How Novice Elementary Teacher Leaders in Mathematics are Positioned in Advice and Information Networks

In this paper we examine how elementary classrooms teachers who are pursuing their Elementary Mathematics Specialist certification—who we refer to as Elementary Mathematics Specialists in Training (EMSTs)—are positioned in their advice and information networks for mathematics. Analyzing the advice networks of six elementary schools in one district, we found that EMSTs were sought out by more individuals than other teachers, and when sought out by others, provided advice at a greater frequency than formal leaders. EMSTs' advice-interactions were often with grade level peers, with interactions in the same grade occurring at a greater frequency than those spanning grade levels. We also found that, in the school with a formal mathematics-specific leader, advice interactions were primarily directed at the formal leader, including the advice-seeking of the EMSTs at that school. Based on our findings, we conclude with implications for how teacher education programs and school administrators can support mathematics teacher leaders in enacting leadership from their classrooms.

Keywords: teacher leaders; elementary mathematics specialists; teacher social networks

Introduction

Mathematics teacher leaders have the potential to play an important role in supporting instructional improvement (e.g., Harris & Muijs, 2005; Smylie et al., 2002). While some teacher leaders occupy formal positions (e.g., as coaches), many are full-time classroom teachers, enacting leadership through less formal means (McGatha & Rigelman, 2017; York-Barr & Duke, 2004). Though they are not typically afforded dedicated time for leadership, teacher leaders with full-time classroom responsibilities may be viewed as more credible sources than formal leaders and be more likely to engage with other teachers about classroom instruction (Spillane & Kim, 2012). Therefore, a potentially productive type of informal leadership that mathematics teacher leaders can enact is providing advice and information about mathematics teaching and learning.

The extent to which teacher leaders can engage in such leadership, however, depends on the context of their schools. A collegial and collaborative school culture, for example, supports teacher leadership, while hierarchical and formal designations can increase distance between teachers and make teacher leadership less effective (Smylie, 1992; York-Barr & Duke, 2004).

Prior research on teachers' advice networks has primarily focused on centrality—how important certain individuals are in the network (e.g., Berebitsky & Andrews-Larson, 2017)—and less so on the nature of advice interactions, or the ways in which school structures mediate advice-seeking. Our study extends this literature by examining both the centrality and nature of elementary mathematics teacher leaders' advice-giving, and how teacher leaders are positioned in relation to two specific school structures—grade level distinctions and formal mathematics-specific leadership positions. In doing so, we reveal important ways mathematics teacher leaders support the teaching and learning of their colleagues, and raise implications for how schools and administrators can support and leverage teacher leadership in promoting school-wide change.

Orienting Perspectives

In the following, we describe the perspectives that oriented our attention to advice- and information-networks, particularly in relation to school's organizational structures. We first, however, provide some background on teacher leadership and mathematics teacher leaders.

Mathematics Teacher Leadership

In this paper, we define teacher leadership as teacher actions that "influence colleagues, principals, and other members of school communities to improve teaching and learning practices with the aim of increased student learning and achievement" (York-Barr & Duke, 2004, p. 288). Researchers have argued that investing in teacher leadership can support school-wide instructional improvement (e.g., Harris & Muijs, 2005; Smylie et al., 2002). For example, in mathematics, teacher leaders with specialized content knowledge and expertise can provide sustained professional development to colleagues in their schools and districts (Gibbons et al., 2017; McGatha et al., 2015).

One way to develop mathematics teacher leaders is through elementary mathematics specialist (EMS) programs. Integrating leadership skills with content and pedagogical knowledge for teaching mathematics, EMS programs aim to influence the teaching of EMS professionals, as well as the teachers and schools they work with (Association of Mathematics Teacher Educators, 2013). With expert knowledge and skill, EMS professionals can engage in leadership to support colleagues to develop their knowledge and instruction for mathematics.

Teacher leaders can engage in leadership through a variety of formal and informal roles (York-Barr & Duke, 2004). In mathematics, some teacher leaders take up formal positions as mathematics coaches (either part or full-time) with primary responsibilities to support teachers in improving their mathematics instruction (Ellington et al., 2017; McGatha & Rigelman, 2017). Others continue as full-time classroom teachers, enacting leadership in more informal ways. This formal/informal distinction is important because those that maintain full-time classroom responsibilities are afforded a special peer-status that comes with an understanding of the affordances and constraints of teaching (Mangin & Stoelinga, 2008; Swars Auslander et al., 2023). However, without a formally designated position that confers legitimacy and authority, teacher leaders must convince others of their expertise through other means, such as specialized knowledge and skill (Berg & Zoellick, 2019; Diamond & Spillane; 2016). Most of the research on teacher leadership, particularly in mathematics, has focused on those with formal positions, and less so on those that maintain full-time classroom responsibilities (Baker et al., 2022; de

Araujo, 2015; McGatha, 2017). Our paper adds to this literature base by exploring the leadership of full-time elementary mathematics teachers (see also Swars Auslander et al., 2023).

