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The Role of Intra- and Inter-School Professional Interactions in Teacher Professional Learning: A Social Network Analysis of Primary Schools in Mashhad

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Abstract

This study examined the structure of professional interaction networks among primary school teachers and their relationship to professional learning. Using social network analysis, we investigated 69 second-cycle primary school teachers in District 3 of Mashhad through a census approach. Data were collected using two instruments: the Teacher Interaction Network Analysis Questionnaire and the Teacher Professional Learning Questionnaire (Liu et al., 2016), and analyzed using ERGM and PLS approaches. Key findings revealed that teachers' network size significantly influences their positional capital within the network, which in turn directly affects their professional learning. While intra-school professional consultations showed a significant positive relationship with professional learning, inter-school consultations at the district level demonstrated no significant effect. ERGM analysis identified several critical factors shaping network ties: school homophily emerged as the strongest predictor, followed by out-degree based on educational qualifications, in-degree based on school role (teaching vs. administrative), and out-degree based on teaching experience. Notably, teachers with higher qualifications (Master's and PhD) and less experience were more active in seeking peer consultations, with administrative staff (principals and deputies) receiving the majority of these professional inquiries. These findings highlighted the localized nature of professional learning networks and suggest opportunities for strengthening inter-school collaboration to enhance teacher development.

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Introduction

Teacher professional learning (TPL) is increasingly recognized as a socially situated and dynamic process, deeply shaped by the nature and quality of educators' interactions within and across school boundaries (Chen & Chen, 2025; Sutherland et al., 2023). While considerable research has examined these professional interactions—particularly in decentralized Western education systems that emphasize teacher autonomy and foster collaborative cultures (Alajmi & Al-Qallaf, 2022; González-Alfaya et al., 2024)—our understanding of such networks within centralized, top-down systems remains limited. This study addresses this critical gap by exploring the Iranian educational context, a markedly hierarchical system where policy decisions are highly centralized and teacher agency may be constrained (Kiany et al., 2011). In Iran, the formal structures of school governance often emphasize hierarchical authority and compliance, yet emerging evidence suggests that these formal mechanisms may only partially explain how teachers learn and grow professionally. Informal, organically developed networks of collegial exchange appear to play a pivotal role in facilitating knowledge sharing, fostering trust, and developing pedagogical expertise (Mehrmohammadi, 2015; Tajik & Mohammadkhani, 2017; Moolenaar, 2012). Indeed, studies have shown that these informal interactions may serve as more effective drivers of instructional innovation and sustained professional development than conventional top-down initiatives (Baker-Doyle & Yoon, 2011; Sole et al., 2018).

Social Network Analysis (SNA) offers a powerful methodological lens to uncover the structure and functioning of these relational networks. Through analytical tools that assess network characteristics such as centrality, tie strength, brokerage roles, and overall network density, SNA facilitates a deeper understanding of knowledge diffusion, the spread of innovation, and the relational dynamics that underpin teacher learning (Brown et al., 2016; Zheng & Spires, 2012). Prior research highlights the significance of certain network actors—such as central connectors who drive the diffusion of ideas, and brokers who bridge isolated groups—alongside cohesive subnetworks that both support trust and, paradoxically, may reinforce insularity (Moolenaar, 2012). Despite a growing consensus on the importance of social networks in supporting teacher development (Bridwell-Mitchell & Cooc, 2016; Demir, 2021), most studies continue to concentrate on contexts characterized by decentralization, flexibility, and high levels of teacher autonomy. By contrast, centralized systems such as Iran's remain significantly underexplored. Given its bureaucratic rigidity, strong policy control, and constrained spaces for teacher initiative, Iran presents a unique and under-investigated context for examining how professional networks function under such conditions (Mehrmohammadi, 2015). The integration of digital technologies into teacher professional learning further complicates this landscape. While national platforms like SHAD have been introduced to support instruction, their effectiveness is constrained by infrastructural limitations, insufficient training, and a misalignment with traditional, top-down pedagogical models (Akbari, 2021). The dominant instructional approach in Iran remains largely lecture-based, which may impede the formation of robust, meaningful digital professional learning communities (Shafiei et al., 2022). These challenges—stemming from the complex interplay between formal and informal, online and offline, and intra- and inter-school professional networks—highlight the need for a more nuanced, context-sensitive approach to understanding teacher learning within centralized systems. To address these gaps, this study employs SNA to systematically investigate the structure and dynamics of teachers' professional interactions within and across schools in Mashhad, Iran. Focusing on primary school teachers, the research aims to map the relational patterns that underlie professional learning in both formal and informal contexts. Specifically, the study seeks to answer the following research questions:

1. What are the structural characteristics of teachers' professional interaction networks?
2. Which teacher-related characteristics influence the formation of professional interaction networks?
3. To what extent do intra-school and inter-school interactions impact teachers' professional learning?

Theoretical framework

This section provides an integrated perspective on teachers' professional learning, emphasizing its social and interactive nature in contrast to traditional models. Utilizing research from the literature, this framework delves into the critical importance of professional interactions in driving teacher growth, the formation of social capital within learning networks facilitated by these interactions, and the utility of Social Network Analysis for gaining deeper insights into these relational dynamics.

