The Development of Communication Networks of Pre-Service Teachers on a School-Led and University-Led Programme of Initial Teacher Education in England

Abstract. This study examines the communication networks of 77 pre-service teachers in mathematics and science on university and school-led programmes in England. Communication as an indicator for establishing contact is considered as the starting point of building social capital among peers. Communication, advice-seeking and friendship network data were collected over four time-points during each programme. The descriptive results suggest limited boundary-spanning between the university and school-led programme types. Longitudinal modelling in RSIENA showed that friendship is a significant early-stage predictor of development of communication networks. By the end of the programme advice-seeking becomes a significant predictor of network development. Neither interpersonal trust, nor perceived self-efficacy were found to be consistent predictors of change in pre-service teacher communication networks.

Keywords: pre-service teachers; social networks; communication; social capital; SIENA

1. Introduction

Over recent years, changes to policies governing the provision of initial teacher education have focused predominantly on expanding the school-based component of training programmes. The increased time trainee teachers spend in schools rather than in universities, means that networks involving peers will be subject to change and churn over time. Peer networks can play an important role in the development of trainee teachers (e.g. Hodgson, 2014; Liou & Daly, 2018; McCormack, Gore, & Thomas, 2006). Based on an expectation that peer networks develop differently between university-led teacher training

and more school-based teacher training courses, we seek to investigate tie formation in the peer communication networks of two teacher training cohorts over four time points across an academic year. Research into communication networks in organizations (Contractor, Whitbred, Fonti , & Steglich, 2012) suggests that communication networks may provide an understanding of the informal structure of an organisation which reflects interactions that develop naturally among colleagues. The growth of communication ties may be considered as the starting point of building social capital. Although there is research on pre-service teachers' informal online communication with their peers for professional development, such as sharing instructional and classroom management tools (e.g., Steinbrecher & Hart, 2012), less is known about the general development of communication measured in peer networks over time. We define communication as the exchange of information by any medium, as a first step to being able to realise social capital and so access resources or support through the peer-communication network. The aim of this research is better understand the factors which influence the development of communication networks among mathematics and science pre-service teachers during a one-year programme of postgraduate teacher education. We examine the extent to which selection processes (i.e., tie formation) in communication networks among peers are related to friendship and support networks (cross-network effects) and whether they are related to programme and personal characteristics, such as type of programme, gender, self-efficacy, and trust. Given the importance of peer relationships for pre-service teachers as a source of mutual support beneficial to the learning and well-being of teachers (e.g., Le Cornu & Ewing, 2008; Liou et al., 2017), we firmly place our study in the context of social network and social capital theory. We will first set out the policy background and relevant literature, then describe

how we used stochastic actor-based models to analyse appropriate research questions, and finally present findings and conclusions.

1.1. Policy context: a shift towards more school-based teacher training

For many years, teacher preparation programmes in England were mainly led by higher education institutions such as university-based Schools of Education. In these 'University Led' (UL) programmes, Higher Education institutions are responsible for recruitment of graduate students and arranging sufficient school placement experience. A UL graduate training programme usually commences with a university-based phase at the start of the course, working with other trainee teachers, and being taught by university tutors. Despite the label of 'University Led', trainee teachers on UL programmes in England are required to spend a minimum of 24 weeks in placement schools (Department for Education, 2019), developing their ability to plan, manage and lead the teaching of multiple classes. At the end of a graduate UL programme teachers achieve qualified teacher status (QTS), which is a requirement to teach in a state-maintained school and are usually awarded an academic qualification in the form of a postgraduate certificate in education (PGCE).

There have been major changes in Initial Teacher Education (ITE) in England since 2010 (see Authors, 2018a). One of the biggest transformations has been a shift of control away from universities and toward schools (Department for Education, 2017a, 2017b). This trend has also been observed more widely across European countries (Murray, 2016). In England the shift to more school-centred routes to achieve QTS has led to the introduction of 'School Direct' (SD) programmes in which schools, rather than universities, take the main responsibility for the recruitment of graduate students to their ITE programmes, to fit the prevailing vacancies for staffing in the schools that are leading the training programme. A

key point of divergence between the two routes is that 'salaried' positions are available to SD applicants, with the trainee being a temporary paid member of staff at the school during the period of initial training. This typically occurs when a candidate for a SD programme already works within a school in a role such as a teaching assistant or has an existing relationship with the school. Since their introduction, many SD programmes have developed in such a way that the lead schools responsible for recruitment and training work in collaboration with a university. In some cases, the university may simply be externally validating the work of in-school training to ensure it meets the required level for the academic award of the PGCE. In other SD programmes, lead schools will commission universities to provide some, or all, of the academic elements of the programme and the development of pedagogy and teaching skills. The reality on the ground therefore, is that UL and SD routes into teaching may be closer in programme design and implementation than their titles might suggest. Like UL programmes, graduate level SD courses typically last at least one year, with the minimum placement period of 24 weeks spent in at least two schools (Department for Education, 2019). On both the UL and SD courses, trainees usually aspire to become part of the placement school's teaching team with the support of other teachers in the schools, and their appointed teacher mentors. Both routes therefore mirror aspects of an 'apprenticeship model' of teacher training within the workplace (McNamara & Murray, 2013). Despite this convergence of experience over time, we are interested to see if differences remain in the way that trainees on each programme develop their communication networks with other student teachers, as a precursor to developing social capital within their peer group.

1.2. Tie formation of pre-service teachers' communication network

A social network consists of relational connections or ties among actors (e.g., individuals; see Wasserman & Faust, 1994). Social network theory concerns the role of relationships in transferring knowledge or information and social influence which makes behavioural or attitudinal change possible (Liu, Sidhu, Beacom, & Valente, 2017). The social structure determines how information may flow among individuals. Contractor et al. (2012) proposed a multi-theory for investigating communication networks. They distinguished endogenous and exogenous mechanisms for tie formation in communication networks. Endogenous mechanisms explain tie formation based on structural effects in the network, i.e., reciprocity and transitivity. They used social exchange theory and balance theory as theoretical underpinnings for the endogenous structural effects of reciprocity and transitivity. Exogenous mechanisms explain tie formation based on external factors to the tie formation, i.e., personal attributes and other network effects, such as friendship. Physical proximity and homophily were used as the underlying theoretical framework to explain exogenous effects.