Researchers have examined how teacher leadership can support teacher learning (Gigante & Firestone, 2008). For example, in studying the leadership opportunities of eight EMS teacher leaders with full-time classroom responsibilities, Conner and colleagues (2022) found that informal leadership tasks (e.g., answering colleagues' questions; co-planning) afforded teacher leaders with more "developmental" opportunities (Gigante & Firestone, 2008) to increase colleagues' knowledge of teaching mathematics, while formal leadership tasks (e.g., curriculum committee member; grade level chair) tended to support teachers' work without providing opportunities to develop their knowledge. For example, almost all the mathematics teacher leaders reported engaging in informal conversations with colleagues, in the hallways or during bus duty, where they provided advice and information about mathematics teaching. Because advice and information-giving has the potential to increase teachers' knowledge (Spillane & Kim, 2012), it represents a particularly powerful form of leadership that full-time classroom teacher leaders can engage in. We turn our attention to this next.

Advice and Information Networks

We focus on advice- and information-giving because, through social ties with colleagues (Spillane et al., 2012), teachers gain access to important resources needed to improve their practice (Darling-Hammond et al., 2009). Indeed, researchers have found that teachers' interactions, especially those of greater frequency and substance, and with individuals with greater expertise, are positively related to improvements in both their knowledge (e.g., Frank et al., 2004; Munter & Wilhelm, 2021) and instruction (e.g., Penuel et al., 2009; Sun et al., 2014).

Employing social network analysis, researchers have found that formal leaders with subject-specific roles (e.g., mathematics coaches) occupy the most central positions in advice networks, providing advice and information to the most individuals (e.g., Berebitsky & Andrews-Larson, 2017; Hopkins et al., 2013). Teacher leaders are also central, providing advice and information to more people than other teachers (Hopkins et al., 2013; Spillane & Kim, 2012; Spillane & Hopkins, 2013). Findings regarding how administrators are positioned have been mixed, however. While Spillane and Hopkins (2013) found that principals provided advice to more people than teachers, Spillane and Kim (2012) found that two thirds of principals did not belong to their mathematics instruction network at all (i.e., principals did not provide or seek advice). Similar mixed findings were found with respect to other administrators like assistant principals (see Berebitsky & Andrews-Larson, 2017; Spillane & Kim, 2012).

The research on advice and information networks in mathematics has primarily focused on *centrality*—how important certain individuals are in the network (e.g., Berebitsky & Andrews-Larson, 2017)—and less so on the nature of those interactions. However, it is not just interactions with others that support teacher learning; it also matters who teachers interact with and what they talk about. For example, Coburn and colleagues (2012) found that access to expertise, frequent ties, and substantive interactions were all essential for supporting teachers to maintain reform-oriented instruction when supports for reform were withdrawn.

First, it is important to consider the extent to which ties afford individuals access to expertise, as researchers have found that interactions with individuals with greater levels of expertise were positively associated with improvements in teacher's own knowledge and instruction (e.g., Munter & Wilhelm, 2021; Spillane et al., 2018; Sun et al., 2014). One mode for accessing different kinds of expertise is through interacting with individuals from different subgroups. Theoretically, ties that *span* subgroups, like grade levels or schools, facilitate access to information that may not be available in one's immediate network (Granovetter, 1973) by providing access to "multiple knowledge pools" (Reagans & McEvily, 2003, p. 242). In one study, Langer (2000) found that, compared to teachers in schools that were less academically successful, teachers in academically successful schools had access to and participated in multiple networks, including those with individuals outside their immediate network.

Another important dimension of advice interactions is the *strength* of relationships between individuals, often measured in terms of the frequency of interactions. Researchers have found that strong ties facilitate the transfer of complex knowledge (e.g., Reagans & McEvily, 2003). For example, interactions with colleagues who have developed more ambitious instructional visions can support improvements in teachers' own visions, particularly in cases where interactions are more frequent (Munter & Wilhelm, 2021). While strong ties support the exchange of ideas between individuals, weak ties play an important role in the diffusion of information across networks, as ties that span different subgroups are often weak ties (Granovetter, 1983). In schools, for example, ties between teachers at different grade levels may be weak, as these interactions are less frequent, but may be important for disseminating information across the grades and throughout the school.

In addition to strength, the *depth* or substance of interactions also matters. Learning how to implement ambitious and equitable mathematics instruction requires more than just sharing materials or lesson plans, but also substantive conversations about, for example, children's thinking and instructional strategies for using children's thinking in whole-class mathematical discussions (Coburn & Russell, 2008). Indeed, researchers have found that teachers who develop reform-oriented beliefs are more likely to engage in such high-depth interactions, particularly with colleagues with more reform-oriented beliefs (e.g., Spillane et al., 2018).

However, there is little social network research that has examined these characteristics of mathematics teacher leaders' interactions with their colleagues. Therefore, our study contributes to this literature base by investigating how novice mathematics teacher leaders are positioned—in terms of centrality, span, strength, and depth—in their networks for mathematics instruction. While we do not explicitly examine access to expertise, as we further describe in our methods, the mathematics teacher leaders in our study do possess forms of expertise that researchers have found are important for instruction and student learning (Campbell & Malkus, 2011; Kutaka et al., 2017; Munter & Correnti, 2017).