Teachers' Professional Learning

TPL represents a new approach to professional development, marking a shift away from traditional methods such as workshops and conferences toward experiential, socially embedded processes where knowledge is co-constructed through reflection, collaboration, and workplace interactions (Hallinger, 2011). Unlike static training models, TPL thrives in environments where educators engage in collective problem-solving, share

expertise, and refine practices through feedback loops with colleagues exemplified by approaches such as lesson study in schools (Harper-Hill et al., 2022; Trulsson et al., 2023). Central to this process are two interdependent elements: (1) workplace environments that foster trust, autonomy, and reflective dialogue, and (2) professional interactions—both formal and informal—that bridge individual and organizational goals (Adams, 2017; Tran et al., 2017). Supportive leadership and a collaborative school culture act as catalysts, enabling teachers to transform routine exchanges into opportunities for growth (Park & Byun, 2021; Tai & Omar, 2022). However, the efficacy of these interactions hinges on contextual factors such as resource availability, workload equity, and institutional hierarchies, which can either amplify or stifle collaborative potential (Tahir & Musah, 2020). In the present study, therefore, professional learning is increasingly conceptualized as a dynamic, ongoing, interactive, developmental process, rather than as a series of isolated activities (Liu et al., 2016). Drawing on previous research (e.g., Hallinger et al., 2017; Liu et al., 2016; Talebizadeh et al., 2021), it consists of four dimensions: collaboration, reflection, experimentation, and reaching out to the knowledge base.

The Pivotal Role of Professional Interactions in Teachers' Professional Learning

Professional interactions among teachers—whether direct or indirect, formal or informal, physical or virtual—play a central role in shaping effective TPL. These interactions foster network exchanges, build trust-based relationships, and enable collaborative educational efforts (Penuel et al., 2009; Sjoer & Meirink, 2016). When focused on work-related matters and aligned with professional and organizational objectives, such interactions are defined as *professional interactions* (Miskel & Hoy, 2003). Collaborative social interactions and knowledge-sharing environments serve as catalysts for expanding professional networks and enhancing teacher development (Maindonald & Braun, 2010). Effective professional interactions promote knowledge exchange, shared problem-solving, and the co-construction of practices, contributing to enriched work environments and stronger collegial ties (Hunuk et al., 2019; Hunt, 2019). Continuous feedback and meaningful collaboration within these interactions foster collective learning, significantly advancing the effectiveness of TPL (Harper-Hill et al., 2022; Trulsson et al., 2023).

The success of professional interactions—and by extension, TPL—is deeply influenced by contextual conditions. Research underscores the vital roles of school leadership, trust among staff, and a supportive school learning culture (Park & Byun, 2021; Tai & Omar, 2022; Yu & Chao, 2023; Kalkan, 2016). Constructive environments encourage reflection, peer learning, and open dialogue, whereas constraints such as limited time, insufficient resources, and lack of institutional support can impede effective interaction and learning (Adams, 2017; Tahir & Musah, 2020). Professional interactions are foundational to the creation and sustenance of Professional Learning Communities (PLCs). These communities offer structured spaces for ongoing collaboration, shared accountability, and the exchange of knowledge and practices. Through fostering a culture of collegiality and discursive engagement, PLCs enhance instructional quality, support teacher development, and contribute to improved professional performance (Shaw, 2022; Trulsson et al., 2023; Hunt, 2018; Hunuk et al., 2019; Liang et al., 2024; Zhang et al., 2024; Saclarides, 2022; Boada, 2022; Poulsen et al., 2024; Sjoer & Meirink, 2016; Shannon et al., 2021; Gonzalez, 2024; Admiraal et al., 2016; Peña Ros, 2023; Yu & Jang, 2023; Nguyen et al., 2024; Nipyrakis et al., 2023; Antinluoma et al., 2021; Shah & Malik, 2024; DuFour, 2004; Carmi et al., 2022; Banoğlu et al., 2023).

In parallel, teachers' Professional Learning Networks (PLNs) are crucial in building and sustaining social capital—a web of professional relationships characterized by mutual support, shared resources, and collaborative opportunities (Demir, 2021; Sole et al., 2018; Bridwell-Mitchell & Cooc, 2016). This networked capital enhances school functioning and deepens professional relationships, leading to improved student outcomes and sustained teacher development (Bridwell-Mitchell & Fried, 2020; Zhang et al., 2024; Liang et al., 2024). Key elements such as trust, mutual respect, and shared norms (Alajmi & Al-Qallaf, 2022; Demir, 2021; Bridwell-Mitchell & Cooc, 2016; Penuel et al., 2009; Yu & Chao, 2023; Mei Kin & Abdull Kareem, 2021) are essential for enabling open communication, joint problem-solving, and the effective exchange of instructional strategies within both PLNs and PLCs.

Understanding Professional Interactions Through Social Network Analysis

Social Network Analysis provides a powerful framework for understanding the intricate relationships within professional settings. Shifting the focus from individual characteristics, SNA examines the patterns and structures of connections among individuals or groups. By mapping and analyzing these connections, it offers valuable insights into how information flows, influence is exerted, and collaborative efforts are organized. This is clearly exemplified in Moolenaar's (2012) research, which demonstrates how SNA can illuminate the nature and extent of teacher collaboration, impacting teaching practices, innovation adoption, and school improvement.