Based on social exchange theory (Blau, 1964; Homans, 1974), students may connect to each other mutually because of sharing valuable (informational or material) resources (Monge & Contractor, 2003). In addition to increased reciprocity in communication networks, we would expect a tendency towards transitivity, as individuals intend to connect to "third parties" because this creates more stable relationships (see Krackhardt & Handcock, 2006). Transitivity is an indicator of the degree of balance in the network. Based on the balance theory (Heider, 1958), students seem to be satisfied with a balanced network, i.e., two students share a common partner (Feld & Elmore, 1982; Monge & Contractor, 2003; Scott, 2000). When this extends to a group of three students (a triad) or more, each with

reciprocal strong ties to other members of the group, so-called Simmelian ties (Krackhardt, 1998), the result is usually a relatively stable social structure (Krackhardt & Handcock, 2006).

Geographical proximity (propinquity) and homophily (similarity) are exogenous key drivers of tie formation (Reagans, 2011). Individuals are more likely to connect or to become friends when they are physically close together (Feld & Carter, 1998; Kadushin, 2012). Across the academic year, pre-service teachers on UL programmes move from being in close proximity within a group of peers working in the university-based phase of the programme, to being one of only a few trainee teachers working in the same school placement. As proximity tends to decrease during the ebb and flow of pre-service teacher training, structural tie formation with peers might change over time (Borgatti & Cross, 2003). Other (exogeneous) factors that have been shown to be associated with tie formation may then come more strongly into play, such as friendship (McPherson, Smith-Lovin & Cook, 2001; Siciliano, 2015), trust (Shazi, Gillespie, & Steen, 2015) or perceived self-efficacy (Siciliano, 2015; Liou & Daly, 2018). When students get to know each other they may become friends over time, when they develop trustworthy relationships (Fehr, 1996); and/or because they notice that they are more or less similar to each other (homophily; McPherson et al., 2001).

1.3. Social capital of pre-service teachers

Social network theory is related to social capital (Prell, 2006). Where social network theories emphasize the structure and patterns of social connections within a network, social capital is mainly related to valuable resources for obtaining goals (cf. Liou & Daly, 2018). Social capital was initially defined by Loury (1987) in terms of different resources derived from family relationships or from a community. These resources contribute to the cognitive and social development of individuals, and so, in turn, contribute to the development of human

capital. This relates also to the conceptualization of Coleman (1990) that social capital resides in the structure of relationships among individuals to realize individual goals. Through the development of relational ties, individuals have access to different resources (such as information, knowledge, and support) within their networks. Based on social trust, norms and values (Coleman, 1990) individuals can achieve personal goals that could not be achieved without these relationships and resources. Coleman (1990) also reiterated that such social relations vanish if they are not maintained, and norms depend on regular communications (p. 321). Lin (1999) proposed a network-based model of social capital that distinguishes a person's access to and mobilization of valuable resources such as information and knowledge, which are obtained through networks of social relations.

Training to become a teacher represents a major transition from study to work. Besides meeting university and government requirements for new teachers, pre-service teachers must build new social networks as they navigate working relations with academic staff, new peers and, above all, a new work context. During their training more and more emphasis will be placed on this school context and how to build social capital within a changing peer-network. To our knowledge, less is known about pre-service teacher's social capital building within their network than those of novice teachers (Liou et al., 2017; Liou & Daly, 2018). Derived from what we have gleaned from studies of early-career teacher education and development, social relations may also contribute to the survival of pre-service teachers, as well as providing resources to support their professional learning and the development of core teacher competences (e.g. Hudson, 2012; Le Cornu & Ewing, 2008; McCormack et al., 2006). The resulting relationships that pre-service teachers develop may provide a resilient

context to support them as they make the transition to newly qualified teachers (Gu & Day, 2007).

Social capital can develop to take on different forms. Hudson (2012) mentions how novice teachers refer to a range of key actors in their social support networks. These range from senior and experienced colleagues in their school, through to support from spouses, friends, and family members. Le Cornu and Ewing (2008) also highlight the importance of relationships between peers as a source of mutual support that is beneficial to both professional learning and personal well-being. Authors (2018a) have investigated changes in the balance of internal (peer) and external (others) in the support networks of pre-service teachers across the training period. A key source of support is the 'teacher next door' (Hudson, 2012, p. 76), which suggests both physical and social proximity of an empathetic and understanding peer. When individuals are closely connected, they will communicate easily with each other and by doing so they may exchange information, support and build trustworthy relationships. This relates to two key aspects of social capital: the social network structure and relational trust (Falcone & Castelfranchi, 2011; Lin, 2001).

We include support and friendship networks in our models in our efforts to understand the multiplex of relationships between these networks and tie formation in communication networks. Academic support is about sharing knowledge or information, and asking for study-related support, which is related to performance goals (Authors, 2016; Nebus, 2006; Gaševic, Zouaq, & Janzen, 2013; Tomás-Miquel, Expósito-Langa, & Nicolau-Juliá, 2015). Friendships tend to be more reciprocal relationships, offering emotional support and help to each other to deal with stressful experiences, for example internship during teacher training. Friends may provide personal or emotional support and help cope with stressful

situations (Buote et al., 2007; Wilcox, Winn, & Fyvie-Gauld, 2005), such as the transition to study at university.