Teacher Leadership within School Organizational Structures

Because individuals are embedded in school infrastructures that enable and constrain how they interact with others, it is important to consider teacher leadership in relation to these broader structures (Hopkins et al., 2013; Smith et al., 2017). Schools have a formal organizational structure, including formally-designated positions such as principal, instructional coach, or teacher. As previously noted, prior research suggests that these formal role designations are related to advice-giving (Berebitsky & Andrews-Larson, 2017; Spillane et al., 2012). In this paper, we specifically attend to the presence or absence of mathematics-specific formal leaders (e.g., mathematics coaches) as these individuals are typically the most central in advice and information networks for mathematics (Spillane & Kim, 2012; Spillane & Hopkins, 2013).

While the presence of instructional coaches is related to greater levels of advice-interactions (Coburn & Russell, 2008; Spillane & Hopkins, 2013), such formal, hierarchical designations can inhibit teacher leadership (Wenner & Campbell, 2017; York-Barr & Duke, 2004). For example, in schools with top-down conceptions of leadership, teachers may doubt the legitimacy of leadership coming from those without a formal position, including teachers attempting to lead from within their classrooms (Friedman, 2011; Mujis & Harris, 2006). Moreover, formal positions signal authority and expertise, and without such formal designations, teacher leaders must convince others of their expertise through other means (Berg & Zoellick, 2019; Diamond & Spillane; 2016). However, teachers may not be aware of colleagues' expertise, particularly if teacher leaders are not publicly positioned as experts (Conner et al., 2022). This is especially important for advice-seeking, as teachers tend to go to those with greater levels of perceived expertise and experience (Berebitsky & Andrews-Larson, 2017). In one study, Hopkins et al. (2013) found that coach positions served as markers of expertise and promoted these individuals' centrality in advice networks.

Another formal structure important to how schools are organized is grade level distinctions. Teachers, especially those in elementary schools, often work in grade level units (e.g., Daly et al., 2010), participating in the same organizational routines (e.g., grade level meetings) and teaching the same curriculum. These grade level structures have implications for how schools are organized relationally, in terms of network structure for advice and information-seeking. Indeed, researchers have found that teachers are more likely to provide and seek advice and information from grade level peers than from those who teach in different grades (e.g., Spillane et al., 2012). We conjecture that a similar pattern exists with how teachers and mathematics teacher leaders interact: that teachers primarily seek advice from teacher leaders in the same grade level, and teacher leaders primarily provide advice to grade level peers. Grade level interactions, however, may not provide teachers with information made available through interactions that span the grades, such as how important mathematical concepts progress through the grade.

Research Questions

In this paper, we analyze social network data from six elementary schools in one district to examine the advice and information interactions of school staff, particularly attending to how mathematics teacher leaders are positioned in their networks for mathematics instruction. Specifically, our research questions are: 1) How are novice teacher leaders positioned in their advice and information networks for mathematics, especially compared to other teachers and formal leaders? 2) In their school networks, how are novice teacher leaders positioned in their school's grade level structures and in relation to a formal mathematics leader?

Methods

Study Context

The data analyzed for this paper is part of a larger project in which 24 teachers in a U.S. Midwestern state received funding to complete Elementary Mathematics Specialist (EMS) certification at two universities (Site 1, n = 13, and Site 2, n = 11) and serve as informal leaders in their schools, while continuing as elementary classroom teachers. In this study, we focus on survey data that was collected in Fall 2019, the first year of teachers' participation in their EMS programs. Because teachers were not formal leaders, nor necessarily identified by school administration or colleagues as experts, we consider them novice teacher leaders, or Elementary Mathematics Specialists in Training (EMSTs).

For this paper, we focus on the 13 participants at Site 1. These participants were recruited through an invitation sent out via district channels. Thirty-six teachers completed an application, which consisted of questions about teaching assignment, experience, reasons for applying, perspectives on major issues facing teachers of elementary mathematics, experience with professional development, involvement in school improvement initiatives, and participation in school or district leadership. Applicants also submitted a video of their mathematics instruction with a written reflection on the video. After an initial review of the applications, the program director (author two) called each applicant's principal to describe the program and discuss the potential of each applicant for success in a leadership role in their school. This included a discussion of how they were viewed by other teachers in their building.

After teachers were admitted to the program, they began their coursework with a leadership course offered in the form of a Summer Institute, which included participants from both sites. During the institute, each EMST was interviewed using the Visions of High-Quality Mathematics Instruction (VHQMI) protocol (Munter, 2014). Analysis of these interviews revealed that the cohort overall had a relatively robust vision for high quality mathematics instruction, emphasizing: the role of the teacher as "one who proactively supports students' learning by intentionally structuring classroom activities to afford genuine mathematical work and then coparticipating in that work," (Munter, 2014, p. 590); mathematical talk that is focused on developing conceptual understanding and makes use of student contributions; and mathematical tasks that include high levels of cognitive demand (Silver & Stein, 1996). Figure 1 shows that most of the 13 EMSTs were rated at Level 3 (out of 4) or above for each aspect of instructional practice (see Munter, 2014 for a detailed description of each aspect and criteria for ratings). In this respect, the EMSTs in our study had forms of expertise that researchers have found are important for instruction and student learning (e.g., Munter & Correnti, 2017).

