portals. Teachers' tweets related to their challenges on how to use some of the digital tools. For example, teachers were asked about the use of the national learning management system, called Unified Education System, that the Saudi Ministry of Education launched for Saudi teachers and students. For example, one teacher tweeted the following:

Can anyone help me to know how I can use Unified Education System? It is the first time I am dealing with this platform.

Teachers also tweeted about another national platform called IEAN. This platform includes many online resources related to the national curriculum. Here is an example of a teacher's tweet about the e-book for the national curriculum:

You can find all of the primary books in this IEAN<URL provided>.

Also, there was discussion about some challenges of the pedagogical aspects of technology adaption. For example, one science teacher tweeted the following:

I have difficulty monitoring and assessing students' online collaborative learning. It was easy for me during class. I can see the students, but here, I just receive the final work.

Teachers also tweeted about some tools that support the pedagogical aspects of technology. For example, one secondary teacher tweeted that,

You can use some collaborative cloud generator for brainstorming activities with your students.

Also, there was discussion regarding issues related to online classroom management. For example, one teacher said that,

I have difficulty making my students focus. I feel that I am speaking with myself. Some students have poor internet connections, so they do not hear me well.

Other teachers provided information on how teachers can overcome difficulties of managing classroom online. For example,

To manage your class, you have to set some rules before the start of the lesson.

Tweets reflected the affective posts. During the pandemic, teachers acknowledged other teachers' help and appreciated it. For example,

I really want to thank you for this helpful video. It makes my life easier. Thank you, a lot.

Tweets also included supplications to God to protect them from the diseases and asked God to facilitate the learning process:

May God protect us from this disease and facilitate our work. I ask Allah to give you the strength to do your teaching.

Teachers also attempted to encourage each other through Twitter. For example, one teacher tweeted:

Do not worry, you can do it. I believe in your experience in dealing with this matter.

Teachers showed several concerns and fears in their tweets related to student assessment. For example, one primary teacher tweeted that,

I am worried about my students' assessment. The parents helped their children by provide answer. How I can ensure the quality of my assessment?

Also, there was fear and concern about the ability to use online learning tools. For example, one teacher tweeted

I am afraid if I can do my teaching very well online.

In general, teachers discussed several issues related to digital transformation and expressed some positive and negative feelings.

4.2 | RQ2: Changes in teachers' networks

The second research question focused on the effects of the pandemic on the teachers' network development. Table 3 shows a significant increase in the average size of teachers' ego networks during the COVID-19 pandemic. Table 4 shows that teachers added on average 9.77 (new ties) people to their networks and kept most of their connections and lost, on average, around 1.93 from their connections. In terms of the distribution of their new connections, Table 4 illustrates that 51.05% of their new ties were with alters from the same department while 48.95% of their new ties were with alters in different departments. In addition, 70.01% of their new connections were from people from the same country and 29.99% from a different country. Figure 2 shows the social network visualization of Teacher A both before and during COVID-19. Teacher A is female science teacher. Teacher A increased their connections during COVID-19. Teacher A

TABLE 3 Comparison of teachers' network structure

	Before COVID-19		During COVID-19		T-test	Cohen-d value
	Mean	SD	Mean	SD		
Network size	12.22	3.84	20.07	6.08	-18.10**	1.79
Indegree	5.33	2.12	10.03	4.38	-11.48**	1.36
Outdegree	6.98	2.49	13.62	5.12	-15.29**	1.65
Ties from same discipline (internal ties)	8.06	2.36	11.33	3.18	-11.17**	1.10
Ties from different discipline (external ties)	4.14	2.98	8.73	4.79	-11.43**	1.13
Discipline E-I index	-0.39	0.32	-0.19	0.35	-3.88*	0.38
Ties from same country (internal ties)	9.89	3.79	15.37	5.49	-12.82**	1.16
Ties from different country (external ties)	2.33	1.08	4.69	1.81	-12.03**	1.58
Country E-I index	-0.57	0.29	-0.50	0.21	-2.18*	0.27

* $p < 0.05$; ** $p < 0.01$.

TABLE 4 Level of new, lost and kept teachers' tie

	Sum	Mean	SD	% of the ties from similar discipline	% of the ties from different discipline	% of the ties from same country	% of the ties from different country
New ties	997	9.77	4.56	51.05%	48.95%	70.01%	29.99%
Lost ties	197	1.93	1.11	53.29%	46.70%	51.26%	48.73%
Kept ties	1050	10.29	3.94	65.33%	48.38%	82.95%	17.04%

not only kept most of their ties (10 out of 14) but also added new 19 ties.

