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ARTICLE



Who chooses whom for professional interaction? A sociometric inquiry into teacher leadership

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ABSTRACT

Given the dyadic and multi-layered nature of professional relations, informal teacher learning mostly goes through complex, non-linear, and context-dependent professional interactions. Advice-seeking relationships (ASRs) are the most common form of informal interactions between teachers. However, due mostly to analytical constraints, little is known about the factors influencing ASRs in school settings. The paper aims to provide an empirical base for understanding the informal leadership exercised through between-teacher ASRs around technological and pedagogical expertise. To that end, inferential social network analysis (SNA) techniques are employed. Results showed teacher perception of positive school culture promotes pedagogical ASRs. Administrative leadership is significant in one-way advice flows from administrators to subordinates. Interpersonal similarities by gender and teaching experience are influential in peer selection for ASRs. Hybrid-expertise teachers, being equally headed for technological and pedagogical advice, occupy more central position in advice-networks. Regardless of school culture, technology-savvy teachers are more preferred for ASRs. The more teachers provide colleagues with technological advice, the more they assume a leading position for pedagogical advice, but not vice versa. Overall, the present SNA study sheds light on relational complexities of teacher leadership for professional learning that otherwise might not be salient when investigated using linear models on individual metrics.

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Introduction

In today's relationally complex world, teacher leadership is less manifested in formal/positional authority, while it is far more networked through informal professional interactions both within and across school boundaries (Muijs 2015, Spillane *et al.* 2015, Diaz-Gibson *et al.* 2017, Azorín 2019, Harris *et al.* 2021). In this account, advice-seeking relationships (ASRs) are promising to be the very fabric of those collegial ties by which certain teachers assume informal leadership positions on the advice networks (Coburn *et al.* 2010, Shea 2020). There is broad agreement that professional interactions pave the way for informal teacher leadership by facilitating the spread of knowledge, innovation, and change in teacher networks, which in turn add to school improvement by enhancing collective learning mechanisms (Farley-Ripple and Buttram 2013, Hargreaves and O'Connor 2018, Azorin 2020).

Beyond this theoretical coherence, however, a practical question of how ASRs can harness teacher leadership and permeate organisational learning culture throughout the school is still up for discussion, given the lack of empirical evidence. One probable reason for this scarcity lies in the decades-long confusion over what teacher leadership means in a practical sense (York-Barr and Duke 2004, p. 288): ‘Teacher leadership is an umbrella term that includes a wide variety of work at multiple levels in educational systems, including work with students, colleagues, and administrators and work that is focused on instructional, professional, and organisational development’. Building the concept with such a broad scope may provide scholars and practitioners with a general sense but cannot refer to what teacher leadership does and does not entail (Schott *et al.* 2020). When considered in generic terms, therefore, teacher leadership can potentially fit into a large variety of positions and meet the needs of any situation. Yet, this ‘muddiness’ cannot offer practical guidance unless the content and context of those professional interactions leading to teacher leadership are clearly defined (Wenner and Campbell 2017). To avoid such conceptual ambiguity, the current study parsimoniously addresses teacher leadership in terms of teacher engagement in professional interactions and advice-provider positionality in multiplex advice networks (Siciliano 2017). Following York-Barr and Duke’s (2004) definition, the present study views teacher leadership as the process through which teachers, both individually and collectively, encourage their colleagues, administrators, and other members of the school community to enhance teaching and learning with the goal of improving student learning and accomplishment. In this way, teacher leadership is reflected through the distributed leadership lens of Spillane and Coldren (2011), taking into account between-teacher professional interactions, such as ASRs, resulting cultural changes and social influence process that may support or impede teaching and student learning on the whole.

The integrity of teachers’ technological and pedagogical competencies has largely been addressed in a growing number of studies guided by technological pedagogical content knowledge (TPACK) model (Koehler *et al.* 2013, Mishra and Koehler 2006, Gur and Karamete 2015). Research on teacher networks has also shown that technological and pedagogical knowledge sharing are more likely to occur between teachers when they confronted with a problem demanding any of these skillsets (Frank *et al.* 2004, Farley-Ripple and Buttram 2013). Yet, the concurrent nature and reciprocity of technological and pedagogical advice exchanges between teachers have not yet been thoroughly investigated (cf. Ryymin *et al.* 2008). These informal advice-seeking conversations happen among educators in every school, though, they are, by their nature, difficult to study systematically because of their informality. In response to this complexity, the paper suggests that the application of social network analysis may be a helpful approach to addressing this issue.

When choosing with whom to engage in ASRs, for instance, teachers are expected to contact expert colleagues, such as technology-savvy teachers for ICT-related problems or senior teachers for pedagogical issues in particular (Frank *et al.* 2004). More precisely, technology-savvy teachers refer to expert colleagues who are more preferred as informal teacher leaders than others to be sought out for professional advice about educational technologies (Kelly 2015). While some may turn to colleagues with *hybrid expertise* as they can incorporate both technological and pedagogical expertise into their professional interactions (Ryymin *et al.* 2008), Margolis (2012) defines hybrid expertise in terms of professional abilities for teachers to inspire their colleagues to learn and to bridge knowledge acquisition between professional subgroups in a multilayered manner. Therefore, we can infer that the subject matter of the sought advice may distinctly pinpoint those to whom advice-seekers would more likely turn as a source of knowledge (Hakkarainen *et al.* 2004, Spillane 2005, Spillane and Hopkins 2013).

For the most part, nevertheless, a teacher’s pedagogical expertise is not directly observable to colleagues since instructional practices usually remain behind closed-classroom doors (Willhelm *et al.* 2016). The real-life implication of shared knowledge matters its transferability; as a matter of fact, pedagogical ASRs concerning tacit knowledge domains (e.g. classroom management) are rarely established between teachers (Siciliano 2017). As such, social transmission of tacit and

explicit knowledge operates by individual, relational, and context-driven organisational processes, depending upon the perceived knowledge difference between interacting parties (Edwards 2005). Based on these theoretical arguments, the present study sets out to untangle this complexity at multiple levels but in connection.