[FIGURE 1 HERE]

In this paper, we focus on social network data from the six elementary schools (Briar, Palm, Reed, Rowan, Thorn, Woods; pseudonyms) in one district where Site 1 EMSTs worked. The 13 EMSTs worked together in school-based teams, ranging in size from 1-3 EMSTs. For the 2019-2020 school year, the student population at the six schools varied greatly (see Table 1). Briar had the most students, with 664, while Thorn had 147. All but one school (Woods) had less than 40% of students that identified as white, or that received free or reduced-price lunch (FRL)—according to the U.S. Department of Education, 40% is the qualifier for schools with high percentages of students from low-income families to receive "Title 1" designation and fund use (n.d.). By contrast, Woods was designated as a Title 1 school given that 76% of its students received FRL. Moreover, 61% of its population were students of color. Woods was also the only school with a formal mathematics-specific leader, a "Title I Mathematics Specialist" who had previously completed an EMS certification and whose role was primarily to work with students designated as needing additional support for mathematics. The other schools did not have any formal mathematics-specific leaders. The district in which these six schools were situated also employed two formal mathematics leaders at the district central office: an elementary (grades K-5) mathematics coordinator, and a secondary (grades 6-12) mathematics coordinator.

[TABLE 1 HERE]

Data Collection

We sent a survey to all teachers in the six elementary schools the 13 EMSTs at Site 1 taught at. 128 teachers responded, with a response rate of 84%, ranging from 72% to 92% depending on the school. For this study, we focus on a set of items related to advice- and information-seeking interactions in mathematics, which were based on those developed and validated in other studies (Pitts & Spillane, 2009). Specifically, these items asked, "During this past school year, is there a person in your building or district you have turned to for advice or information about teaching mathematics?" (Middle School Mathematics and the Institutional Setting of Teaching, n.d.). Respondents wrote the names of up to three individuals, and for each, were asked "how often do you seek advice or information from this person" and "what type(s) of advice or information do you seek from this person? Please check all options that apply." The options for these questions are described in the following section.

Analysis

For each individual that responded or was named, using the school and district websites, we collected data for the individual's role (e.g., formal leader; EMST; teacher), associated site (e.g., central office; school), and, if applicable, grade level. We considered nominated individuals as formal leaders if they had an assigned formal leadership position and had no classroom teaching responsibilities (e.g., district mathematics coordinators, principals, the Title I Mathematics Specialist at Woods). And, because the survey was distributed to only teachers, we categorized all the participants that responded, besides our EMSTs, as teachers. In the following, we describe our analysis for each research question.

Research Question One

To describe how EMSTs were positioned in their advice networks, we considered two measures for centrality, as well as the span, strength, and depth of advice interactions (or *ties*). First, we considered *degree centrality*, which measures how well connected an individual is in a network (Freeman, 1979), and can be broken into in-degree—the number of people who sought out that individual for advice and information—and out-degree—the number of people that individual sought out. We also considered *betweenness centrality*, which measures brokering, or the extent to which an individual connects two other people in the network (Freeman, 1979).

In addition to centrality, we calculated measures to describe the nature of ties individuals had with others. Based on our literature review, we considered whether ties spanned workgroups, as well as the strength and depth of ties. For *span*, between two teachers (or a teacher and an EMST), we considered whether the tie extended beyond the individual's grade level (1 = yes, 0 = no). For ties with teachers that taught multiple grade levels, if the two individuals had at least one overlapping grade, we considered this as not spanning grade levels. Ties between a teacher (or EMST) and a formal leader were considered spanning since the tie extended beyond functional subgroups. For *strength*, we considered frequency, which teachers reported by selecting one of four options: "a few times a year" (1), "once or twice per month" (2), "once or twice per week" (3), and "daily or almost daily" (4). For substance or *depth* of interactions, we based our definitions on those of Coburn and Russell (2008), with three options: low (1), medium (2), and high (3) (see Table 2). Low-depth interactions were relatively surface-level, involving the sharing of materials, or discussing pacing or whether students "got it." By contrast, high-depth interactions addressed substantive instructional issues including students' thinking about mathematics and how to support and build upon students' thinking. Because respondents were able to select multiple options, we calculated an average depth, as well as whether the tie included at least one high-depth activity (1 = yes, 0 = no).

[TABLE 2 HERE]

For any relation between two individuals, there are two possible ties: one from person A to person B, and the other from person B to person A. For example, if person A responded that she asked person B for advice daily, then the strength of person A's out-tie with person B, as well as the strength of person B's in-tie with person A, would be 4. Sometimes, participants listed "grade level team" instead of specific individuals. In such cases, we included all teachers at that school that taught the same grade (not including those that taught multiple grade levels) and applied the same score for each individual for the aforementioned measures.

For each individual, we calculated their degree and betweenness centralities, and the average span, strength, and depth of their ties. For individuals that were named but did not respond to the survey (e.g., formal leaders), we only calculated measures for in-ties (i.e., ties where others reported going to this individual for advice and information). Then, we compared these measures among EMSTs, teachers, and formal leaders and tested differences for significance using analysis of variances with permutation tests. Because social network data are not independent, we used UCINET software (Borgatti et al., 2002) to conduct a random replication procedure with 5000 permutations (Carrington et al., 2005; Spillane & Hopkins, 2013).