SNA proves to be a valuable tool for

understanding professional interactions due to its ability to reveal hidden structures beyond formal hierarchies, identifying key connectors, isolates, and subgroups. It facilitates the understanding of information flow, identifies influence through centrality measures, and analyzes collaboration patterns via network density and cliques. As highlighted in Moolenaar's work (2012), these aspects are crucial for understanding teacher dynamics. Furthermore, SNA's utility extends to analyzing communication patterns to identify key actors and mediators (Maya-Jariego et al., 2023), understand trust patterns (Brown et al., 2016), analyze teacher isolation (Bakkenes et al., 1999), examine the development of PLCs (Diehl, 2020), and map interactions in various environments (Lin et al., 2016; Zheng & Spires, 2012).

Moolenaar's (2012) research likely utilizes key SNA concepts to analyze teacher collaboration. These include nodes (representing teachers), edges (representing interactions), network density (indicating overall interconnectedness), and centrality measures (such as degree, betweenness, and closeness) to identify influential teachers. Concepts like cliques (tightly-knit groups) and structural holes (gaps in the network) are also likely explored to provide a comprehensive understanding of the collaborative landscape. The application of SNA, as demonstrated by Moolenaar's findings, offers practical benefits for designing effective collaboration initiatives, identifying key influencers to support change, addressing teacher isolation, evaluating the impact of interventions, and improving communication and knowledge sharing. By mapping the flow of information, trust, and collaboration within teacher networks, SNA provides a data-driven perspective on professional learning, enhancing our understanding of how teachers engage with PLCs and how these engagements ultimately influence pedagogical development (Sole et al., 2018; Baker-Doyle & Yoon, 2011). This underscores the significant role of SNA as a tool for gaining actionable insights into professional interactions, particularly within the educational context explored by Moolenaar. In this study, we defined a network as the set of professional interactions among teachers consistent with social network analysis frameworks (Moolenaar, 2012). This definition is linked to our study's focus on intra- and inter-school interactions and their role in professional learning, ensuring clarity and alignment with our theoretical framework.

Method

This study employs social network analysis to investigate the structure and impact of intra- and inter-school professional interactions on teachers' professional learning among primary school teachers in District 3 of Mashhad, Iran. We adopted a quantitative survey approach to collect data on teachers' professional interaction networks, aligning with the study's primary aim of mapping relational ties across a whole network of 69 second-cycle primary school teachers. This methodological choice was driven by the unique requirements of SNA, which necessitates comprehensive and systematic data on interactions among all network members to analyze network structures and their effects accurately (Moolenaar, 2012; Luke, 2015). Quantitative surveys, specifically name-generator questionnaires, were selected as the most effective method for capturing the breadth and frequency of intra- and inter-school professional interactions. These instruments allow researchers to collect standardized data on who interacts with whom, enabling the construction of complete network maps suitable for advanced statistical analyses such as Exponential Random Graph Modeling (ERGM) and Partial Least Squares Structural Equation Modeling (PLS-SEM) (Hair et al., 2021).

Sample and data collection procedure

Data were collected from 69 in-service, second-period (grades 4–6) primary school teachers working across 16 public elementary schools, achieving a 100% response rate through total population sampling. These schools were purposefully selected due to the presence of stable teaching staff who had worked together for at least one academic year, enabling the analysis of sustained professional interactions. District 3 of Mashhad City was chosen because it hosts the highest concentration of experienced teachers among all educational districts in the city, providing a robust context for examining professional networks. This whole-network approach ensured comprehensive mapping of intra- and inter-school professional ties, critical for analyzing network characteristics, including low density (0.01), high eigenvector centrality (0.95), and strong school homophily (β=3.842, $p<0.001$).

The sample was predominantly female (88.4%), consistent with the gender distribution of primary education teachers in District 3. Educational qualifications among participants included bachelor's degrees (53.6%), master's degrees (34.8%), doctorates (4.3%), diplomas (5.8%), and postgraduate diplomas (1.4%). While the teachers had an average of 22.8 years of total teaching experience (M = 22.77, SD = 8.2; range = 3–38), their average tenure within District 3 was only 6.7 years (M = 6.67, SD = 7.1; range = 1–30), suggesting reliance on newly established intra-school professional ties for support and collaboration. On average, each school had 4.3 participating teachers (M = 4.3, SD = 2.1), all of whom had at least one full academic year of shared professional experience, ensuring stable interaction

patterns. Schools had an average student population of approximately 250 (M = 250.0, SD = 90.5). Further demographic information is presented in Table 1.