Multifaceted nature of ASRs

Frank (2009) demonstrated that the emergence of ASRs among teachers is highly responsive to individual features of interacting teachers, relational difference or similarity thereof, and the school's organisational context, analysed at, respectively, micro, meso, and macro levels. *Micro-level factors* involve individual teacher characteristics that are influential in the decision-making of ASRs, such as gender, age, positional authority, teaching experience and grade level, and taught subject field. According to the findings of Moolenaar *et al.* (2014a), male teachers are more sought out for advice exchanges, while female teachers are positioned as advice seekers. Similarly, Bridwell-Mitchell and Lant (2014) concluded that female school principals are more eager than their male counterparts to solicit advice from colleagues. Furthermore, older and more experienced teachers may be more inclined to participate in ASRs than younger and less experienced colleagues (Moolenaar 2010). Taking individual principal and middle leadership roles into account, recent research by Lee and Ip (2023) has shown that being a principal or subject head has influences on professional learning communities. Likewise, Spillane (2005) also showed that teachers' subject fields partake in ASRs, partly irrespective of what formal positions they hold in the school hierarchy.

From a more relational aspect, not only individual characteristics of advice-providers but also those of advice-seekers are relevant to ASRs (Frank *et al.* 2010). Thus, common characteristics of both parties might have a share in the emergence of ASRs (Frank and Zhao 2005). Given the two-sided nature of social relationships, (dis)similarities of individual characteristics come into play as *meso-level factors*. They involve local and mostly unconscious regularities in the growth of interpersonal relations, e.g. shared personal attributes. To exemplify, teachers may have a tendency to seek advice from colleagues who are of the same gender, similar age, teaching experience, grade level, and subject field (Coburn *et al.* 2010, Daly 2010, Moolenaar 2010, Penuel *et al.* 2010).

Depending on the school's organisational context, a series of school-level variables are defined as *macro-level factors* conducive to systemic influence on ASRs. In this scope, a long line of research shows that teacher leadership is of direct relevance to schoolwide shared values supporting professional learning (Coburn 2001), organisational trust (Bryk and Schneider 2002), learning organisation (LO) culture (Senge *et al.* 2000), and innovative school climate (Moolenaar *et al.* 2014b). Among them is the LO culture that has long been highlighted as an effective collective learning framework in education literature (Dexter 2008, Finnigan and Daly 2012, Siciliano 2017). LO culture refers to a set of professional learning orientations that encourage individual, team, and systems learning in the nested sociocultural context of teacher, classroom, and school (Senge *et al.* 2000, Zhao and Frank 2003). The rise of such a collectively perceived LO culture is essential not only for individual teachers' professional development but also for the school improvement (Finnigan and Daly 2012). Beverborg *et al.* (2020) have recently demonstrated that the articulation of a shared school vision is able to promote teachers to share information with their colleagues. Besides, having facilitated ICT-related advice exchanges among teachers, LO culture strengthens technology-informed communication patterns and school effectiveness (Dexter and Anderson 2002). More specifically, Dexter (2008) underscores the growing importance of team learning, shared vision, and systems thinking components of the LO culture by which teachers' learning needs regarding the pedagogical use of ICT could be met. In a similar vein, Frank (2009) concluded that a teacher's self-identification with the school collective serves as a moderator for accessing more information resources embedded in the teacher communities. By extension, the spread of LO culture proved to inspire relatively expert teachers to establish ASRs with their comparatively less expert peers, and thus, to continue to learn out of their expertise domain (Farley-Ripple and Buttram 2013).

Drawing upon complexity theory, there is an emerging and convincing body of literature suggesting that the impact of teacher leadership can be primarily seen in the growth of teacher professional learning that may contingently occur within a group of teachers and further extend to interconnected teacher sub-groups leading to school improvement as a whole (Morrison 2010, MacBeath *et al.* 2018, Margolis 2020, Margolis and Strom 2020). As the formation of those evolving relationships is non-linear, iterative, and recursive to a large extent, it is complicated to trace collaborative interactions in school communities (King and Holland 2022). Recognising the dynamic interplay of individuals, their actions and the school system, complexity theory renews the focus on ‘information flows’ as the primary unit of analysis (Margolis and Strom 2020). Analysing these complex and collaboratively produced phenomena by knowledge sharings attunes us to including networked meso-level factors that underscores the shared teacher agency sitting between individual (micro-level) and collective (macro-level) teacher agencies (Margolis 2020, Strom and Viesca 2020). By this means, Andrews *et al.* (2020) implicate that ‘professional learning at the micro-level must interact with organisational learning at the macro-level’ (p. 635). Based on these theoretical arguments and empirical evidence on the multifaceted nature of ASRs, in the present paper, we seek answer to the following research question:

RQ-1: To what extent do micro- (gender, age, teaching experience, departmental or administrative leadership), meso- (interpersonal similarity of the aforementioned micro-level factors), and macro-level factors (average teacher experience and perceived LO culture in schools) account for the emergence of technological and pedagogical ASRs between teachers?

Structure matters: professional interactions situated in social networks








Despite the growing body of research on multilevel factors influencing pedagogical and technological ASRs *separately*, little is known about how these two professional knowledge domains might simultaneously be interrelated on advice networks. In order to fulfil this notable gap in the literature, we *jointly* address concurrent pedagogical and technological ASRs in the present study, using a state-of-the-art analytical as well as theoretical approach of *social network theory*.

What makes social network theory distinctive is its reflections on the fundamental concept of the network. A network is composed of a set of network actors, along with ties connecting these actors by virtue of their existing relationships (Wasserman and Faust 1994). Out of the five different types of network ties (i.e. similarities, social relations, mental relations, interactions, flows), ASRs refer to as ‘interactions’, which may be thought of as discrete events repeating in time (Borgatti and Ofem 2010).