Research Question Two

Informed by the literature, we also examined how EMSTs were positioned in their school's grade level structures and in relation to the mathematics-specific formal leader. Because we were interested in the school networks, we did not include any district central office leaders. Of the six schools, only Woods had a mathematics-specific formal leader: the Title I mathematics specialist. With respect to grade level structures, we considered the extent to which EMSTs sought and provided advice to those outside their grade level (i.e., the extent to which ties spanned grades), and how tie span might be related to strength and depth.

To illustrate our findings, in this paper, we focus on EMSTs in three schools, selected based on variation, including whether there was a mathematics-specific formal leader, the size of schools, and the variation in school networks. Specifically, we included Woods because it was the only school with a mathematics-specific formal leader. We also included Briar and Rowan because these schools had the smallest and greatest number of ties to EMSTs, respectively. We looked for similarities and differences across these three schools in how EMSTs were positioned in relation to the school's formal structures outlined earlier. For example, we considered how EMSTs were positioned in their school's grade level structures, including the grades they teach as well as other grades.

For each school, using the "igraph" package in R (Csardi & Nepusz, 2006), we created diagrams for the school's advice and information network for mathematics. In network maps, individuals are represented with vertices, and ties are represented by arrows connecting two vertices. Ties are directed, so an arrow pointing from one individual to another indicates that the first individual sought the second one out for advice and information. Tie strength (i.e., frequency of interaction) is represented by the thickness of the arrow. To construct network maps, igraph uses the Fruchterman-Reingold (1991) method, which places vertices that share more (frequent) ties closer together, and those with fewer (and less frequent) ties farther apart. Moreover, vertices with greater in-degree centrality (i.e., more people sought advice and information from this individual) are placed towards the center of the network, and those with ties amongst themselves are grouped together (Contandriopoulos et al., 2018; Decuypere, 2020).

Findings

First, we describe the positioning of EMSTs in their advice and information networks for mathematics compared to other teachers and formal leaders. Then, we turn our attention to how EMSTs are positioned in their school's grade level structures and in relation to a formal mathematics-specific leader.

EMSTs' Positioning Compared to Formal Leaders and Other Teachers

Overall, the EMSTs in our study occupied central positions in their advice and information networks for mathematics (see Table 3). 11 of the 13 EMSTs were sought out for advice by at least one individual, and all EMSTs had at least one tie. By contrast, 19.35% of teachers (not including EMSTs) had no ties. On average, EMSTs were sought out by more people than other teachers (in-degree, $p < 0.01$), and were more often positioned as brokers for advice (betweenness, $p < 0.001$). There were, however, no significant differences in advice-seeking behavior (out-degree), nor differences in span, strength, or depth of in or out-ties.

[TABLE 3 HERE]

Only three formal leaders were reported as individuals whom teachers sought out for advice and information, and none of those were school principals or assistant principals. The three formal leaders named were the district elementary mathematics coordinator, an instructional coach in the district special education department, and the Title I mathematics specialist at Woods. These three formal leaders had the highest average in-degree value (7.33). In fact, the district mathematics coordinator and Title I mathematics specialist provided advice and information about mathematics to the most individuals ($n = 12$, $n = 9$, respectively). Because there were many formal leaders (e.g., principals) who were not nominated, and would have had an in-degree value of 0, the average in-degree for the three nominated formal leaders is significantly greater than what would be the average in-degree for all formal leaders. Therefore, we did not compare in-degree centralization between all formal leaders and EMSTs. We did, however, compare the strength and depth of the ties that were reported. While depth did not differ, when sought out by others, EMSTs provided advice and information at a greater frequency than the three formal leaders (in-strength, $p < 0.05$). Specifically, the frequency of

EMSTs' interactions with others were, on average, very close to "once or twice per week" (2.924), while the formal leaders' interactions was closer to "a few times per year" (1.389).

EMSTs' Positioning in School Organizational Structures

We also wondered about the ways in which EMSTs were positioned relative to school organizational structures, specifically, the school's grade level distinctions and in relation to the mathematics-specific formal leader. The only school in our sample with a formal mathematics leader was Woods. Regarding grade level structures, EMSTs' advice interactions were primarily with grade level peers: 71% of EMSTs' advice-seeking ties were with grade level peers, and when sought by others, 65% of ties were with teachers in the same grade. Though EMSTs made up only 9% of the teachers working in the six schools, 40% of teachers' ties spanning the grades were to EMSTs. However, we found that ties spanning the grades were less frequent than interactions within the grade. For interactions EMSTs had with others, the average frequency for ties within the grade was "once or twice per week" (3.08), while the frequency of ties spanning the grade levels was less than "once or twice per month" (1.667).

A similar pattern emerged across all teachers' ties: ties within the grade were, on average, close to "once or twice per week" (2.969) while ties spanning the grades were close to "once or twice per month" (2.041). At the school level, we found significant between-school differences for span ($p < 0.05$) and strength ($p < 0.01$) of in-ties, and span ($p < 0.01$) and strength ($p = 0.08$) of out-ties (see Table 4), suggesting that some schools had greater across grade level advice interaction, or frequent sharing of advice. There was also great variation across schools in network density—the total number of ties divided by the total number of possible ties. For example, a density of 0.5 indicates that half of all possible ties were reported. Briar had the least dense network (0.021), while Rowan's network was the most dense (0.065). To illustrate how

EMSTs were positioned in relation to these school structures, we share network diagrams for three schools: Briar, Rowan, and Woods (see Figure 2).