Table 1. Demographic Characteristics of Participating Teachers (N = 69; Schools = 16)

Variable	Category/ Statistic	n (%) / Value
Gender	Female	61 (88.4%)
	Male	8 (11.6%)
Education level	Diploma	4 (5.8%)
	Postgraduate diploma	1 (1.4%)
	Bachelor's degree	37 (53.6%)
	Master's degree	24 (34.8%)
	Doctorate	3 (4.3%)
Total teaching experience (years)	Mean (SD)	22.77 (8.20)
	Median (Q1–Q3)	23 (19–28)
	Range	3–38
Teaching experience in District 3	Mean (SD)	6.67 (7.10)
	Median (Q1–Q3)	3 (2–11.5)
(years)	Range	1–30

Instruments

Two questionnaires were used for data collection. First, we collected data related to interactions between teachers using an open-ended name-generator questionnaire. This questionnaire, which has been validated by educational experts, measures teachers' intra-school and inter-school interactions in the field of educational issues (including teaching, classroom management, ambiguity about various directives, and working with educational and specialized software). To map the network of intra-school and inter-school interactions, teachers were asked to respond to two questions: *1- To ask your educational questions, which colleagues do you turn to in school? 2- To ask your educational questions, which of your colleagues outside the school (at the level of District 3) do you turn to? (With emphasis on the non-retired colleagues)*. Respondents could name colleagues who were at any level in the organizational hierarchy, were at the same level or other levels, worked in the educational or administrative sectors, and asked them their questions in real or virtual spaces. Given that the name-generator questionnaires require the disclosure of individuals' names, one of the important ethical considerations is to maintain the confidentiality of the respondents' information. To this end, when distributing the questionnaires among the participants, we first provided explanations to the participants about the nature of the research and the method of data analysis. We convinced them that the data were going to be analyzed anonymously and with all personal identifiers removed. Thus, during the data analysis, each person was given a code to ensure the anonymity of the participants, and codes were used in the analyses instead of names. Then, we asked them to declare their willingness to participate in the survey. Finally, a commitment form was used to assure the participants that their information would be kept confidential.

Second, the teacher professional learning scale was used as the main dependent variable to measure the extent to which teachers take part in workplace professional learning. The scale was originally developed by Liu et al. (2016), consisting of 25 items that grouped under four concepts: collaboration, reflection, experimentation, and reaching out to the knowledge base. All items are measured using a five-point Likert type scale (ranging from 1 = strongly disagree to 5 = strongly agree). The TPL scale was translated and adapted into the Iranian culture by Talebizadeh et al. (2021). In this study, as presented in Table 2, the factor loadings of all components exceed the recommended threshold of 0.70, indicating that the items are appropriate measures of their respective constructs (Hair et al., 2021). Convergent validity was then assessed using the AVE index, while internal consistency reliability was examined through the Alpha, rhoC, and rhoA indices (Hair et al., 2021, p. 80). As shown in Table 2, the AVE values are above 0.50 and the Alpha, rhoC, and rhoA coefficients are all greater than 0.70, suggesting strong correlations among the items within each construct. These findings support the reliability and validity of the measurement model, consistent with previous research such as Talebizadeh et al. (2021), which reported a reliability coefficient of 0.95.

Table 2. Validity and reliability of professional learning questionnaire

Factor	Loading
Collaboration	0.87
Reflection	0.94
Experimentation	0.85
Knowledge Base	0.94
Professional Learning	
α = 0.92	
rhoC = 0.94	
rhoA = 0.95	
AVE = 0.81	

$N = 69$.

Data Analysis

To present a clear picture of the network of teachers' professional interactions explain how this network is formed by teachers' characteristics and examine the impact of teachers' intra-school and inter-school professional interactions on their professional learning, a three-step process was followed:

First, to describe the structure of the complete network, indices such as *mutuality*, *density*, *geodesic*, *clustering coefficient*, and *network centralization* were calculated using the *igraph R*-package. *Mutuality* is the ratio of reciprocal ties to the total number of ties in the network. The *density* is the ratio of the number of existing ties to the total number of ties in the network. The *geodesic* is the average length of the shortest path between each pair of network nodes. The *clustering coefficient* shows how well nodes can establish ties among their network members. The *network centralization* shows how well a graph is formed around its central nodes. The fewer the number of central nodes in a graph, the greater the probability that the graph is central around those nodes. Conversely, in less centralized graphs, the probability that the degree of centrality of nodes is approximately equal is higher. Depending on the type of centrality of nodes (degree, between-ness, or eigenvector), the network centralization can also be degree, between-ness, or eigenvector.

Second, we used the *Exponential Random Graph Model* (ERGM) to model the effect of teachers' characteristics on the formation of professional interactions between them. ERGM is one of the most powerful and widely used approaches for building and testing statistical network models. Because it allows for predicting the characteristics of the whole network using the characteristics of actors and the structure of the network. For example, having a specific characteristic may affect the formation of new ties. Also, having similar characteristics may affect the formation of a tie between two actors. All ERGMs contain the edges factor. This factor acts as a starting point for the model, ensuring that the simulated networks have a similar number of ties to the observed network, and using logistic transformation, it shows the overall density of the network (Luke, 2015). To examine the effect of characteristics such as school, education, teacher position in the school (educational or administrative), and teaching experience according to the type of variable, four factors were used: *nodematch*, *mutual*, *nodeofactor* for nominal and ordinal variables (or *nodeocov* for interval variables) and *nodeifactor* for nominal and ordinal variables (or *nodeicov* for interval variables). The *nodematch* factor tests the hypothesis of homophily (the tendency to form relationships with similar people). Whether the probability of forming a tie between two teachers who are in the same school increases compared to two teachers who are not in the same school. Whether the probability of forming a tie between two teachers who have the same level of education increases compared to two teachers who do not have the same level of education. The *mutual* factor in directed networks tests the hypothesis of reciprocity of relationships based on a given attribute. Does the probability of establishing a tie from the first teacher to the second teacher, both of whom have the same level of education, increase under the influence of a tie from the second teacher to the first teacher? The *nodeofactor* (or *nodeocov*) factor and the *nodeifactor* (or *nodeicov*) factor test the out-degree and in-degree hypotheses, respectively, based on a given attribute. Does the out-degree of teachers with higher education increase significantly compared to the out-degree of teachers with lower education? Does the out-degree of teachers with higher teaching experience increase significantly compared to the out-degree of teachers with lower teaching experience (out-degree hypotheses)? Similar hypotheses can be raised for in-degree as well. In addition, does the in-degree of educational teachers increase significantly compared to the in-degree of administrative teachers (in-degree hypotheses)? The ERG model was estimated using the *ergm R*-package.