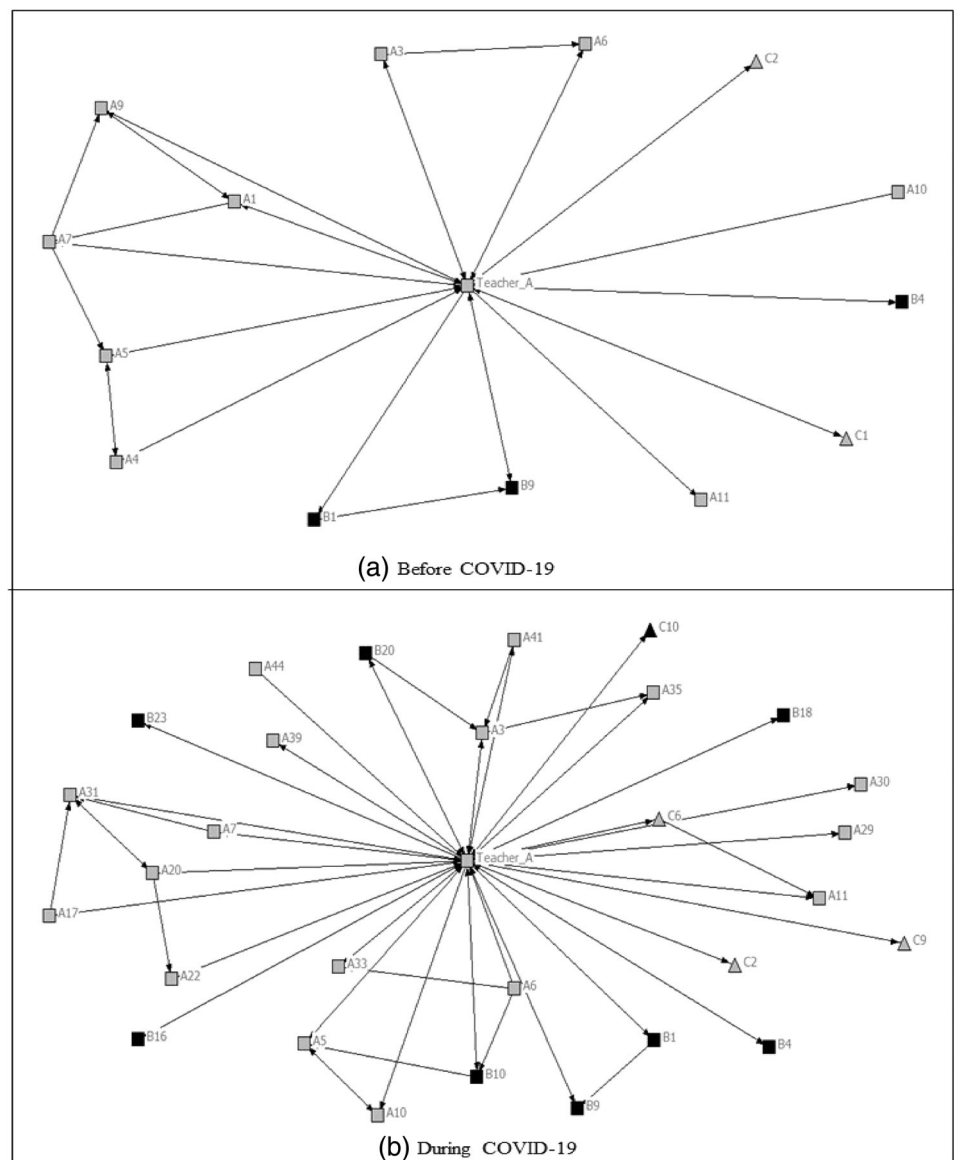
Table 3 shows that the mean number of ties that teachers created (out-degree) significantly increased from 6.98 to 13.62 during COVID-19. Similarly, the mean number of ties that a teacher received (in-degree) showed significant growth from 5.33 to 10.03 during COVID-19. Figure 2 shows that Teacher A increased her out-degree from 12 to 27 and her in-degree from 10 to 20. It seems that during COVID-19, teachers doubled their ingoing and outgoing ties. In both periods (before and during COVID-19), the number of outgoing ties was slightly higher than the ingoing ties. This means that teachers were active in creating connections and sending posts, rather than only receiving posts.