[TABLE 4 HERE]

Briar was one of the larger schools in our sample, and had the lowest network density (i.e., had the least total ties relative to possible ties). A substantial number (31%) of teachers had no relationships with others, though the ties that were present were quite frequent (second highest strength). The Briar network also had more substantive interactions (highest average depth rating). However, none of the respondents reported ties with individuals outside their grade level. In Figure 2, we can see this fragmentation in Briar's advice network where ties are siloed by grade level. As such, EMSTs at Briar were disconnected from their colleagues. Overall, EMSTs did not have many ties: only one EMST sought out colleagues for advice and information, with the other two being sought out by others. All EMSTs' ties were with peers teaching the same grade, though these ties were quite frequent, occurring, on average, at least "once or twice per week" (3.17). Of EMSTs across the six schools, the EMSTs at Briar had the least ties, but of the second-highest frequency.

[FIGURE 2 HERE]

In contrast to Briar, the network at Rowan was the densest. Only 9% of teachers had no ties. However, teachers' ties were not as frequent or deep, though many interactions spanned across grade levels; these were often teachers seeking EMSTs for advice. In addition to being sought out, both EMSTs at Rowan went to colleagues for advice and information. Because of this, the EMSTs at Rowan connected and brokered advice and information about mathematics across the first and 3-5 grade levels. Though the kindergarten and second grade teachers were disconnected from those in other grades, they had fairly reciprocal relationships as teachers reported ties with one another. In seeking and providing advice across the grade levels, the ties EMSTs had with their colleagues were not as frequent, occurring less than “once or twice per month” (1.92). Of EMSTs across the six schools, the EMSTs at Rowan had the most ties, but of the lowest strength (frequency).

Woods was the only school with a mathematics-specific formal leader. Though the school had an average network density, most ties went to the formal leader. In Figure 2, the centrality of the formal leader is depicted in her vertex being centered in the star diagram. Ties spanned outside the grade level, though this was, again, only to the formal leader. So, similar to the ties at Briar, teachers were isolated from those outside their grade, and sometimes, even from those in the same grade. Ties were somewhat frequent but were less substantive (relatively low depth). Both EMSTs at Woods only sought the formal leader for advice, and only one was sought by others—grade level peers.

Discussion

In this paper, we explored how novice elementary mathematics teacher leaders were positioned in their advice and information networks for mathematics. Our analysis suggests that EMSTs occupied central positions. Specifically, compared to other teachers, EMSTs provided advice and information to more teachers, as well as brokered relations among school staff to a greater extent. While three formal leaders—two of whom had mathematics-specific roles—were sought out by more individuals than EMSTs, we also found that other formal leaders without mathematics-specific roles (e.g., principals) did not figure in the advice network at all. With respect to centrality, our findings align with previous research finding that mathematics teacher leaders were more central than teachers and formal leaders without subject-specific positions (e.g., Hopkins et al., 2013; Spillane & Hopkins, 2013), but not as central as mathematics-specific formal leaders (e.g., Berebitsky & Andrews-Larson 2017; Spillane & Kim, 2012).

Our study, however, extends these findings related to centrality in two key ways. First, we examined the nature of advice interactions. As noted in the literature review, it is not just advice interactions that support teacher learning; how often teachers interact and what they interact about also matters (e.g., Coburn & Russell, 2008). Though we did not find any differences between EMSTs and teachers with respect to tie span (interactions across grade levels) or frequency (strength), or among EMSTs, teachers, and formal leaders regarding the substance (depth) of advice interactions, we found that, when sought out by others, EMSTs provided advice and information at a greater frequency than formal leaders. This is important because interactions of greater frequency can better support the development of complex knowledge (e.g., Reagans & McEvily, 2003), like visions of high-quality mathematics instruction (Munter & Wilhelm, 2021). These findings likely reflect the EMSTs' roles as informal leaders who continue to function as classroom teachers. Compared to formal leaders, teacher leaders may be more likely to engage with other teachers about classroom instruction, through not only proximity (Spillane et al., 2017), but also through formal structures like grade level teams and department meetings (Daly et al., 2010).

Second, findings from our study contribute to the literature regarding how mathematics teacher leaders are positioned in their school's grade level structures and in relation to the formal mathematics-specific leader. Regarding grade level designations, the majority of EMSTs' ties were with teachers at the same grade level, though we also noticed an inverse relation between tie span and frequency, where ties connecting the grades were, on average, less frequent than ties within the same grade level. For example, Briar's advice network was fragmented by grade level, so EMSTs at Briar only had ties with their grade level peers, though these interactions were of the greatest frequency. By contrast, EMSTs at Rowan served as bridges within their school, brokering advice and information across the grades. Their interactions with colleagues were, however, relatively infrequent.

Researchers have found that teachers tend to seek advice from grade level peers (Spillane et al., 2012), likely because these teachers participate in the same routines (e.g., for grade level meetings), teach the same curriculum, and their classrooms are located near one another (Spillane et al., 2017). So, when teacher leaders—like the EMSTs at Rowan—broker advice and information across the grade levels, these interactions might not be as frequent because there are fewer opportunities for interaction. Ties that span grade levels, however, afford individuals access to expertise that may not be available in their immediate network (Reagans & McEvily, 2003), such as information about how important mathematical concepts progress through the grade levels and instructional routines for mathematics that are being employed in different grades. Moreover, these ties can facilitate the diffusion of information across the entire school network (Granovetter, 1973; 1983), as these interactions bridge and connect the grades.