The underlying premise of social network theory is that specific patterns of local interactions, when they regularly emerge within a specific network structure, may have *structural effects* on the entire network configuration (Daly 2010). That is to say, social relationships are made up of local ties between particular individuals that do, albeit partly, come from the structural influence of a particular set of theoretically hypothesised interaction patterns that together make up the overall network, ultimately. Three key conceptualisations – *cohesion*, *centrality*, and *connectivity* – are essential to describe how these different kinds of structural impacts might make up the overall network configuration of advice networks (Ofem *et al.* 2013):

- Cohesion accounts for the extent to which teachers, as network actors, is directly connected. Larger cohesion can be interpreted as a source for stronger relationships among network actors (Dion 2000). Even though many different parameters can be used to measure cohesiveness, the two are particularly interesting for the current study’s context: density and reciprocity. Network density is a measure of how well connected all teachers are, calculated by dividing the total number of observed ASRs by those of all possible ones. Reciprocity

Table 1. Structural network effects.

Structural Effects	Visualization of Interaction Patterns	Interpretations
Arc		Baseline propensity for the occurrence of ASRs, indicating network density of ties.
Reciprocity		Tendency of teachers to have reciprocal ASRs, indicating mutual collaboration.
Simple Connectivity		Tendency of teachers to engage equivalent incoming and outgoing ASRs, indicating the correlation between incoming and outgoing ties.
Popularity spread		Tendency for centralisation in providing ASRs, indicating the presence of popular advice-provider actors on the network.
Activity spread		Tendency for centralisation in seeking ASRs, indicating the presence of popular advice-seeker actors on the network.
Path closure		Tendency of teachers to give advice to a group of colleagues, also to give advice to another who seeks advice from the same group. It indicates the transitive closure of the network for the flow of knowledge.
Popularity closure		Tendency of teachers to be sought out for advice by a group of colleagues, also to seek advice from each other. It indicates the transitive closure of the network between popular actors.

manifests the symmetry between incoming and outgoing ties, indicating the quality of relationships (Krackhardt 1992).

- Centrality captures the prominence and, thus, informal leadership potential of a network actor due to his/her positional advantage and influence area over the network. In the simplest term, centrality means the proportion of times that a network actor nominates others or is being nominated by others. A larger centrality value of a network actor means greater robustness for this actor on the network (Ofem *et al.* 2013). In this paper, we attend to in-degree and out-degree centrality parameters which indicate the number of sought and provided ASRs for each network actor. Focusing on these parameters, we draw on the network centrality of hybrid-expertise teachers who allocate both technological and pedagogical knowledge resources for their networks. In this way, we investigate whether hybrid-expertise teachers occupy a central position in multiple advice networks due to their in-degree and out-degree centralities (Ryymän *et al.* 2008).
- Connectivity accounts for indirect ASRs that are mediated through adjacencies. This feature assumes that any interaction patterns linking two focal actors to a third party may produce similar consequences for the focal actors. Only when two ties of ASRs among three actors are closed with another transitive tie being established between two focal actors, could then we infer the *structural equivalence* of these focal actors (Robins *et al.* 2009). That is, a transitive tie established between two focal teachers represents a likelihood for the occurrence of triadic closure among a group of teachers. Such transitivity may be viewed as an indicator of homophily

between teachers in general terms. Thus, controlling for the connectivity of teacher interactions, we can examine the extent to which technological and pedagogical ASRs have transitive ties.

Basic structural network effects pertaining to cohesion, centrality, and connectivity features, as used in the present study, are illustrated in Table 1. The arrowed ties below represent the flow direction of ASRs. The transitive ties are circled to indicate the social closure of local teacher interactions.

Considering advice exchange ties as proxy of professional interaction (Moolenaar *et al.* 2014a), social network theory provides this study with an insightful analytical framework to examine what particular structural effects and relevant interaction patterns, as depicted in Table 1, are associated with individual and collective knowledge acquisition among teachers. Therefore, we set the second research question as follows:

RQ-2: Which structural effects are associated with the concurrence of technological and pedagogical ASRs in distinct school contexts where teachers perceive high-level or low-level LO culture?

Method

Sampling procedure

Data were collected through single-stage stratified cluster sampling of 414 teachers in 10 schools. For the stratification procedure, the initial dataset came from 1105 teachers in 69 Turkish public schools where are located in a large urban district. The level of LO culture was measured as the stratification variable by surveying teacher perceptions and then cluster units and schools were ranked by the LO scores aggregated at the school level. Taking school rankings into consideration, 69 schools/clusters were stratified into top- and bottom-half groups. Later on, five schools from each stratum (i.e. the best vs. worst five schools by the perceived LO culture) were randomised. At last, a follow-up SNA questionnaire was administered to 414 teachers in these randomly selected 10 schools.

A minimum response rate of 70% is recommended to obtain reliable estimates as a rule of thumb (Kossinets 2006). Since the response rate of one school remained under the suggested threshold, it was excluded from further analysis. As such, sociometric data of 339 teachers clustered in nine schools were analysed to respond to the RQ-1. While conducting SNA corresponding to the RQ-2, multiplex advice networks of three schools did not converge with the simulated data by SNA software and, thereby, the second part of SNA was carried out with 186 teachers in six schools. Critical to the reliability of whole-network SNA applications is the representativeness of the investigated networks in themselves. The response rates, ranging from 71 to 98%, that we reached in the current research are large enough to provide reliable estimates. Note that we use the word 'teacher' in the paper as an umbrella term referring to all educators in a school, regardless of their administrative or faculty headship responsibilities, so as to emphasise the non-tenured status of school and departmental administratorship in the Turkish education system. Thus, formal leadership positions were subsequently assigned to network nodes (teachers) as individual and dyadic (relational) attributes during the data analysis.

Measurement instruments

LO questionnaire

The LO questionnaire is composed of two parts. In the first part, teachers responded to three questions as to their gender, age, and the number of years teaching at current school. In some previous research (Leithwood *et al.* 1998, Garcia-Morales *et al.* 2006), these descriptive variables

were treated as control variables to investigate their confounding effect on LO culture. Accordingly, we also controlled for the effects of these variables on the LO culture.