Third, we employed *Partial Least Squares Structural Equation Modeling* (PLS-SEM) to examine the effects of teachers' intra-school and inter-school professional interactions on their professional learning. PLS-SEM is a non-parametric technique that does not rely on assumptions of

normal data distribution and is well-suited for analyzing small sample sizes, as it achieves relatively high statistical power under such conditions. It can also handle data measured on interval or relative scales. The primary aim of PLS-SEM is to maximize the explained variance of endogenous latent variables by sequentially estimating partial relationships through PLS regressions. Overall, it is considered an appropriate method for theory development and for predicting the variance of dependent variables, particularly when data are non-normally distributed or sample sizes are limited (Hair et al., 2021). In this study, PLS-SEM was estimated and visualized using the seminr package in R.

Results

Description of the Structural Characteristics of Teachers' Professional Interactions Network

The structural characteristics of the teachers' professional interactions network in District 3 of education, Mashhad City are described in Table 3**.** As can be seen, this network consists of 158 elementary school teachers in District 3 of education, Mashhad city as network nodes connected by 244 ties. The content of relations is the exchange of professional information between teachers. The mutuality index shows that only 13% of the network ties are reciprocal. The network density is too low and equal to one percent. Therefore, it is a sparse network. The geodesic index indicates that each teacher can connect with other teachers through 3.88 ties on average. With a clustering coefficient of 14%, this network does not have the potential to form sub-networks with strong intra-group relationships. In other words, teachers in this network have poor networking performance. The degree, between-ness, and eigenvector centralization indices show how much a network is formed around nodes with high degree, between-ness, or eigenvector centrality. Since the values of degree and between-ness centralization indices are too low (equal to 3 and 1 percent, respectively), it can be said that the teachers' professional interactions network is not formed around teachers with high degree or between-ness centrality. However, given the high value of the eigenvector centralization index, it can be concluded that this network is essentially formed around teachers with high eigenvector centrality. These are associated with the majority of teachers who have a high score of degree centrality in the network.

Table 3. Structural characteristics of teachers' professional interactions network

Network Index	Value
Number of Nodes	158
Number of Ties	244
Mutuality	0.13
Density	0.01
Geodesic	3.88
Clustering Coefficient	0.14
Degree Centralization	0.03
Between-ness Centralization	0.01
Eigenvector Centralization	0.95

In Figure 1, the names of the schools are represented by capital letters, and the tie between each pair of teachers from two different schools is represented by a colored bar. The number of bars indicates the number of inter-school links, and the two ends indicate the schools to which that tie belongs (for example, teachers from school M are connected to 3 teachers from schools C, I, and O). It is worth noting that schools J and L have been removed from the graph because they lacked inter-school ties. In total, only 5 out of 16 schools have more than 5 inter-school ties (C, F, H, O, and P). In general, the number of inter-school links is much weaker than the intra-school ties.

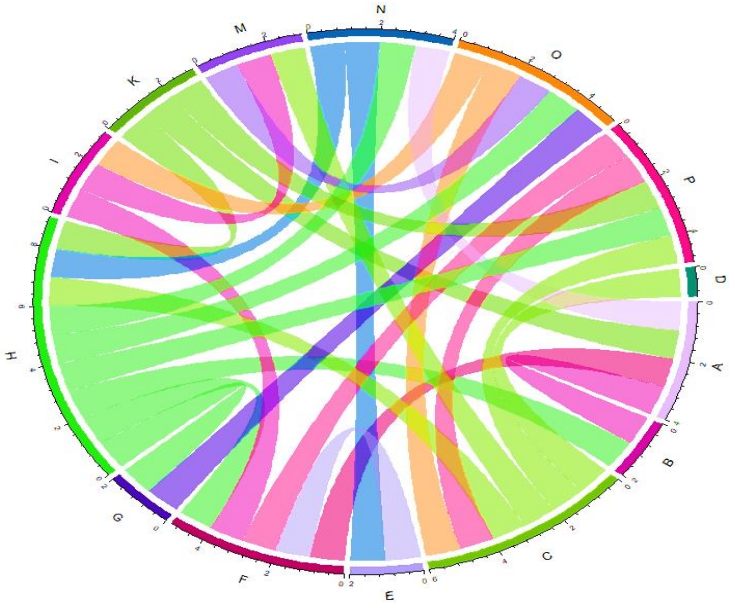

Figure 1. Graph of teachers' inter-school professional interactions

The Effect of Teachers' Characteristics on the formation of professional interactions

The ERG model was used to examine the effect of teachers' characteristics on the formation of professional interactions between teachers. Initially, all four characteristics—school, education, position in school, and teaching experience—were included in the model (Model 1 in Table 4). Characteristics that did not significantly impact the model were removed, resulting in the revised model (Model 2 in Table 4). The estimation results for both models are presented in Table 4.