In addition, similar to prior research that identified subject-specific formal leaders as the most central actors in school networks (Spillane & Kim, 2012; Spillane & Hopkins, 2013), we found that, at Woods, most interactions—including those of the EMSTs—were with the formal mathematics leader, the Title I mathematics specialist. The centrality of this formal leader was visibly represented in the star structure of the Woods network, which was not present in the Briar or Rowan networks. Prior research has found that teachers seek advice from those they perceive as having greater levels of expertise (Berebitsky & Andrews-Larson, 2017), and that coach positions serve as one marker of expertise (Hopkins et al., 2013). We suspect that this was likely happening at Woods, where the Title I mathematics specialist position signified to teachers the formal leader's subject-matter expertise and facilitated her centrality in the school's advice network. Without a formal role designation, the EMSTs at Woods might have been perceived as less expert, especially given that it was only their first year in the EMS program and colleagues might not have been aware of their developing knowledge.

Limitations and Future Directions

Before discussing the implications of our findings, we first wish to acknowledge limitations of our study and related possibilities for future research. The first is that our sample was limited to the six elementary schools where our EMSTs worked. Therefore, our findings are not generalizable to other subject areas, secondary grade levels, or different district contexts, though we hope our findings to be useful to those studying teacher leadership networks in similar settings. A second limitation is related to the scope of the claims warranted by our data. We can only report EMSTs' positioning in their mathematics advice networks based on data collected the first year of their EMS program. With a broader scope, subsequent research could examine EMSTs' advice-giving over time, or even the impact of such advice interactions—with varying span, strength, and depth—on colleagues' knowledge and instruction.

Implications for Practice

One of the implications of our findings is related to the division and coordination of leadership between formal leaders and teachers who exercise leadership through informal means. Because effective professional development includes sustained learning opportunities over time and sensitivity to local contexts (e.g., Sztajn et al., 2018), it seems that there are opportunities for formal leaders to enlist novice teacher leaders with mathematical expertise in change efforts. For example, teacher leaders like the EMSTs in our study could serve as brokers for efforts initiated at the district level, as well as sources of information regarding teachers' perspectives and impressions of these efforts. This could include formal leaders explicitly positioning teacher leaders as resources for ongoing conversations about mathematics teaching and learning that was initiated in formal professional development settings, through informal mentorship or serving as leaders of professional learning teams, book studies, etc. at their individual schools.

While we found that mathematics teacher leaders provided advice and information at a greater frequency than formal leaders, our findings also revealed that there were no significant differences among EMSTs, teachers, and formal leaders with respect to the depth, or substance, of advice interactions. Since supporting teachers to improve their beliefs and instructional practices likely requires engaging in substantive conversations (Coburn et al., 2012; Spillane et al., 2018), we encourage teachers leaders, when interacting with colleagues, to engage in high-depth interactions such as those focused on examining children's thinking or discussing instructional issues like how to make use of students' strategies in a whole-class conversation.

These possibilities have implications for administrators and teacher educators that support the work of teacher leaders, including programs that certify Elementary Mathematics Specialists. Since graduates of such programs take on a variety of formal and informal roles (de Araujo et al., 2017), understanding how mathematics expertise is distributed through school and district networks can help teacher educators prepare EMSs to support instructional improvement at any of these levels. This could include helping teacher leaders recognize the influence that can be achieved through frequent and substantive interactions with teachers in nearby classrooms, as well as the ways that school structures, such as the silo-ing of grade level teams, can limit the flow of information. And if EMS professionals do obtain formal positions as mathematics leaders, they could be better prepared to leverage the expertise of other teacher leaders in their school improvement efforts.

Our findings also highlight the limited nature of some of the advice and information networks that exist in schools, limitations that could be attended to by school leadership. For schools with only grade level connections, like Briar, it might be helpful to leverage teacher leaders as agents for promoting across-grade collaboration. The presence of a mathematics specialist at Woods seemed to promote advice-seeking, but such interactions were dominated by the formal leader. Because teachers seek advice from those they perceive as a more knowledgeable other (Berebitsky & Andrews-Larson, 2017), administrators and formal leaders could support more collaboration among teachers and teacher leaders by publicly recognizing the expertise of teacher leaders (e.g., Conner et al., 2022). And, for schools with a robust network of within and across grade level connections, like Rowan, teacher leaders can be mobilized to support bottom-up change across a school by, for example, creating additional opportunities for teacher leaders to share their practice, visit classrooms, and talk with colleagues teaching at different grade levels.

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Table 1

Teacher and Student Information for Six Schools

	Briar	Palm	Reed	Rowan	Thorn	Woods
Number of EMSTs	3	3	2	2	1	2
Number of Teachers	36	35	26	24	11	21
Total Student Enrollment	660	700	470	400	180	330
% Racial/ethnic makeup						
white	72	59	70	77	83	35
Black	10	13	10	7	3	41
Asian	6	12	6	4	*	3
Hispanic	4	6	6	5	3	8
Multi-race	8	10	9	7	9	13
% Receiving free/reduced lunch	24	35	30	26	37	76

Note: To maintain anonymity, we rounded information about student population and demographics. Information was compiled from the state department of education website.