1.4. The role of self-efficacy and trust in the formation of ties

In contrast to social capital, human capital comprises individually acquired skills, such as knowledge, beliefs and attitudes (Coleman, 1990). Self-efficacy is the self-belief to succeed in a certain domain or task (Bandura, 1977, 1997) or the "I-can-do-it"- cognition (Bandura, 1997; Kraft, Rise, Sutton, & Røysamb, 2005). Self-efficacy may be a student characteristic, through which the effects of social capital are mediated. Students enter university with beliefs about their own abilities (Bandura, 1977, 1997; Wigfield & Eccles, 2000). Apart from the development of networks, these beliefs may also change over time due to experiences and can be influenced by interactions with others (Liou & Daly, 2018; Siciliano, 2016). This is likely to take place in class among peers (Bandura, 1977, 1997; Usher & Pajares, 2008). In the context of teacher training, self-efficacy has also been shown to be an important factor. McCormack et al. (2006) showed that feedback from others is important for teacher's self-efficacy in the beginning of their career. They need this feedback to remain motivated to continue with training for the teaching profession. Liou et al. (2017) utilised survey and cross-sectional social network techniques to examine the relationship between the social capital of pre-service teachers and their professional development. They concluded that emotional support, interpersonal trust, and perceived self-efficacy are associated positively with pre-service teachers' teaching competencies. It seems a reasonable assumption that pre-service teachers are likely to be influenced by their perception of self-efficacy and trust within themselves, and within others, as they develop their communication ties with their peers in order to reach out for support and advice. This is especially important as the

development of specific teaching competencies are regularly assessed across the duration of the programme. The emphasis on the development of communication networks across the duration of the programme of training, particularly academic support, emotional support or support for strategies, also reinforces that self-efficacy and peer trust should be taken into account when studying development of pre-service teachers' networks over time. Previous studies (cf. Liou et al., 2017; Liou & Daly, 2018) have namely indicated that trust and self-efficacy are associated with tie formation and tie change in longitudinal development of advice seeking networks. The evidence for the effect of self-efficacy is equivocal as Siciliano (2016) found that self-efficacy was not significantly associated with the formation of advice seeking ties among in-service teachers. The current study provides an opportunity to add to the evidence base for the effects of these attributes on networks.

1.5. The current study

Within the context of multiple phases of education, social capital has been positively associated to achievement (e.g. Authors, 2016, 2018b; Cemalcilar & Gökşen, 2014; Dufur, Parcel, & Troutman, 2013). Although it can be assumed that pre-service teachers build and mobilize their social capital within their peer networks, so far, relatively little is known about the way trainee teachers' social capital within their peer network develops over time. In the context of first-year university students, Authors (2016) highlighted that previous studies were particular in their target audience, for example focusing on international students or ethnically diverse student groups, or that they focused on only a few dimensions of the social capital construct. Considering the importance of building social capital through communication and the role of self-efficacy and trust in previous research (Liou et al., 2017), we posit that we should look at trainees' development of communication networks and the

link with finding support for strategies, academic support and friendships over time. This study utilised whole, peer network data rather than more limited egocentric network data around a series of individuals (Fox & Wilson, 2015). We analyse our longitudinal social network data with stochastic actor-based models (Snijders, 2001, 2005). This statistical method allows us to investigate communication network formation across the academic year given student characteristics (trust, self-efficacy), cross-network effects (support networks for developing teaching strategies, and friendship), and the network structure simultaneously. By doing so, we move beyond prior research of the role of networks, self-efficacy, and trust in pre-service teachers that apply cross-sectional social network tools (e.g., Authors, 2018a; Liou et al., 2017; López Solé, Civís Zaragoza, & Díaz-Gibson, 2018).

We address the following research questions:

RQ1: How do the communication networks of pre-service teachers of mathematics and science develop over time?

RQ2: To what extent do students communicate with each other when they are friends and when they need support for developing teaching strategies?

RQ3: To what extent does communication between students over time relate to the type of programme, gender, self-efficacy and trust?

We expect that it is more likely that trainee teachers develop or maintain a communication network tie with each other when they start the time period as friends or when they have already sought advice from a peer concerning developing their teaching strategies. Based on homophily (McPherson et al., 2001), we expect that it is more likely that trainees connect to

each other when they are from the same gender or programme or have similar perceptions of self-efficacy and trust.

2. Methodology

2.1. Research design

The study employs a longitudinal survey design with surveys of both peer support and wider networks of pre-service teachers. The peer network data is complete network data in that respondents indicated peer relations between themselves and all other trainees in their cohort of mathematics or science.

2.2. Participants

For this study 37 mathematics (18 female) and 40 science (20 female) pre-service trainees of a cohort of the secondary Initial Teacher Education (ITE) programme at a university in the south of England were approached. Table 1 shows the response rates across four time points. Attrition of participants resulted from trainees' non-response and withdrawing before completing the programme.

Table 1.
Response rate across four time points.

Subject	T1	T2	T3	T4
Mathematics (37)	35 (95%)	28 (81%)	29 (94%)	29 (90%)
Science (40)	38 (95%)	33 (83%)	32 (86%)	31 (83%)
Total	73	61	61	60

2.3. Instruments and variables

For the *communication networks*, trainees were presented with a complete roster of names

from their subject peer-cohort (mathematics or science) and asked whether they had any communication with this trainee during the last month. This bounded approach to eliciting peer networks is commonly used in similar network studies (e.g. Liou et al, 2017). A positive response to this question would lead to participants being asked to indicate to which fellow students they had turned for different types of support during the same time-period, including *support with developing teaching strategies*. For the *friendship networks*, trainees were asked which of their peers they considered to be a personal friend. The networks were scored on a dichotomous scale with 1 = presence of a tie and 0 = absence of a tie.

Self-efficacy (12 items; $\alpha = 0.96$) was assessed with a scale originally developed by Tschannen-Moran and Hoy (2001). The scale consists of three subscales: classroom management, student motivation, and instructional skills. Examples of items within each sub-scale are "How much can you do to get children to follow classroom rules?", "How much can you help your students value learning?" and "How well can you provide an alternative explanation or example when students are confused?". Participants responded to each item on a 9-point Likert-scale from 1= "not at all" to 9= "always".