Table 4. The estimation of the ERG model

	Model 1		**Model 2**		
	B	S.E.	*B*	S.E.	**MC**
Edges	-5.007***	0.404	-4.809***	0.270	-
Nodematch School	3.766***	0.151	3.842***	0.145	**0.96**
Nodematch Education	0.014	0.141			
Mutual by Education (0)	0.455*	0.219			
Mutual by Education (1)	0.020	0.296			
Nodeofactor Education (1)	0.329*	0.148	0.284*	0.147	**1.00**
Nodeifactor Education (1)	0.248	0.151			
Nodeifactor Position (1)	-0.249*	0.145	-0.291*	0.141	**1.00**
Nodeocov Teaching Experience	-0.039***	0.009	-0.039***	0.009	**0.88**
Nodeicov Teaching Experience	0.001	0.010			

Notes: $* p < 0.05$, $** p < 0.01$, $*** p < 0.001$.

According to Table 4 (Model 1), the first factor affecting the formation of teachers' professional interaction network is homophily in school (Nodematch School). The positive and significant impact of this factor indicates that teachers in each school prefer to ask their professional questions to colleagues from their school rather than teachers from other schools. The second factor is the formation of mutual ties between teachers with a bachelor's degree or less (Mutual by Education (0)). The positive and significant impact of this factor shows that the formation of reciprocal ties between teachers with a bachelor's degree or less is more likely than between teachers with a higher degree. By removing factors that do not have a significant impact, the influence of the above factor also becomes insignificant. As a result, it was removed from the final model (see Model 2 in Table 4). The third factor is the out-degree of teachers by educational level (*Nodeofactor Education*). The positive and significant impact of this factor indicates that the tendency to ask professional questions increases with increasing education. In other words, the network of professional interactions of teachers with higher education (master's degree or higher) is wider than the network of professional interactions of teachers with lower education. The fourth factor is the in-degree of teachers by position in the school, which includes teaching or administrative positions (*Nodeifactor Position*). The negative and significant impact of this factor indicates that the in-degree of administrative teachers is significantly higher than the in-degree of

educational teachers. In other words, most teachers ask their professional questions to the school administrative staff (i.e., the school principal and assistants) rather than to other teachers. The last factor is the out-degree of teachers by teaching experience (*Nodeocov Teaching Experience*). The negative and significant impact of this factor shows that increasing teaching experience leads to a decrease in referring to other teachers to ask professional questions. In Model 1 (in Table 4), the effects of factors such as homophily in education (*Nodematch Education*), the formation of reciprocal ties between teachers with master's degree or higher (Mutual by Education (1)), in-degree of teachers by educational level (Nodeifactor Education), and in-degree of teachers by teaching experience (Nodeicov Teaching Experience) were not significant. By removing the above factors in Model 2 (Table 4), it was determined that the other remaining factors in the model, except for Mutual by Education (0), still had a significant impact. Model 2 (in Table 4) constitutes the optimal model of this study. The Edges term is the constant value of the model. Monte Carlo simulations were used to examine the fit of the optimal model (Model 2 in Table 4) to reality, the results of which are presented in the last column of Table 4. If the MC value exceeds 0.05, it indicates that the model fits reality. As can be seen in Table 4, the MC value for all factors in Model 2 is greater than 0.05, which means a good fit of the model to reality.

The Effect of Intra-School and Inter-School Interactions on Teachers' Professional Learning

The PLS model was used to examine the effect of intra-school and inter-school professional interactions on teachers' professional learning. In this study, we found a positive and significant relationship between the size of teachers' networks and their out-degree, which refers to the number of times teachers refer to one another when asking professional questions. This correlation is strong, with a value of 0.83, and it is significant at the 0.001 level. Thus, it is assumed that teachers who have larger networks, or more contacts, are more likely to establish greater intra-school and inter-school relationships. The estimated path coefficients and significance levels are presented in Table 5, and the corresponding model is shown in Figure 2.