In terms of the distribution of teachers' network ties among alters (those who were directly connected) before COVID-19, Table 2 shows that around 65.95% were internal ties (alters from the same subject discipline), and 34.05% were external ties (alters from different subject disciplines). During the COVID-19 pandemic, 56.45% of ties were internal and 43.55% were external. The t-test revealed significant growth in teachers' ties both with alters from the same and different subject disciplines. In terms of the E-I index, the negative value of the E-I index before COVID-19 indicates that it was to a great degree homophilous, with most interaction happening within the same academic discipline. During the COVID-19, The value of the negative E-I index was decreased which indicate that the teachers' networks became more heterogeneous. Differences in average scores

of E-I indexes show that there was a slight but significant decrease in the E-I index over time. This means that although the teachers increased their connections with alters from different disciplines, the majority of ties were with alters from the same disciplines. Figure 2 illustrates that Teacher A increased her internal ties from 11 to 20 and her external ties from 3 to 9 during COVID-19, but the majority of their connections were with teachers from the same discipline.

In term of teachers' interactions with alters from the same country and different countries, Table 2 shows that around 65.95% were alters from the same country and 34.05% were alters from a different country (29.15% Middle East, 3% USA and 1.9% UK). During the COVID-19 pandemic, 56.45% of ties were in the same country and 43.55% were in a different country (37.95% Middle East, 3.5% USA and 2.1% UK). Table 3 shows that the ties between teachers and alters from the same country increased significantly during COVID-19. There was a slight increase over time between teachers and alters from a different country. In both periods, the value of country E-I index was negative. The negative values of the E-I index indicate that teachers' interactions were largely homophilous, with most activity occurring between alters from the same country. This means that the majority of teachers' ties were with alters from the same country. Tests indicated there were slight significant differences in average scores of E-I indexes over time. As shown in Figure 2, Teacher A increased her connections with people from the same country, from 12 to 25, and alters from different countries, from 2 to 4, during COVID-19.

FIGURE 2 Ego network of teacher A. Grey node represents teachers from similar discipline; Black node represents teachers from different discipline; Up triangle node represents teachers from different country; Square node represents teachers from similar country



In terms of the differences among primary, middle and secondary teachers in the following variables (network size, in-degree, out-degree, internals and externals ties, country E-I index and discipline E-I index), ANOVA was used to measure if there any difference between them. The results showed that there were not any significant differences between them.

5 | DISCUSSION

This study seeks to respond to gaps in the literature related to teachers' use of PLNs during COVID-19 by examining the structure of and interactions of teacher's networks on Twitter.

The first research question looked at changes in the volume and nature of teachers' PLN posts before and during the COVID-19 pandemic. The findings indicate that on average teachers posted more during the pandemic than before. This result may be

explained by the fact that the increase in post frequency occurred during lockdowns, when the majority of face-to-face activities, including professional learning workshops and training courses, were suspended. Therefore, teachers may have used Twitter as a space for professional development. As highlighted in social capital theory, teachers' PLNs can support and enhance their experience of professional learning (Fox & Wilson, 2015). Another explanation for this result is the digital transformation of the majority of school activities and education departments (Azorín, 2020). Some schools and education departments have Twitter accounts and tweeted information helpful for teachers during the crisis. Hence, teachers may have used Twitter as a channel through which to contact education departments. This implies that teachers use of PLNs on Twitter during COVID-19 contributed to their formation of social capital as teacher can access to different resources, which played a significant role in facilitating teachers' acquisition of knowledge and information.

The results also show that there was an increase in all categories of teachers' cognitive posts. Moreover, the highest percentage of posts was related to providing information, followed by asking questions. The qualitative data explain the reason for this increment. As shown in the analysis of teachers' tweets, teachers discussed issues related to the digital transformation of teaching activities online, such as the use of digital tools, pedagogical aspects of using the technology and monitoring students online. Recent studies show that moving to emergency online learning during the pandemic put teachers and the Ministry of Education under pressure, as offering intensive and comprehensive support to teachers and schools was not an easy task (Hodges et al., 2020). As seen in other studies (Pamuk, 2011), in order to apply technology effectively, teachers' knowledge and skills need to be developed. Moreover, Frank et al. (2004) found that the formation of social capital helps people to apply new technology. This implies that teachers turned to PLNs on Twitter during COVID-19 to increase their knowledge and enhance their skills with technology. A recent report from UNESCO (2020) highlighted the importance of reinforcing teachers' professional learning communities and peer learning during COVID-19 to enable them to share information and challenges, find solutions and learn from each other. Carpenter and Krutks (2015) found that educators used Twitter to reflect on their practice, ask questions and find solutions. Rodesiler (2015) found that English teachers used Twitter to engage in collaborative problem solving in order to enhance their practice. Risser (2014) found that teachers could use Twitter to get new ideas about teaching and provide information to support other teachers. The large volume of cognitive posts during COVID-19 identified in this current study may indicate that teachers engaged with their PLNs for knowledge sharing and building, which helped them to stay informed about current issues and challenges and understand how they could overcome them. Such processes play a role in building teachers' social capital, which allows them to acquire new knowledge and skills that help them to improve their classroom practice. This process of gaining support and knowledge may have encouraged teachers to continue using PLNs on Twitter during the COVID-19 pandemic.