In the second part of the questionnaire, the Learning School Scale (LSS) by Subas and Cetin (2014) was administered to 1105 teachers. Teacher responses are scored on a 4-point Likert-type scale ranging from 1 (strongly disagree) to 4 (strongly agree). As for its psychometric properties, the LSS is capable of explaining 59% of the observed total variance with changing factor loadings in the range of .51 and .81 (KMO=.86; $p < .001$). Cronbach's α coefficient is .94 for the overall scale, indicating satisfactory internal reliability.

SNA questionnaire

The first part of the SNA questionnaire involves teacher demographics of gender, age, administrative/departmental headship status, and teaching experience by years at current school. In the second part, we used a name roster in which a principal, vice-principal(s), and teachers were listed by a name generator. By name lists, teachers were asked to nominate as many colleagues as they preferred about:

- (1) 'To whom do you turn for seeking advice on the use of educational technologies in your school?'
- (2) 'To whom do you turn for seeking advice on pedagogical issues in your school?'

Analytical approach

SNA is a robust analytical approach derived from graph theory and matrix algebra. The graph theory suggests mathematical solutions that visualise real-life problems, depicting entities as nodes and their connections in matrices. For doing so, SNA makes use of sociometric measures drawn from dyads (i.e. ties between a pair of actors), triads (i.e. ties among three actors), multiple triads (i.e. ties among more than three actors), and networks as whole.

p2 Models

The p2 and exponential random graph models (ERGMs) are two advanced SNA models, which were separately used in this study. For RQ-1, p2 models were performed allowing for the inclusion of multilevel random effects on observed network data (Zijlstra and van Duijn 2003). Ordinary logistic regression is not appropriate for estimating such random effects because sociometric measures do not support the assumption of independent observations (van Duijn and Vermunt 2006). Instead, p2 models are able to predict the likelihood of interaction patterns as a function of the following measures (Zijlstra *et al.* 2006):

- (a) Network-related measures (i.e. contextual ones),
- (b) Dyadic measures (i.e. similarities and differences between individuals),
- (c) Individual measures (i.e. the tendency for an individual actor to receive or give a tie).

In our p2 model, technological and pedagogical ASRs were used as dependent variables in two separate multilevel models. For every pair of teachers, we controlled for the difference between teacher genders, ages, subject fields (in middle and secondary school levels) or grade level (in primary school level) – coded as departmental affiliations, administrative position (i.e. principal/vice-principal), and, if any, head-teacher status – coded as departmental position. Advice-seeking and providing covariates were also regressed on individual teachers' characteristics at the micro-level. As contextual background, we took into account the perceived LO culture and average teaching experience at current school.

Exponential random graph models (ERGMs). In addressing RQ-2, we used exponential random graph models (ERGMs). Albeit fairly complex, the methodological background underlying ERGMs

is well grounded. Robins and Lusher (2013) articulate the five fundamental assumptions underlying ERGMs, as follows:

- Social networks are locally emergent.
- Network ties are interdependent.
- Interaction patterns are elements of ongoing structural construction.
- Multiple relationships can operate simultaneously.
- Social networks are structured, yet stochastic.

In adherence to these assumptions, ERGMs are composed of a set of structural effects (see Table 1) that are proposed to predict the properties of overall networks. As distinguished from p2 models, ERGMs have extensions on multiplex networks so as to verify the relatedness of univariate networks by modelling structural effect parameters (Wang *et al.* 2009). In addition to this, ERGMs allow researchers to set flexible models by which probabilistic predictions can be specified according to theoretical interests.

Meta-analysis

We carried out a meta-analytical procedure to evaluate the results of ERGMs within the top and bottom-half school groups separately. Following Lubbers and Snijders's (2007) meta-analytical approach, estimated errors of structural effect parameters are assumed to be independently and normally distributed with a mean of zero and standard deviations equal to the estimated standard errors. Each analytical approach was performed through the use of applicable statistical software.

Statistical software

The meta-analytical procedure was performed using MLWIN (Rasbash *et al.* 2009). ERGMs and p2 model were carried out using, respectively, XPNET (Wang *et al.* 2009) and StOCNet (Boer *et al.* 2006), which are specialised computer software for the analysis of multiple networks, dyadic/triadic interaction patterns, and their probable antecedents.

Results

Advice-seeking relations embedded in multilevel context

All micro, meso, and macro-level factors were tested for their partial effects on the advice-seeking, advice-providing, density, and reciprocity covariates of ASRs. Results are presented below for technological and pedagogical ASRs with estimated means, standard errors, and reliability intervals. The significant estimates are assigned with an asterisk (Table 2).

The overall means of density and reciprocity effects are controlled by default. Negative values of the overall density indicate that both pedagogical ASRs (Mean = -2.17 , SE = $.02$) and technological ASRs (Mean = -2.89 , SE = $.21$) occur sparsely among teachers. Technically phrased, when the density or reciprocity parameters yield a negative value, this implies that the occurrence likelihood of such ties between random two actors is lower than 50%. However, our finding of a positive reciprocity value suggests that both types of ASRs tend to reciprocally occur between teachers.

Advice-seeking covariates show that none of the micro-level factors enhances the likelihood of seeking pedagogical or technological advice ($p > .05$). As for advice-providing covariates, male teachers are more preferred for both pedagogical and technological advice than their female counterparts (Mean = $-.91$, $p < .05$; Mean = -1.62 , $p < .05$). Likewise, a principal more likely than vice-principals and vice-principals more likely than teachers tend to give both technological and pedagogical advice to their subordinates (Mean = 1.40 , $p < .05$; Mean = 1.64 , $p < .05$). More experienced teachers are more likely to be preferred for seeking pedagogical advice by colleagues (Mean = $.07$; $p < .05$). This is not true, however, for technological ASRs ($p > .05$).

Table 2. P2 model for pedagogical and technological ASRs.