Interpersonal trust (6 items; $\alpha = 0.95$) was adapted from the scales used by Daly and Chrispeels (2008) and Hoy and Tschannen-Moran (2003). Examples of items are "Even in difficult situations, I can depend on my fellow trainees", "I find that my fellow trainees are open to me" and "I also share personal information with my fellow trainees". Participants responded to each item on a 9-point Likert-scale from 1 = "very strongly disagree" to 9 = "very strongly agree".

Demographic and contextual variables were collected: *gender* (0=male, 1=female), *subject* (0=mathematics, 1=science) and *programme type* (0=University Led, 1=School Direct).

2.4. Procedure

All participants were informed about the study aims, the duration of the study and ethical concerns. They were asked to provide their informed consent for participation at the beginning of the survey on each data collection occasion. It took approximately 20 minutes to complete an online questionnaire on each of four measurement occasions during the academic year, respectively in October 2014 (T1), December 2014 (T2), March 2015 (T3) and May 2015 (T4). The study variables were collected at all four time points, except for trust which was not measured at the second time point (see Table 2 for an overview).

Table 2.

Overview of the measurements for each data collection point.

Wave	2014-2015	Network	Covariates	
			Trust	Self-efficacy
1	T1 (October)	✓	✓	✓
2	T2 (December)	✓		✓
3	T3 (March)	✓	✓	✓
4	T4 (May)	✓	✓	✓

Two ITE courses were included: University Led (UL) and School Direct (SD). Time points were partly determined based on programmatic moments that were related to the course structures of both UL and SD courses. Each of the courses provides a route to become a qualified teacher of their subject in secondary schools. The courses span across an academic year (September to June). Trainees in the SD group spent time in schools immediately, from the beginning of their course. In both UL and SD courses, trainees would usually not take responsibility for class teaching until after a period of acclimatisation and observation of qualified teacher practice lasting several weeks. From that point trainees might then take on parts of lessons, building up to teaching whole lessons at a pace appropriate to the

individual trainee teacher. Trainees on the UL course would commence with a period of time based at the university before embarking on their first school placement. SD trainees had fewer total days based in the university, about half, 20 days, compared to UL's 40 days across the year. SD trainees would have workshops and seminars on aspects of teacher practice based in their school or a nearby school, as well as attending days for university-based classes.

Thus, each course had two periods of school placement experience. For UL trainees each placement was preceded by a period of university-based study and T1 and T3 were scheduled during or just after these university- based phases. T2 and T4 occurred during the school placement phases. SD trainees did not have the same university-based periods of study before each placement. They attended the university for occasional days of teaching to supplement other initial training and orientation within the placement school.

2.5. Analytical approach

2.5.1. Stochastic actor-based modelling

In this study, pre-service teachers' communication networks are investigated longitudinally. This provides insights into the development of peer interactions over time and allows us to track changes in both network position and personal attributes over time within the networks. In social network data, assumptions for using conventional statistical techniques, i.e. independent observations, is usually violated. Therefore, social network data requires the use of statistical tools dealing with interdependency. In a social network, the change of a relation from one actor to another actor occurs simultaneously with changes in other relationships in the same network and changes in the individual attributes. For example, a teacher trainee might communicate with another teacher trainee from the same

programme or because they have a friend in common. Stochastic actor-based models are equipped to account for the interdependency of changes in networks over time and are commonly used for the analysis of longitudinal social network data (Snijders, 2001, 2005; Snijders, Van de Bunt, & Steglich, 2010). To model the change of the communication networks while controlling for cross-network effects (support for developing strategies, friendships) and individual attributes, such as gender, self-efficacy and trust, we use the data-analysis package SIENA (Simulation Investigation for Empirical Network Analysis; Ripley, Snijders, Boda, Vörös, & Preciado 2019) within the programming language R. RSIENA is suitable for dichotomized social network data in which a dyad of two actors is represented with either a 1 (presence of a tie) or a 0 (absence of a tie).

2.5.2. Model specification

For the participating trainee teachers in either mathematics or sciences, we investigated selection in communication peer-networks. Therefore, we specified one model across the consecutive waves (i.e., from T1 to T2, from T2 to T3, and from T3 to T4).

First, we specified the network effects. A basic rate parameter refers to the change rate in the communication interactions over time. *Outdegree/density* is the tendency of pre-service teachers to establish (or break) communication ties to their peers regardless of any other processes. *Reciprocity* is the tendency to form (or break) mutual ties. In network analysis the dyad (where a tie exists between two actors) is the most basic unit of social structure. In these networks with directed ties, a dyad can be formed from trainee 'i' nominating trainee 'j', from trainee j nominating trainee i, or from a reciprocated nomination. In addition to these basic network effects, we included transitivity, the tendency of group formation, i.e., transitive triplets and transitive reciprocated triplets. A *transitive triplet* is formed from the

tendency for triplets to eventually undergo transitive closure when trainees i and k form a direct tie as well as their mutual connection through trainee j. This process is colloquially referred to as "a friend of a friend becomes my friend" (Burk, Steglich, & Snijders, 2007). *Transitive reciprocated triplets* refer to a structure in which all the ties are reciprocated, when all members of the triad are mutually connected to one another.

Secondly, we also include cross-network effects from the previous time point to test whether the presence of a connection in a network added as an independent variable to the model explains the pattern of tie formation and dissolution in the communication network. These explanatory network variables based on friendship and advice seeking networks were measured at the start of each period (i.e. T1 for T1 to T2, T2 for the time period T2 to T3 and so on).