A major implication of teachers' use of Twitter during COVID-19 was the increased opportunity to gain encouragement and reassurance. In line with social capital theory, Zou et al. (2018) argue that increasing the frequency of social interaction can provide a positive emotional experience and a sense of belonging to the community. The findings in this study show that both positive and negative affective posts increased during COVID-19. However, the number of positive affective posts was higher than the number of negative posts. These findings are consistent with those of Arora et al. (2021), who found that people posted more positive affective posts on Twitter than negative ones. The qualitative data in this study provide explanation for this result. Teachers were worried about the disease and about changing their teaching mode and may have tried to support each other emotionally by providing encouragement, appreciation and prayer to reduce the level of stress and fear. According to several researchers, such as Trust et al. (2016) and Xing and Gao (2018), teachers use Twitter as a platform to experience emotional support from a large

professional learning community. In addition, teachers' cultural and religious beliefs influence the level of positive emotional support; in this study, prayer was the second highest expression that teachers posted on Twitter to reduce the level of stress among teachers. Kaasa (2019) found that cultural and religious values can shape individual social capital. This implies that teachers networking with other teachers during COVID-19 potentially led to the formation of social capital, which allowed for the building of strong ties of solidarity with others and offered an exciting opportunity to gain encouragement and reassurance.

The second research question focused on understanding the change in teachers' professional relations on Twitter. The findings show that the size of the teachers' networks increased over time and that teachers not only kept most of their ties but also formed more ties during the COVID-19 pandemic. Moreover, teachers not only increased their activities of sharing information and asking questions by establishing relations with others (out-degree), but the number of people who responded to their questions and comments (in-degree) also increased. This suggests that teachers broadened their network to discuss their teaching practice with more people to seek solutions and provide support for others. This finding is in line with the social network theory, that is, having a large network can increase the opportunity of encountering and accessing a variety of resources (Van Waes et al., 2018). Azorín (2020) emphasized the importance of teachers building their professional learning networks during the difficult period of the pandemic in order to the education responses to the difficulties caused by the COVID-19 pandemic. One possible explanation for the results of this study is that social distancing may have reduced the frequency of teachers' face-to-face network support, forcing them to attempt to close the gap by finding support and help in a virtual environment. This is consistent with the results of other studies (Carpenter & Krutka, 2016) that show that teachers use Twitter to reduce their sense of isolation. The findings of this study suggest that the pandemic led to the emergence of a culture of collaborative networks, leading to a shift in teachers' learning from individual to collaborative and filling the gap left by reduced face-to-face PLN support. This could conceivably have led to the formation of social capital through access to the PLNs on Twitter during the pandemic. It appears that Twitter had a sustained influence on teachers forming social network relations for the period of the crisis.

In line with the principles of social network diversity, the teachers increased their interaction not only with teachers from similar departments but also from different departments. However, teachers communicated more with teachers from the same discipline. This result is similar to results of other studies related to teachers' professional networks in face-to-face contexts (Rienties & Kinchin, 2014) and on social media, such as Facebook (Alwafi et al, 2020) and Twitter (Risser, 2014), all of which found that teachers prefer to contact people from similar departments and areas of expertise. As highlighted in social network theories, network homophily is useful for teachers to discuss complex issues, but a lack of network diversity may limit the innovation (Burt, 2000). Previous studies have indicated that a lack of engagement between teachers from different departments may be

related to the difficulties that teachers encounter when attempting to express their ideas to people outside their departments (Oncu & Ozdilek, 2013). This might explain why the majority of teachers primarily contact people on Twitter from the same discipline. Teachers may find it difficult to explain their discipline's terminologies and express their ideas to other teachers, who do not know their academic jargon.