	Pedagogical ASRs (N = 9 Advice Networks)			Technological ASRs (N = 9 Advice Networks)		
	Estimate	SE	95% CI	Estimate	SE	95% CI
Overall mean						
Density	-2.17	.02		-2.86	.21	
Reciprocity	1.74	.19		1.72	.28	
Advice-Seeking Covariates						
<i>Micro-level factors</i>						
Gender (Male vs. Female)	.35	.25	(-.13/.83)	.37	.29	(-.18/.90)
Age	.01	.02	(-.05/.04)	.05	.02	(-.01/.09)
Experience in years	.02	.05	(-.06/.15)	.02	.06	(-.07/.15)
Administrative position	-.05	.71	(-.17/1.61)	.54	.82	(-.67/2.14)
Departmental headship (Teacher vs. Headteacher)	.01	.31	(-.56/.63)	.43	.48	(-.56/1.21)
Advice-Providing Covariates						
<i>Micro-level factors</i>						
Gender (Male vs. Female)	-.91*	.28	(-1.51/-.45)	-1.62*	.31	(-2.26/-1.13)
Age	.01	.02	(-.02/.05)	-.02	.02	(-.06/.03)
Experience in years	.07*	.03	(.01/.12)	.02	.05	(-.07/.13)
Administrative position	1.40*	.41	(.62/2.24)	1.64*	.67	(.26/2.67)
Departmental headship (Teacher vs. Headteacher)	.20	.43	(-.46/1.35)	1.02	.70	(-.00/2.79)
Density Covariates						
<i>Meso-level factors</i>						
Homophily of gender	.67*	.06	(-.78/-.54)	.62*	.07	(-.75/-.48)
Homophily of age	.01	.01	(-.01/.01)	.01	.01	(-.02/.01)
Homophily of experience	.03*	.01	(-.05/-.02)	.02*	.01	(-.03/-.00)
Homophily of administrative position	-.36*	.11	(.15/.55)	.05	.13	(-.34/.15)
Homophily of departmental position	.02	.08	(-.17/.15)	.10	.11	(-.32/.14)
Homophily of taught subject-field	13.18*	3.71	(3.32/18.26)	19.60*	7.20	(4.59/30.56)
<i>Macro-level factors</i>						
Average teacher experience	-.20	.31	(-.88/.38)	.58	.38	(-.15/1.23)
Average LO culture	.69	.59	(-.39/1.84)	-1.07	.86	(-2.49/.55)
Reciprocity Covariates						
<i>Meso-level factors</i>						
Homophily of gender	-.12	.17	(-.18/.47)	.01	.25	(-.49/.47)
Homophily of age	.01	.01	(-.03/.03)	.01	.02	(-.06/.04)
Homophily of experience	-.01	.01	(-.03/.03)	.03	.02	(-.08/.02)
Homophily of administrative position	.70*	.14	(-.97/-.43)	.66*	.22	(-1.09/-.22)
Homophily of departmental position	-.02	.17	(-.38/.29)	.06	.28	(-.71/.40)
Homophily of taught subject-field	-11.34*	3.99	(-16.89/-.95)	-17.29*	7.24	(-27.83/-1.97)
<i>Macro-level factors</i>						
Average teacher experience	-2.98*	1.03	(-4.92/-.98)	-.46	1.31	(-3.24/1.69)
Average LO culture	5.15*	1.74	(1.81/8.82)	.57	2.51	(-3.64/5.84)

Note. Significant effects are denoted by the asterisks (*), that is to say, the mean parameter estimate is greater than two times the standard error in absolute value; SE= Standard error; CI= Confidence interval.

Results with regard to density covariates suggest that the similarity of gender (Mean = .67, $p < .05$; Mean = .62, $p < .05$), teaching experience (Mean = .03, $p < .05$; Mean = .02, $p < .05$), and subject field (Mean = 13.18, $p < .05$; Mean = 19.60, $p < .05$) are related to the occurrence likelihood of denser technological and pedagogical ASRs in schools. Remarkably, the result of negative homophily points out that pedagogical ASRs are more likely to occur between administratively superior teachers and their subordinates (Mean = -.36, $p < .05$).

Concerning reciprocity covariates, technological and pedagogical ASRs are more likely to occur reciprocally within the closed boundaries of superior and subordinate teacher groups (Mean = .70, $p < .05$; Mean = .66, $p < .05$). Cross-departmental interactions, however, are less likely to occur in a reciprocal way (Mean = -11.34, $p < .05$; Mean = -17.29, $p < .05$). In schools where teachers reported higher years of teaching experience on average, the density of pedagogical ASRs is lower

(Mean = -2.98 , $p < .05$). One of the key findings is that the higher teachers perceive the LO culture, the more teachers tend to form pedagogical ASRs reciprocally (Mean = 5.15 , $p < .05$).

Network structure did matter? Interrelatedness between technological and pedagogical ASRs

In an attempt to answer the second research question, we shift the research focus to simultaneous technological and pedagogical ASRs. Estimated structural effect parameters, standard errors, standard deviations, and χ^2 parameters are presented below. The significant structural effect parameters are assigned with an asterisk.

Results show that overlapping pedagogical and technological ASRs are more likely to occur in the top-half schools (Est. = 2.77 , SE = $.06$). All four types of multivariate mixed reciprocity effects were involved in ERGMs. The first type of mixed reciprocity effect (i.e. PT), including one-way pedagogical and one-way technological advice ties, is significantly positive in both top and bottom-half schools (Est. = $.88$, SE = $.26$; Est. = $.89$, SE = $.43$). That is, teachers tend to seek technological advice from colleagues when they give them pedagogical advice in return, and vice versa. The second type of mixed reciprocity effect (i.e. PPT), depicting two-way pedagogical but one-way technological advice ties, is significantly negative in the top-half schools (Est. = -1.28 , SE = $.36$). In other words, teachers from the top-half schools do not prefer to seek technological advice from colleagues with whom they already exchanged pedagogical advice. The third type of mixed reciprocity effect (i.e. PTT) is insignificant ($p > .05$), although it produced a remarkable variation across schools in chi-square tests (SD = 4.40 , $\chi^2 = 6.95$). The fourth type of mixed-reciprocity effect (i.e. PPTT), including two-way pedagogical and technological advice ties, is also insignificant in the top-half schools ($p > .05$). Since there were no reciprocal ties in two schools from the bottom-half group, meta-analysis of this structural effect was not applicable for the remaining one school.