Thirdly, we model the effect of demographic covariates on the development of the communication peer-networks, including the course type *(School Direct*, SD, compared to University Led, UL) and *gender* (female compared to male) as well as measured attributes of self-perceived *self-efficacy* and *interpersonal trust*. These individual attributes were included as ego, alter, and the so-called homophily effect. Ego (sender) effects refer to the extent to which the ego nominates his or her peers, whereas alter (receiver) effects refer to the ego who receives nominations from his or her peers. Homophily refers to the tendency to communicate with others who are more similar to the focal actors in terms of background characteristics, school programme, and level of self-efficacy or trust (see McPherson et al., 2001). This is modelled with interaction terms of ego (sender) and alter (receiver) on trust and on self-efficacy respectively (see Ripley et al., 2019). Homophily effects suggest that it is

more likely that a tie develops when students are in the same programme (SD vs UL), have the same *gender*, and have the same tendency of scores on self-*efficacy* and *trust*.

3. Results

3.1. Descriptive network statistics

Descriptive network statistics for the communication networks of mathematics and science pre-service teachers are depicted in Table 3 and Table 4. These descriptive network statistics are calculated with the SNA-package in the R programme. Mathematics trainee teachers had 11 nominations to peers on average in their communication network at T1 and this reduces to an average of 4 peers at T4. The standard deviation decreases for incoming ties from 6.66 to 3.62 and for outgoing ties from 8.33 to 4.21. Science trainee teachers had initially a lower average of 9 peer nominations at T1 and this reduces to an average of 4 peer nominations by T4 in the communication network. The standard deviation decreases from 4.71 to 2.29 for incoming ties and from 6.25 to 5.03 for outgoing ties. The proportion of mutual communication relationships increases over time for mathematics trainees from 47% to 59%, while transitivity decreases from 70% to 62%. For science trainees, the proportion of reciprocal communication ties decreases from 48% to 29% from T1 to T4 and transitivity from 55% to 40%. The overall network density, referring to the ratio of actual ties divided by all possible ties, decreases over time for mathematics trainees from 31% to 11%, and also for science trainees from 23% to 10%. The Jaccard index indicates sufficient stability for mathematics and science trainees (i.e., above 30%; Ripley et al., 2019), to enables us to perform longitudinal social network analysis. Across the four time points, on average for mathematics trainees 47 communication ties emerged, 137 ties dissolved, and

195 ties maintained. For science trainees, 85 ties emerged, 153 ties dissolved, and 161 ties maintained.

Values of the Programme E-I Index (Krackhardt & Stern, 1988), calculated in UCINET (Borgatti, Everett & Freeman, 2002), indicate the degree of heterogeneity in the programme groups. A value of -1.0 would indicate complete homogeneity and +1.0 indicate complete heterogeneity. Compete homogeneity means that groups made up exclusively of UL trainees communicating exclusively with other UL trainees and likewise SD communicating only with other SD trainees (see Borgatti, Everett, & Johnson, 2013). This is illustrated by the sociograms in Figure 1 (for science trainees only) to illustrate visually how a relatively strong separation is maintained between UL and SD trainees between T1 and T4.

Table 3.

Network descriptive statistics of the communication peer networks of mathematics pre-service teachers

Mathematics	T1	T2	T3	T4
Network descriptives				
Average degree	11.32	8.51	6.95	4.08
Stdev[1] Indegree	6.66	5.67	5.24	3.62
Stdev[1] Outdegree	8.33	7.62	6.39	4.21
Reciprocity	47%	45%	52%	59%
Transitivity (proportion)	70%	66%	63%	62%
Transitivity (weak census)	3900	2296	1571	345
Density	31%	24%	19%	11%
Programme E-I index	-0.790	-0.905	-0.852	-0.841
Change	T1 - T2	T2 - T3	T3 - T4	
Jaccard index	55%	48%	50%	
No. of ties dissolved	158	130	122	
No. of ties created	53	72	15	
No. of ties maintained	263	186	136	

Note. [1] *Stdev* refers to standard deviation. Weak census refers to the total number of transitive triads[1]

Table 4.

Network descriptive statistics of the communication peer networks of science pre-service teachers

Science	T1	T2	T3	T4

[1] see https://www.rdocumentation.org/packages/sna/versions/2.4/topics/gtrans.

Network descriptives				
Average degree	9.05	9.30	5.05	4.03
Stdev[1] Indegree	4.71	4.46	2.88	2.29
Stdev[1] Outdegree	6.25	8.50	4.72	5.03
Reciprocity	48%	35%	38%	29%
Transitivity (proportion)	55%	60%	41%	40%
Transitivity (weak census)	2107	2268	486	286
Density	23%	24%	13%	10%
Programme E-I index	-0.901	-0.828	-0.734	-0.816
Change	T1 - T2	T2 - T3	T3 - T4	
Jaccard index	47%	34%	39%	
No. of ties dissolved	129	228	102	
No. of ties created	138	59	59	
No. of ties maintained	236	146	103	

Note. [1] *Stdev* refers to standard deviation. Weak census refers to the total number of transitive triads