Table 5. The estimation of the PLS model

	Original Est.	**Bootstrap Mean**	**Bootstrap SD**	**T Stat.**	**CI**	
					2.5%	**97.5%**
Ego-net Size → In-school Out-degree	0.633	0.630	0.099	6.413	0.402	0.782
Ego-net Size → Bet-school Out-degree	0.773	0.771	0.059	13.180	0.643	0.871
In-school Out-degree → Professional Learning	0.366	0.379	0.101	3.619	0.177	0.567
Bet-school Out-degree → Professional Learning	-0.004	0.007	0.109	-0.030	-0.191	0.218
(*In-school Out-degree*)$\boldsymbol{R^2}$	0.401					
(*Bet-school Out-degree*)$\boldsymbol{R^2}$	0.598					
(*Professional Learning*)$\boldsymbol{R^2}$	0.133					

According to Table 5, since the T-statistic for the first two paths is greater than 1.96 and the estimated confidence interval for these paths does not include zero, we find that the teacher's network size (the number of her contacts) has a significant impact on both her intra-school and inter-school professional referrals. The positive impact of network size on both paths indicates that the amount of intra-school and inter-school professional referrals increases with increasing network size. In addition, the T-statistic for the third path is greater than 1.96, and the estimated confidence interval for this path also does not include zero. Therefore, the impact of intra-school professional referrals on professional learning is positive and significant at the 0.05 level. This is while the T-statistic for the fourth path is less than 1.96, and the estimated confidence interval for this path includes zero. In other words, the impact of inter-school professional referrals on professional learning is not significant at the 0.05 level.

As can be seen in Table 5, the r^2 value of professional learning is 0.13. In other words, 13 percent of the variation in professional learning is explained by intra-school professional interactions.

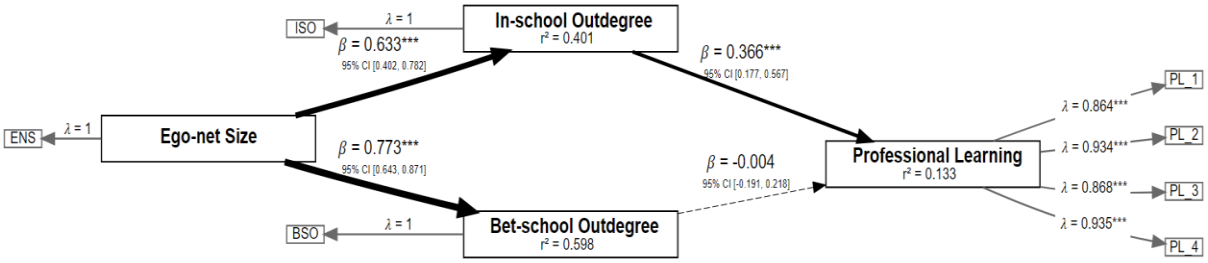

Figure 2. The PLS model

Discussion and conclusion

This study investigated the structure of professional interaction networks among elementary school teachers in District 3 of Mashhad City, explored the teacher characteristics influencing the formation of these interactions, and examined the impact of both intra-school and inter-school interactions on teachers' professional learning. The findings reveal a sparsely connected network with distinct patterns of interaction shaped by teacher characteristics and differential effects on learning based on the locus of interaction. The network analysis reveals a sparse professional landscape characterized by low density (0.01), limited mutuality (0.13), and low clustering (0.14). This indicates a network where connections are relatively few, often non-reciprocal, and teachers do not form tightly-knit, overlapping cliques. While degree (0.03) and betweenness (0.01) centralization are low, suggesting the absence of dominant hubs or brokers based on sheer connection count or bridging positions, the high eigenvector centrality (0.95) points to a structure where influence and access to information are concentrated among a set of interconnected teachers who are themselves well-connected.

Furthermore, the structural analysis highlighted the significant disparity between intra-school and inter-school ties. Visual inspection (Figure 1) and the low number of inter-school connections, with some schools completely isolated, underscore the strong tendency for interactions to occur within school boundaries. This finding is crucial for understanding the context of professional collaboration in this district. This strong school homophily emerges as the most influential factor in network formation according to the Exponential Random Graph Model (β=3.842, p<0.001). Teachers exhibit a pronounced preference for seeking professional support from colleagues within their own school. This tendency aligns with existing literature suggesting that pre-existing trust and familiarity built through daily interactions within the school environment foster stronger, more readily accessible professional ties (Kolleck et al., 2021; Banoglu et al., 2023). This finding underscores the school as the primary locus of professional interaction.

The ERGM analysis (Table 4, Model 2) definitively identified school homophily as the most potent factor driving tie formation (β=3.842, p<0.001). Teachers demonstrated an overwhelming preference for seeking professional support from colleagues within their own school. This aligns with prior research emphasising the role of physical proximity, pre-existing trust, and the familiarity fostered through daily routines in strengthening intra-organizational ties (Kolleck et al., 2021; Banoglu et al., 2023). Beyond school affiliation, specific teacher characteristics significantly influenced interaction patterns:

1. *Educational Qualification:* Teachers holding advanced degrees (Master's or higher) were more likely to initiate professional learning interactions (Nodeo factor Education β=0.284, p<0.05). This suggests that advanced education may cultivate a disposition towards collaborative knowledge construction and result in larger ego-networks, as supported by the correlation between out-degree and ego-net size.
2. *Administrative Position:* School administrators (principals and vice-principals) received significantly more professional learning inquiries compared to classroom teachers (Nodeifactor Position (1): β=−0.291, p<0.05; negative coefficient indicates higher in-degree for administrators). This likely reflects the hierarchical structure of the Iranian educational system, where administrators are perceived as key sources of official guidance and evaluative information, although teaching peers might offer more contextually relevant pedagogical advice.
3. *Teaching Experience:* Increased years of teaching experience were associated with a reduced tendency to seek professional learning support from colleagues (Nodeocov Teaching Experience: β=−0.039, p<0.001). While novice teachers understandably rely heavily on peer support, more experienced educators may increasingly depend on their accumulated practical wisdom (Cardno, 2005; Ben-Amram, M., & Davidovitch, 2024). However, this potentially limits opportunities for reciprocal learning and prevents

experienced teachers from engaging with novel pedagogical perspectives, hindering continuous professional growth.