The mixed popularity effect including two simultaneous incoming technological and pedagogical advice ties (i.e. In-2-Star-PT) is significantly positive in the top-half schools (Est. = $.12$, SE = $.03$). That is, some hybrid-expertise teachers are more equally sought out for both pedagogical and technological ASRs in these schools and, thereby, they are more likely to perform teacher leadership in advice networks. The second type of the mixed popularity effect with three simultaneous incoming advice ties, depicted by two pedagogical and one technological ASRs (i.e. In-3-Star-PPT), turned out to be significantly negative in the top-half schools (Est. = $-.01$, SE = $.00$). This suggests that some hybrid-expertise teachers who are sought out for pedagogical advice twice as much as technological advice are less likely to occupy a central position in the top-half schools. The last type of mixed popularity effect with three simultaneous incoming advice ties, depicted by one pedagogical and two technological ASRs (i.e. In-3-star-PTT), proved to be significantly positive in both top and bottom-half schools (Est. = $.01$, SE = $.00$; Est. = $.02$, SE = $.00$). That is to say, some other hybrid-expertise teachers who are sought out for technological advice twice as much as pedagogical advice are more likely to occupy a central position as informal teacher leaders. Concerning the structural equivalence of multiple ASRs, the mixed popularity closure (PTT) effect is significantly positive in both top-half and bottom-half schools (Est. = $.48$, SE = $.11$; Est. = $.52$, SE = $.17$). This means that certain technology-savvy teachers who are sought out for technological advice by the same group of colleagues are more likely to seek pedagogical advice from each other in general.

Discussion

Homophily tendency in professional interactions

It is widely acknowledged that social relationships tend to be homophilous (McPherson *et al.* 2001). Consistent with this theoretical orientation and some earlier empirical research (Frank and Zhao 2005, Coburn and Russell 2008, Moolenaar *et al.* 2014a), we conclude that a teacher's teaching

experience by years, gender, and administrative position, as well as the between-teacher similarity thereof, are related to technological and pedagogical ASRs. In line with Moolenaar's (2010) study, we also contend that the more experienced teachers become the more central position they occupy in the pedagogical advice networks. That is, teachers with similar years of experience have more tendency to engage in technological and pedagogical ASRs.

In addition, some studies pointed out that teachers have more tendency to contact each other when they share a common experience (Coburn and Russell 2008, Moolenaar *et al.* 2014a). Yet, our research came up with a contrasting result, as the more years of experience teachers shared, the less they established reciprocal ASRs on pedagogical issues. One explanation could be that teachers who have a lot of experience in the school might consider themselves expert teachers about pedagogical issues. In this case, they may find it unnecessary to establish mutually reinforcing ASRs around pedagogical issues with other experienced teachers in the school context. Supporting this, we realised that when the average experience of the teacher community decreases, teachers become more relaxed about seeking pedagogical and technological advice from differently experienced others, when controlling for the perceived LO school culture.

As teachers tended to interact with colleagues of the same gender in the current study, this finding corroborated the idea of gender homophily in professional interactions (Coburn *et al.* 2010). Nevertheless, we note that male teachers occupied a more central position in advice networks. It may be the reason why males were more likely to be headed for both technical and pedagogical advice as opposed to female counterparts. Some previous studies concluded that male teachers report higher ICT self-efficacy (Sieverding and Koch 2009, Gudmundsdottir and Hatlevik 2017) and more proactive attitudes towards the pedagogical use of ICT (Tondeur *et al.* 2008). On the other hand, these findings may be the result of widespread misogynistic stereotypes that portray females as having relatively low technological literacy (OECD 2019). As Gebhardt *et al.* (2019) reported that, if there are any differences between male and female teachers' ICT use in education, they are quite small in statistical terms and rather inconsistent across countries. Because of these gender-biased beliefs, which presume that technological skills are primarily a man's domain, male teachers may have seemed more knowledgeable than their female counterparts in the current study. As a remedy to this gender-biased perception, we argue that more proactive education policies are required, the ones that promote hybrid-expertise female teachers as role models for school communities. Supporting this argument, Meelissen and Drent (2008) showed that Dutch education policies encouraging female teachers to serve as positive role models in ICT use are significant in a slight increase in the usage of computers in schools. Given the relevant policy difference, it may be the reason why our findings from the Turkish context are inconsistent with the findings of Moolenaar's (2010) study in favour of female teachers' centrality in ASRs in Dutch elementary schools. This self-reflection may therefore give another explanation for male teachers' more central position in advice networks. Alternatively, ruling out all these speculative explanations, this difference could simply be the result of the distinctive cultural context in Dutch schools.

Power(lessness) of formal leadership in informal professional interactions

School principals, vice-principals, and headteachers are expected to be natural advice-providers because of their formal leadership positions, though some previous studies showed that their centrality in the advice networks varies to a great extent (Moolenaar *et al.* 2010, Lee and Ip 2023). To verify this claim through centrality measures, we controlled for two administrative positions, coding as principal/vice-principal at micro- and meso-levels. In a conclusion, administrative superiority of the advice-providers proved to be a significant predictor of both technological and pedagogical ASRs but only for advice-providers.