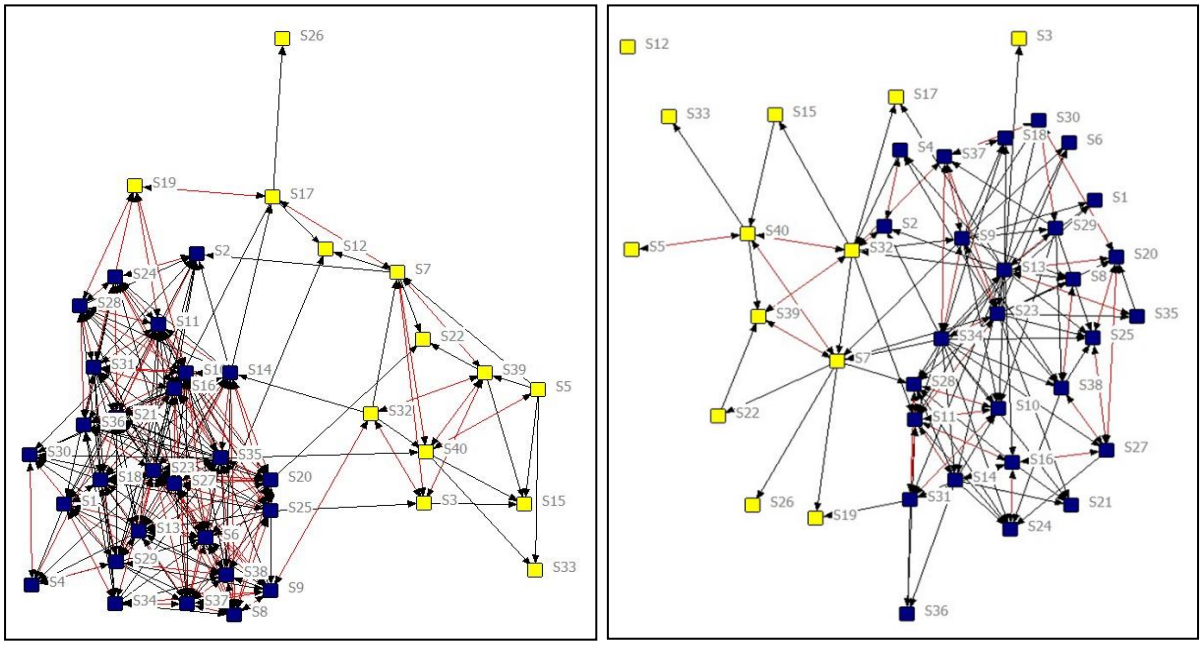

Fig 1. Sociogram visualisations of the communication networks of science trainee teachers at T1 (left) and T4 (right). Dark squares = UL; paler squares = SD.
Note. Sociograms produced using NetDraw software (v2.167; Borgatti, 2002).

3.2. RSIENA results

The results of the models run using RSIENA for each pair of consecutive waves are presented in Tables 5 and 6 below. The parameter estimates for the coefficient associated with each term in the model are given with statistically significant estimates ($p < 0.05$) indicated in bold. For mathematics and science trainee communication networks, the structural network effects are roughly similar. Both networks have positive reciprocity and

transitive triplets parameters except for the final time point in mathematics trainees. This means that trainees tend to reciprocate communication ties and form groups. In triads, it is less likely that trainees reciprocate the communication ties when they form a group (negative transitive reciprocated triplet parameter). In mathematics and in science trainees, friendships increase the likelihood for communication ties until the third wave (positive friendship peer-network). We do not find evidence for this effect across the final wave. When mathematics trainees search for more support for their teaching strategies, it is more likely that they communicate with their peers in the beginning and at the end of the academic year, whereas for science trainees this only holds at the end of the academic year (positive teaching strategies peer-network). The trainee teachers of mathematics and science are more likely to communicate with a peer from the SD programme than from the UL programme (positive alter SD trainee), although this holds for mathematics trainees in the middle of the academic year and for science trainees at the beginning and the end. When science trainees are both from the same programme, it is more likely that they communicate with each other at the end of the academic year (positive same programme type). We do not find evidence for this for the mathematics trainees. Female mathematics trainees are more likely to communicate with their peers, but only in the beginning of the academic year (positive ego (sender) female trainee), while among science trainees it is more likely that trainees seek to communicate with their female peers at the end of the academic year (positive alter female). Among mathematics trainees, peers communicate more often with self-efficacious peers (positive alter self-efficacy). We do not find evidence that self-efficacy plays a role in the communication networks for science teachers. In mathematics trainees, it is less likely that peers communicate with other trustworthy peers at the beginning of the academic year (negative alter trust). In science, this effect is non-

significant. We do not find evidence for homophily effects for trust and self-efficacy among mathematics or science communication peer networks.

Table 5.

RSIENA parameter estimates (standard error) for the effects on network change based on models for each consecutive pair of waves for mathematics trainees.

Communication network change – mathematics trainees	T1 to T2	T2 to T3	T3 to T4
rate basic rate parameter	**12.67**	**34.45**	**7.56**
	(2.36)	**(7.08)**	**(1.52)**
outdegree (density)	**-3.53**	**-2.49**	**-4.24**
	(1.47)	**(0.38)**	**(0.97)**
reciprocity	**1.69**	**1.60**	**1.90**
	(0.35)	**(0.29)**	**(0.67)**
transitive triplets	**0.19**	**0.19**	-0.02
	(0.03)	**(0.03)**	(0.11)
transitive reciprocated triplets	**-0.17**	**-0.15**	0.24
	(0.05)	**(0.04)**	(0.16)
friendship peer-network	**0.76**	**1.18**	0.03
	(0.22)	**(0.19)**	(0.59)
teaching strategies peer-network	**1.13**	0.30	**2.41**
	0.37)	(0.21)	**(0.91)**
alter SD[1] trainee	0.14	**0.72**	-0.33
	(0.07)	**(0.25)**	(0.60)
ego SD[1] trainee	-0.03	0.36	1.33
	(0.29)	(0.28)	(0.79)
same programme type	0.47	-0.07	0.37
	(0.25)	(0.23)	(0.49)
alter female trainee	0.16	-0.01	-0.72
	(0.15)	(0.13)	(0.37)
ego female trainee	**0.52**	-0.02	0.68
	(0.18)	(0.11)	(0.65)
same gender	0.19	0.02	0.64
	(0.14)	(0.13)	(0.42)
alter self-efficacy	0.04	-0.09	**1.27**
	(0.07)	(0.08)	**(0.43)**
ego self-efficacy	-0.05	0.07	-0.29
	(0.07)	(0.07)	(0.59)
homophily self-efficacy	0.002	-0.05	-0.37
(ego self-efficacy × alter self-efficacy)	(0.005)	(0.08)	(0.53)
alter trust	**-0.18**	-0.04	-0.02
	(0.05)	(0.05)	(0.13)
ego trust	-0.05	-0.04	0.21
	(0.04)	(0.04)	(0.25)
homophily of trust	-0.02	-0.001	-0.07
(ego self-efficacy × alter self-efficacy)	(0.002)	(0.007)	(0.07)

Note. [1]SD refers here to school direct. Alter refers to a receiver effect; ego to a sender effect.