This study also found that most of the teachers' communication was with people from the same country before and during the pandemic. A possible explanation for this is that interaction between teachers from different countries may be difficult due to differences in educational systems, curriculums and languages. As seen in the qualitative data, teachers discussed issues around the national educational platform launched by the Saudi Ministry of Education. Similarly, Risser (2014) found that the majority of primary teacher contact in his study was with teachers from the same country and that discussions with teachers from different countries usually focused on common issues such as classroom management. Zhang (2017) found that the lack of intercultural communication competence regarding issues such as language and cultural awareness hindered teachers' participation in discussion with others from different countries. In line with social capital theory, Brown and Duguid (2000) argued that shared language and meaning, such as knowing common linguistic terms, is very important to develop teacher networks and communities. The language barrier may be one obstacle that prevents Saudi teachers communicating with teachers from other countries who do not speak Arabic. Therefore, education programs for teachers should include intercultural communication training (Zhang, 2017) facilitating 'worldmindedness' (Merryfield et al., 2008), thus allowing teachers to be open to other country experiences in dealing with teaching and learning during COVID-19.

As teachers have little access to international networks and teachers from different academic disciplines, one possible implication could be to raise teachers' awareness regarding how to develop networks. According to several researchers (Van Waes et al., 2018), raising teachers' awareness of networking can play a role in helping them build and form their own PLN. Therefore, teachers need support to raise their network awareness in order to build large and diverse networks effectively.

6 | LIMITATIONS

A number of limitations of this study need to be considered. First, the study used a non-random sampling approach and focused on Saudi teachers. Therefore, future research can replicate and build on this work by including random sampling and teachers from different countries. This study used a quantitative approach (SNA and content analysis) to examine teachers' professional networks and qualitative approach (analysis teachers posts). It would be valuable to use other qualitative methods (e.g., interviews) to gain more in-depth information regarding the value of teachers' professional network in helping teachers cope with this difficult time. For example, how teachers' network structures (network size and homophily) impact their classrooms and students' outcomes. Future research can also examine the impacts of teachers' networks on their anxiety and confidence levels.

Another limitation of this study is that it only analyses teacher's interactions on Twitter and does not consider interactions on other social media, such as Facebook, WhatsApp or Telegram. Trust et al. (2016) argues that teachers use different digital platforms to interact with their PLNs. Therefore, it is important that future research is undertaken to analyse teachers' interactions on different social media platforms in order to understand in-depth how teachers develop their PLNs and if there is any difference in content and network structure from one platform to another. Another limitation of this study is that it only focused on alters' academic disciplines and country as factors affecting network structure. Other factors should be taken into account in future research, such as pre-existing relationships between teachers and their alters or the impact of teaching experience. Previous research shows that friendship and working in the same school (Bokhove & Downey, 2018) and teaching experience (Van Waes et al., 2018) may affect teachers' network compositions. Thus, future research can survey both teachers and their alters.

7 | CONCLUSION

This study explores teachers' PLNs before and during the COVID-19 pandemic. School lockdowns and social distancing positively affected teachers' networks and participation on Twitter. Teachers used Twitter to share information and support each other. It seems that the isolation that has followed the COVID-19 outbreak has encouraged teachers to increase their virtual support networks. This finding reveals the significant role that social media platforms, such as Twitter, play in teachers' professional networks. The findings of this study can inform policy-makers of teacher education and professional development who might want to consider using Twitter in their training programmes. The findings of this study show that the number of teachers' posts increased during the COVID-19 pandemic, and the majority of teachers' posts focused on issues around digital transformation. This finding has important implications for the designs of teacher training programmes, which need to focus on the adaptation of technology, and for the continued support of technology use. Teachers also posted an increased number of emotional posts during the COVID-19 pandemic. One reason for this is the possibility that teachers use Twitter to express their feelings and to receive emotional support from the professional teaching community.

Although the findings show that teachers interacted with people from both within and outside their academic disciplines, the majority of interactions were between people from the same discipline and country. Therefore, teachers' awareness of the importance of contacting people outside their disciplines and countries should be considered. Van Waes et al. (2018) emphasizes the importance of increasing teachers' network awareness in order to enhance their professional learning. According to Borgatti and Cross (2003), teachers who are aware of individuals in their network and their resources and attributes, such as expertise, can contact the appropriate people at the appropriate time.

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CONFLICT OF INTEREST

No potential conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing not available due to privacy and ethical restrictions.

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