Consistent with social capital and learning theories, our findings demonstrate a positive relationship between the size of teachers' interaction networks and their centrality, which in turn facilitates professional learning. Engaging with a wider array of colleagues enhances access to diverse information and perspectives, aiding pedagogical problem-solving. This aligns with literature highlighting professional interactions as foundational to collaborative learning communities where educators engage in reflection, knowledge sharing, and pedagogical innovation (Evers, 2015; Kwakman, 2003). Theoretically, this resonates with Hallinger's (2011) view of professional learning as inherently collaborative and Bandura's (1977) social learning theory, which emphasizes learning as a socially mediated process rooted in meaningful relationships. The PLS path model provided crucial nuance, confirming that network size significantly predicted centrality, which strongly predicted professional learning. However, disaggregating interactions revealed that only *intra-school* professional consultations exerted a significant positive influence on professional learning ($\beta=0.366$, $p<0.05$). *Inter-school* consultations showed no statistically significant effect. This finding starkly underscores the functional importance of the immediate school context for professional development in this district. Interactions within the school, likely characterized by shared context, frequent exchanges, and established relationships, appear uniquely conducive to impactful pedagogical knowledge sharing, collaborative problem-solving, and joint planning. The ineffectiveness of inter-school ties for learning likely stems from their scarcity and potential superficiality, reflecting the structural fragmentation observed. The lack of "boundary spanners"—individuals connecting otherwise separate school-based clusters—appears critical. In line with Burt's (2000) theory of structural holes, the absence of actors bridging these gaps limits the diffusion of diverse knowledge and practices across the district, diminishing the potential value of inter-school networks.

Implicit in the preference for intra-school ties and their effectiveness is the crucial role of trust. Meaningful knowledge exchange necessitates relational trust, allowing teachers to share vulnerabilities, seek advice, and offer feedback without fear of negative judgment (Mitchell & Cook, 2016). Teachers gravitate towards colleagues perceived as both expert *and* trustworthy (Kolleck et al., 2021; Banoglu et al., 2023). The relational infrastructure built through daily interaction within schools naturally fosters higher levels of trust compared to the often-weaker ties between colleagues in different schools. Consequently, fostering trust, particularly across school boundaries, emerges as a key leadership challenge (Lee et al., 2016). Trust-based networks enhance relational cohesion, stimulate knowledge flow, and create the supportive climate essential for professional growth (Johnson et al., 2011; Dulfer et al., 2023; Demir, 2021).

Implications for Practice and Policy

Based on the study's findings that professional learning among elementary teachers in Mashhad's District 3 is heavily reliant on strong intra-school networks while inter-school collaboration is weak and underutilized, several key implications for practice and policy emerge. Firstly, recognizing the current strength of within-school ties, it is crucial to prioritize and resource initiatives that further enhance intra-school collaboration, such as allocating dedicated time for peer learning, supporting school-based professional learning communities, and training leaders to cultivate trusting internal cultures. Simultaneously, addressing the identified weakness in inter-school connections requires intentional action: policymakers should consider mandating or funding structured district-wide collaboration programs (like school clusters or subject networks), and district administration should leverage roles like liaisons or "boundary spanners" to build trust and facilitate knowledge exchange across institutions. Furthermore, the study highlights the importance of individual roles; supporting school leaders as information hubs and strategically considering teacher placement—perhaps mixing experienced and novice teachers for mentorship or exploring voluntary cross-school experiences—can help diversify networks and leverage expertise, all underpinned by the need to foster a district-wide culture of trust and professional generosity.

Limitations and Suggestions for Future Research

In the spirit of transparency, we wish to highlight several limitations regarding this study's sample, measures, and data analysis. Building upon these findings and limitations, several avenues for future research are suggested for scholars interested in teacher professional networks and their impact on learning: first, Future research should consider employing a variety of data collection techniques beyond self-report questionnaires, such as interviews, observations, or analysis of communication data (if ethically permissible), to capture a more comprehensive and potentially less biased representation of teacher professional networks, including weaker or less frequently reported ties, particularly those extending across schools. Second, Scholars should examine how informal relationships among teachers interact with and influence formal professional interactions.

Understanding the combined effect of both types of ties is crucial for a complete picture of knowledge flow, support structures, and their impact on teacher professional learning. Mixed-methods approaches could be particularly valuable here. Third, Future studies could delve into the specific types of information, support, and collaborative activities exchanged within different network ties (intra- vs. inter-school, formal vs. informal) and assess how the quality and relevance of these exchanges relate to professional learning outcomes. Forth, Research could design and rigorously evaluate interventions aimed at strengthening both intra-school collaboration and the development of impactful bridging ties across schools, assessing their long-term effects on network structure, teacher behavior, and professional learning.

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