Table 6.

RSIENA parameter estimates for the effects on network change based on models for each consecutive pair of waves for science trainees.

Communication network change – science trainees	T1-T2	T2-T3	T3-T4
rate basic rate parameter	**15.63**	**21.45**	**8.81**
	(2.06)	**(4.34)**	**(1.31)**
outdegree (density)	**-2.53**	**-2.39**	**-3.02**
	(0.24)	**(0.20)**	**(0.30)**
reciprocity	**1.80**	**1.61**	**1.53**
	(0.42)	**(0.27)**	**(0.31)**
transitive triplets	**0.31**	**0.19**	**0.39**
	(0.06)	**(0.05)**	**(0.07)**
transitive reciprocated triplets	**-0.37**	**-0.18**	**-0.43**
	(0.10)	**(0.08)**	**(0.15)**
friendship peer-network	**0.52**	**0.75**	-0.15
	(0.20)	**(0.17)**	(0.35)
teaching strategies peer-network	0.28	0.26	**0.91**
	(0.26)	(0.19)	**(0.36)**
alter SD[1] trainee	**0.61**	0.13	**0.60**
	(0.20)	(0.18)	**(0.27)**
ego SD[1] trainee	-0.12	**0.44**	-0.25
	(0.19)	**(0.19)**	(0.30)
same programme type	0.38	0.10	**0.78**
	(0.19)	(0.14)	**(0.26)**
alter female trainee	-0.18	-0.01	**0.68**
	(0.12)	(0.14)	**(0.19)**
ego female trainee	0.13	-0.20	-0.26
	(0.13)	(0.16)	(0.20)
same gender	**0.27**	**0.28**	0.32
	(0.11)	**(0.12)**	(0.17)
alter self-efficacy	0.02	0.02	0.04
	(0.04)	(0.07)	(0.10)
ego self-efficacy	0.02	-0.11	-0.10
	(0.04)	(0.08)	(0.09)
homophily self-efficacy	0.08	0.06	0.16
(ego self-efficacy × alter self-efficacy)	(0.02)	(0.06)	(0.11)
alter trust	-0.11	0.01	-0.01
	(0.05)	(0.06)	(0.08)
ego trust	-0.09	0.03	0.02
	(0.06)	(0.06)	(0.08)
homophily trust	0.02	-0.09	-0.03
(ego trust × alter trust)	(0.04)	(0.05)	(0.07)

Note. [1]SD refers here to school direct. Alter refers to a receiver effect; ego to a sender effect.

4. Discussion and conclusions

The first research question was how communication networks of pre-service teachers of mathematics and science develop over time. The general pattern of decline in average communication ties between trainee teachers across the duration of the course is most likely linked to changes during the year-long pre-service training course, moving from a period of more intensive university-based training (exclusively so for UL trainees) around T1

to increasing amounts of time spent in placement schools at the other time points. Despite a return to university-based learning for several weeks around the period before T3 for the UL trainees, any potential "bounce" in the average degree resulting from the opportunity this afforded for greater face-to-face communication appears to have ebbed away by the time data were collected early in the second placement by T3. Additionally, the cohesion among trainees decreases over time. The pattern of change in trainee teacher communication networks aligns with the findings of Liou and Daly (2018) who observed a reduction in average degree over time between pre-service teachers seeking new teaching ideas from their peers. Also, in line with Liou and Daly's (2018) findings, the reduction in average degree was associated with an increase or maintenance in reciprocity, as observed in the network descriptives, suggesting a degree of greater or sustained mutuality of communication within this reduced core network. This is supported by the significant and positive coefficients for reciprocity, for both mathematics and science trainees, across each of the three periods of network change. The proportion of transitivity seems relatively high, which can be explained since students may be satisfied with a balanced network, i.e., when two connected individuals have a shared communication partner (see Monge & Contractor, 2003). Transitivity is decreasing over times, which may be due to the fact that students have less lectures at the university at the end of the academic year. Transitive triplets are significantly and positively related to communication ties, but for mathematics trainees it is not significantly related anymore at the end of the academic year. However, we find a negative effect of transitive reciprocated triplets on the communication networks. Reciprocated transitive triplets might fit with the definition of Simmelian ties, where three or more reciprocal ties exists in a group, i.e. of at least individuals (Krackhardt, 1998). In networks with Simmelian ties the group identity becomes more important and may restrict

further tie formation (Krackhardt & Handcock, 2006) as trainees prefer the balance provided by a group offering mutual lines of communication. Overall, the network structures of both mathematics and science trainees seem more or less similar.

The second research question was to what extent students communicate with each other when they are friends and when they need support for developing teaching strategies. In both groups of trainees (science and mathematics), it is more likely that the development of communication over time until T3 is related to friendships at the beginning of each period. T3 (March) marks a key point within the second placement period when all trainees, including those on the UL programme, are working full time in the second placement school. For the final period of the course, from T3 to T4, we did not find evidence of the ongoing relationship of friendships with network growth, as observed by the non-significant coefficient of the friendship parameter for the period T3-T4. By this stage, students were full time in their various placements at their second school and had very few taught sessions at the university. This final time period, however, is significantly associated with support seeking ties focusing on the development of teaching strategies. It might be that by the latter stages of the course, friendships have stabilised and may influence the growth of communication networks as strongly, which in turn allows more instrumental forms of support to emerge as associated with network growth in the models (or re-emerge in the case of mathematics where strategies were significant from T1-T2). It is instructive to see that changes in communication are predicted by instrumental support-seeking behaviour during the period of the programme when trainees are on their main school placement. Investment by course tutors in helping trainees develop support-seeking behaviours during the early part of the course may be a key mechanism for ensuring that strategic ties remain

when trainees have to take much greater initiative to communicate with one another while on placement. McCarthy and Youens (2005) found that trainee teachers of science were more likely seek their peers to develop aspects of their teaching craft, such as subject knowledge, as trainees felt that turning to school-based mentors might compromise assessment of their competence in the eyes of mentors and university tutors. Authors (2018b) found that students will seek out friendship relationships in which they feel safe to share a lack of expertise.