Likewise, pedagogical ASRs are more likely to occur between administrative superiors and their subordinates at the meso-level. A possible explanation for this is that administrators are supposed to spend more time monitoring, training, and mentoring teaching staff as part of their teacher













appraisal and evaluation tasks; hence, teachers might prefer to seek pedagogical ASRs from their superiors as a natural consequence of that formative evaluation process (Arar and Oplatka 2011, Arar and Arar 2016). However, such cross-positional interactions were not supported for technological ASRs. Instead, school administrators tend to establish reciprocal ASRs with other administrators when seeking advice on technological and pedagogical issues. This finding resonates with those by Siciliano (2015) indicating that a teacher with formal status is nearly two times more likely to seek advice from a colleague who has the same formal position. While the possible interference of existing social and spatial environment to ASRs, such friendship and proximity, cannot be ruled out in this association as administrators, when seeking advice, might prefer to ignore the immediate expertise and, instead, turn to other administrators with whom they feel more comfortable and who are more accessible (Siciliano 2017). In contrast to the findings of Spillane *et al.* (2015), as well as Lee and Ip (2023), departmental headship of headteachers turned out to be inconclusive in our study. Coupled with previous findings of the present study, we conclude that teachers tend to engage in reciprocal ASRs with colleagues outside their departments, irrespective of contacted teachers' departmental headship positions. The one caveat is that this result may be due to the uneven distribution of expertise among teachers across departments and, consequently, cross-departmental interactions might be statistically significant between those few expert teachers who are already highly centralised in the advice network (Rivera *et al.* 2010). Overall, we lend support to the importance of informal interactions rather than formal ones structured by teachers' departmental affiliations and administrative positions.

Connectivity of technological and pedagogical ASRs

The significance of concurrent technological and pedagogical ASRs indicates a tendency for teachers to turn to hybrid-expertise colleagues as informal teacher leaders in advice networks. However, this tendency is confirmed only in the top-half schools endowed with high-level LO culture. Besides, in the same schools endowed with positive school culture, teachers tend to seek technological advice from colleagues who are also sought out for pedagogical advice, and vice versa. Note that these overlapping ties lack empirical support for technological ASRs in the bottom-half schools with the low-level LO culture. This means that LO culture is able to reinforce possible transitions between technological and pedagogical ASRs.

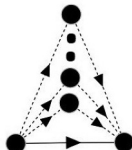
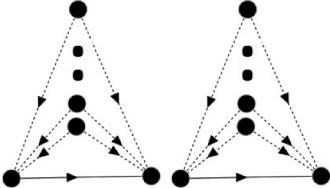
The resulting positive and significant reciprocity values imply the prevalence of social exchanges between teachers, as a baseline propensity. The overall significance of the mixed reciprocity (PT) effect refers to the extensiveness of 'give-and-take' type conventional social exchanges (Blau 1974), regardless of the type of solicited advice and the level of perceived LO culture. In other words, teachers tend to give technological advice, if they, in turn, receive pedagogical advice, and vice versa. Therefore, the estimated negative significance of mixed reciprocity (PPT) in the top-half schools shows that teachers who work in these schools are less likely to prefer seeking technological advice from colleagues with whom they are already in contact for pedagogical issues. Together with our previous findings, this can be interpreted as a signal of network centralisation, as well as informal teacher leadership, given more incoming ties given to hybrid-expertise teachers (Ryymin *et al.* 2008). Because hybrid-expertise teachers are sought out for both technological advice and pedagogical advice equally. Similarly, the mixed popularity effect (In-2-Star-PT) revealed a balanced in-degree centrality for hybrid-expertise teachers in top-half schools. Nevertheless, against the balanced network centrality, the mixed popularity effect (In-3-Star-PTT) signals an overall skewness in the centrality distribution when the hybrid-expertise teachers were sought out more for technical advice than pedagogical advice. Thus, note that the second mixed popularity effect (In-3-Star-PPT) proved to be significantly negative in the top-half schools. This means that the preferability of hybrid-expert teachers for being sought out for pedagogical advice rather than technological one is less likely than by chance in the top-half schools and non-significant in the bottom-half schools.

Table 3. Meta-analysis of ERGMs with multiplex advice networks.

Structural Effects	Visualization	Top-half Schools with High-Level LO Culture (N = 3 advice networks)			Bottom-half Schools with Low-Level LO Culture (N = 3 advice networks)		
		Mean Est.(SE)	SD	χ^2	Mean Est.(SE)	SD	χ^2
Overlapping Arcs8		2.77 (.06)*	.93	3.71	3.27 (1.86)	3.09	1.54
Mixed9 Reciprocity (PT)		.88 (.26)*	.00	.00	.89 (.43)*	.00	.00
Mixed10 Reciprocity (PPT)		-1.28 (.36)*	.00	.00	.09 (.59)	.00	.00
Mixed11 Reciprocity (PTT)		-0.96 (1.17)	1.67	1.27	2.23 (2.61)	4.40	6.95*
Mixed12 Reciprocity (PPTT)		2.06 (1.40)	1.52	1.48	n/a	.00	.00
Mixed Popularity13 (In-2-Star-PT)		.12 (.03)*	.00	.00	.13 (.25)	.38	.62
Mixed Popularity14 (In-3-Star-PPT)		-0.01 (.00)*	.00	.00	-0.02 (.03)	.04	1.10
Mixed Popularity15 (In-3-Star-PTT)		.01 (.00)*	.00	.00	.02 (.00)*	.00	.00
Mixed Connectivity (PT)16		.02 (.04)	.05	.58	.01 (.01)	.14	.67
Mixed Connectivity (TP)17		-0.03 (.05)	.08	2.55	-0.05 (.05)	.05	1.03
Mixed Path Closure (PPT)18		-0.01 (.15)	.18	.44	.14 (.32)	.40	.42
Mixed Popularity Closure (PPT)19		.11 (.24)	.32	.28	-0.38 (.26)	.28	.68

(Continued)

Table 3. (Continued).

Structural Effects	Visualization	Top-half Schools with High-Level LO Culture (N = 3 advice networks)			Bottom-half Schools with Low-Level LO Culture (N = 3 advice networks)		
		Mean Est.(SE)	SD	χ^2	Mean Est.(SE)	SD	χ^2
Mixed Path Closure20 (PTT)		-.10 (.18)	.26	.92	.01 (.26)	.26	.59
Mixed Popularity Closure21 (PTT)		.48 (.11)*	.15	.98	.52 (.17)*	.14	.69

Significant effect is denoted by the asterisk (*) that refers to the mean parameter estimate is greater than two times the standard error in absolute value. Solid lines represent pedagogical ASRs. Dashed lines depict technological ASRs. Standard deviation (SD) refers to the extent to which estimates vary across schools. Mean Est.= Aggregated estimate across schools. χ^2 = Chi-square test with the degree of freedom value of 1.