The third research question was to what extent communication between students over time relates to the type of programme, gender, self-efficacy and trust. The relatively high homogeneity values (indicated by the negative values of Programme E-I index) for the UL and SD programme groups across all four time points suggest that trainees in the two programmes have relatively separate communication networks, with only modest bridging occurring across the two programmes. This is despite the fact they are learning to train in the same subject discipline. In the SIENA-models we only find a homophily effect for the programme for science trainees at the end of the academic year. Although network research revealed segregation for different attributes, such as for achievement or nationality (Authors, 2018b; Rienties, Héliot, & Jindal-Snape, 2013), Liou and Daly (2018) observed a shift to increased programme homogeneity and so less boundary spanning over time in their study. However, this was based on advice seeking between pre-service teachers across four different subject disciplines within the same MEd programme. Based on the marginal evidence for segregation based on programme in this study, future research needs to replicate the current study with a larger sample of cohorts.

At points during the course, particularly early on, SD trainees are more likely to receive new ties from their peers (both UL and other SD) until the final period of the academic year for mathematics and T1 to T2 and T3 to T4 for science. The early development in communication networks of SD trainees is logical since SD trainees are attending the University less frequently (one day every other week), and so ties are likely to form more slowly. Studies have shown that both physical and perceived proximity is important in the initial development of teachers' social networks (Coburn et al., 2010; Le Cornu, 2013; Reagans, 2011).

Self-reported self-efficacy is not consistently and significantly related to the development of communication networks at any time point. We only found a significant alter effect for self-efficacy in pre-service teachers in mathematics at the end of the academic year. One might hypothesise that trainees would seek out their more confident peers, especially early on, in order to seek advice and support with aspects of their training. We have noted previously (Authors, 2018a) that SD trainees report significantly higher levels of self-efficacy early on in the course, due to their increased school experience. By the end of the programme there is no longer a significant difference in reported self-efficacy between UL and SD trainees. The fact that many SD trainees have worked in schools before embarking on their training, for example in roles such as teaching assistants, might indicate that SD is in some ways a proxy for increased self-efficacy.

Controlling for gender in the models did not indicate any consistent, significant patterns in its relationship to the development of communication networks across the course. Likewise, levels of interpersonal trust were also not significantly associated with development in the communication networks in any consistent way. In fact, perceptions of the level of trust in

others (alter receiver effects) were even significantly negatively associated with network development for science trainees across the period from T1 to T2. This may seem counter-intuitive and may be a result of controlling for the friendship networks between trainees, which researchers tend to view as a proxy for trust in others (Liou et al., 2017).

4.1. Limitations

We considered several limitations in our study. Firstly, the study is drawn from a single and small cohort in a single institution, so is limited in scope, and will have issues in terms of transferability across time, and between training contexts. As aforementioned, this study needs to be replicated in different cohorts with a larger sample size and at different programmes or institutions. Secondly, the bounded nature of the peer network data utilised in this study does not take into account the fact that communication networks of the trainee teachers build social capital among a wider range of actors, such as qualified teachers with whom they work, friends outside academia and family. Although we have collected and reported this wider network data at the individual (ego) level (Authors, 2018a), it is more challenging to determine whether the wider ego network data is complete. The focus of the analysis using stochastic actor-based models is on whole network change, and this makes it very difficult to incorporate ego network data in analysis using tools such as SIENA. We tried to be attentive not to over-reach in our inferences for apparently less well-connected trainee teachers such as those on the SD programme, focusing rather on the effects of peer network change. For further research, it is recommended to combine complete network analysis with ego network analysis to get a more nuanced picture of the communication networks of pre-service teachers.

4.2. Implications

It would appear, in common with other studies of network change among student teachers over time (e.g. Liou & Daly, 2018), that there is a pattern of reduction in the average number of ties between pre-service teachers across the duration of their training programmes, reducing down to communication with a core set of peers. Some of the changes observed in this study seem to align with the flow of programme experience, especially the time spent in schools on placement. The maintenance of a core social group may well be important, as a growing number of studies indicate an association between social capital and the final performance of pre-service teachers on their programmes (e.g. Civís et al., 2019, Liou et al., 2017; Smethem, 2007) and among university students in general (Gaševic, Zouaq, & Janzen, 2013).

In contrast to their peers on the UL programme, SD trainees start with a higher proportion of their time in school. It may be that their view of who constitutes a peer within their communication networks, extends beyond their fellow student teachers, facilitated by their earlier opportunities to network with others. Nonetheless, the relative separation of SD and UL trainees may be a concern for ITE tutors and mentors to address, at the very least in terms of helping trainee teachers to tap into wider networks representing the diversity of school training experience, and to help to realise the potential to draw on social capital through the strength of weak ties, to which Granovetter (1973) referred.

To conclude, the results suggest that the cohesion of the communication networks decreases across the academic year, consistent with the decrease in opportunity to meet other pre-service teachers. Friendships established at the beginning of the academic year remained influential on communication networks during the second time period, but decreased during the final period of the course, during which the pre-service teachers were

on their final school placement. During this final period of the academic year, instrumental support seemed to be shared through the communication networks. Students from the SD-programme seemed to be approached for communication more often than UL-trainees, although this finding is not consistent across the academic year for both mathematics and sciences pre-service teachers. We did not find evidence that self-efficacy plays a role in the formation of communication ties.

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