Concerning network connectivity, the significant and positive value of the mixed popularity closure effect (PTT) disclosed transitive pedagogical ties between teachers who are positioned as so-called ‘hubs’ because of their technical expertise in using educational technologies. Seeing that previous research has so far largely focused on the central role of teacher expertise in instructional leadership and advice networks (Hakkarainen *et al.* 2004, Dexter *et al.* 2010, Willhelm *et al.* 2016, Siciliano 2017), one might think that there was nothing new in this line of findings indicating technology-savvy teachers’ popularity in advice networks. On the other hand, to our knowledge, this is the first study indicating the transitivity of pedagogical ties in connecting technology-savvy teachers. To put it another way, pedagogical advice exchanges between two or more preferred technological advice providers may be predicted by their common sub-network/cliQUE members on the overall advice network. Taken together, it is possible to draw a few original conclusions from significant structural effects. For instance, it may be the reason why some technology-savvy teachers are more popular than others in advice networks (see the mixed popularity parameter of In-3-Star-PTT in Table 3) that they are more in touch with each other through sharing pedagogical knowledge and teaching strategies by transitive pedagogical ties (see the mixed popularity closure parameter of PTT in Table 3). Confirming this speculation, technology-savvy teachers’ transitive pedagogical ties incoming from others alike are shown to be seemingly unique pedagogical ties in the bottom-half schools, which may be a way of turning technology-savvy teachers into centralised hybrid-expertise teacher leaders in advice networks. Nevertheless, due to the infancy of evidence-based literature on this issue, we abstain from making broader speculations to err on the side of caution.

Conclusion

As Frost and Durrant (2003), Morrison (2010) as well as Poekert (2012) jointly point out that teacher leadership is built on collegiality and professional interactions rather than power and authority relations. Supporting this stance, the complexity theory informs the current study, which seeks to understand the potential of teacher leadership to enhance professional

interactions by networked advice sharings, while also seeking an answer to Margolis and Strom's (2020) question of 'How are teacher leaders increasing the flow of information about teaching and learning throughout the school and/or district?' (p.615). To better understand how informal teacher leadership could spread through teacher networks, it is crucial to trace and disclose complex interaction patterns by teachers' professional advice exchanges. In this account, there was a need for guidance on how to operationalise this complexity through SNA. Again, following Margolis and Strom's (2020) inquiry, we harnessed the analytical power of SNA because 'This method [SNA] also visualises the extent of the reach and touches teacher leaders are having within a building- including the scope and type of information and feedback loops they are facilitating' (p. 618). The present paper endeavours to fill this research gap by offering an original research design that produced some evidence-based thoughts and suggestions on teacher leadership's natural growth trajectory within complexity. Broadly translated, our results indicate three major findings: 1) stronger LO culture promotes ASRs among teachers beyond basic social exchanges; 2) hybrid-expertise teachers (i.e. those with both pedagogical and technological expertise) are more likely to perform teacher leadership role in advice networks; 3) formally structured professional relations result in one-sided (less reciprocal) exchanges among teachers.

Based on our findings, we can draw some implications for education policymakers and practitioners. First, we suggest that school principals provide greater leverage of LO culture that enables and empowers teachers to commit to their professional development and, thereby, facilitates knowledge transmission between different types of professional knowledge domains within and across departmental boundaries. Second, we implicate that school principals may form and work with hybrid-expertise teachers as informal teacher leaders while maintaining also a collective focus on the overall advice network. When teamed up with hybrid-expertise teachers through advice networks, school principals should be aware of individual and relational teacher characteristics, such as cross-departmental and intergenerational collaborations. As such, it would be wise for school principals to team up with teacher leaders from different subject field and grade-level affiliations. Third, the present work adds to the teacher leadership literature showing that formally structured professional relations are more likely to occur just in a one-sided way (e.g teacher-to-principal). The more qualified, reciprocal interactions come up with informal communication patterns (e.g. cross-departmental or cross-positional ASRs). Therefore, we finally echo Spillane's (2005) call for teacher empowerment: 'Although important, formal structure is not everything. A distributed perspective allows for the possibility that individuals without a formally designated leadership position take on leadership work' (p. 390).

The application of inferential SNA in teacher leadership research may be promising to bridge the existing research gap and provide several implications to international audience. For example, a natural progression of this work is to conduct longitudinal analysis of between-teacher professional interactions at multiple time points. In doing so, evolution and co-evolution patterns of multiplex ASRs may be examined to reveal stability or instability tendency of professional interactions and feedback loops in schools, which in turn accelerate or slowdown information flows between teachers. Another implication for researchers is that further research may use SNA approach to explore how teacher leadership is a facilitator of multiplicitious professional interactions between and across sub-systems, including district-level administrators, out-school colleagues, parents, and students. It might be worth considering that every school is unique for its own human resource capacity as well as contextual factors; hence, the adoption of whole-network SNA approach is methodologically apt in different cultural contexts as it enables uncovering local interaction patterns while controlling for the network structures that are tailored to each network context independently.

Limitations

We acknowledge that a limited number of micro-, meso-, and macro-level factors were involved in the current research. For instance, the network position of formal ICT coordinators was not examined in the present paper since there were only four ICT coordinators in our research population. Still, we recognise that they are the most proper network actors that might have been nominated by other teachers for collaboration on the use of ICT. This is a main limitation of the current research and should be considered in future research.

Another caveat worth mentioning is that ERGM analysis was applied to six schools' advice networks due to technical convergence issues, which are frequently confronted in probabilistic SNA applications. Future research is warranted to reach a larger number of schools as a precaution against this technical limitation. At last, despite the stochastic power of p2 and ERGMs, making causal inferences about ASRs is not the goal of this study. By extension, therefore, further longitudinal and experimental research is needed to explore causal links between positive school culture and proactive teacher behaviours in establishing technological and pedagogical ASRs.

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