Table 2

Depth of Ties

Depth	Types of Advice and Information
Low (1)	• Discussing pacing • Sharing materials or activities • After a lesson, sharing whether students "got it" • Updating one another on a student or students' progress in mathematics
Medium (2)	• Discussing what materials to use for a lesson • Analyzing student work to see if students "got it" • Discussing why some students didn't learn as expected in a lesson in order to plan for future success • Doing mathematics problems together with discussions of different solution strategies
High (3)	• Discussing different ways students are likely to solve tasks • Analyzing examples of student work to understand the different ways that students solve problems • Analyzing examples of student work in order to adjust instruction • Discussing how to make use of student solution strategies in whole class mathematical discussions

Table 3

Means and Standard Deviations of Centrality and Tie Dimensions by Position

	EMSTs	Teachers	Formal Leaders
N	13	124	3
Betweenness	5.231 (10.89)	0.548 (1.876)	
In:			
Degree	2.077 (1.979)	0.694 (0.785)	7.333 (4.643)
Tie Span	0.193 (0.267)	0.086 (0.273)	
Tie Strength	2.686 (0.682)	2.924 (0.620)	1.389 (0.550)
Tie Depth (Avg)	1.902 (0.215)	1.808 (0.269)	1.675 (0.139)
Tie Depth (High)	0.765 (0.377)	0.737 (0.413)	0.398 (0.308)
Out:			
Degree	1.385 (1.003)	0.944 (1.117)	
Tie Span	0.533 (0.420)	0.290 (0.413)	
Tie Strength	2.518 (1.011)	2.522 (0.913)	
Tie Depth (Avg)	2.008 (0.273)	1.825 (0.368)	
Tie Depth (High)	0.900 (0.200)	0.674 (0.434)	

Note: As a reminder to the reader, tie span refers to whether a tie extended beyond a teacher's grade level, strength refers to frequency, and depth refers to the substance of an interaction.

Table 4

Density and Means and Standard Deviations of Tie Dimensions by School

	Briar	Palm	Reed	Rowan	Thorn	Woods
N	29	32	23	23	10	20
Density	0.021	0.029	0.043	0.065	0.044	0.045
In Ties:						
Tie Span	0	0.015	0.028	0.214	0.333	0.200
		(0.071)	(0.118)	(0.385)	(0.471)	(0.447)
Strength	3.083	3.121	2.694	2.702	1.500	3.033
	(0.633)	(0.517)	(0.518)	(0.717)	(0.707)	(0.650)
Depth (Avg)	1.992	1.825	1.843	1.754	1.667	1.694
	(0.186)	(0.216)	(0.308)	(0.224)	(0.923)	(0.232)
Depth (High)	0.875	0.894	0.639	0.659	0.500	0.607
	(0.311)	(0.255)	(0.479)	(0.439)	(0.707)	(0.487)
Out Ties:						
Span	0	0.036	0.083	0.287	0.500	0.750
		(0.133)	(0.289)	(0.399)	(0.577)	(0.380)
Strength	2.917	3.000	2.778	2.546	1.750	2.392
	(0.793)	(0.784)	(0.641)	(0.885)	(1.500)	(0.738)
Depth (Avg)	1.941	1.883	1.907	1.815	2.000	1.774
	(0.250)	(0.328)	(0.326)	(0.347)	(0.816)	(0.365)
Depth (High)	0.833	0.857	0.667	0.667	0.750	0.607
	(0.389)	(0.363)	(0.449)	(0.424)	(0.500)	(0.487)

Figure 1

Visions of High-Quality Mathematics Instruction for 13 EMSTs

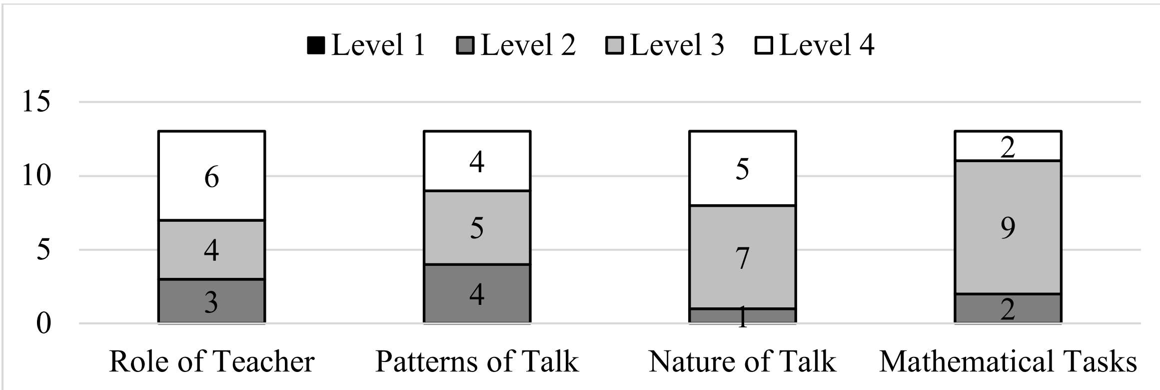
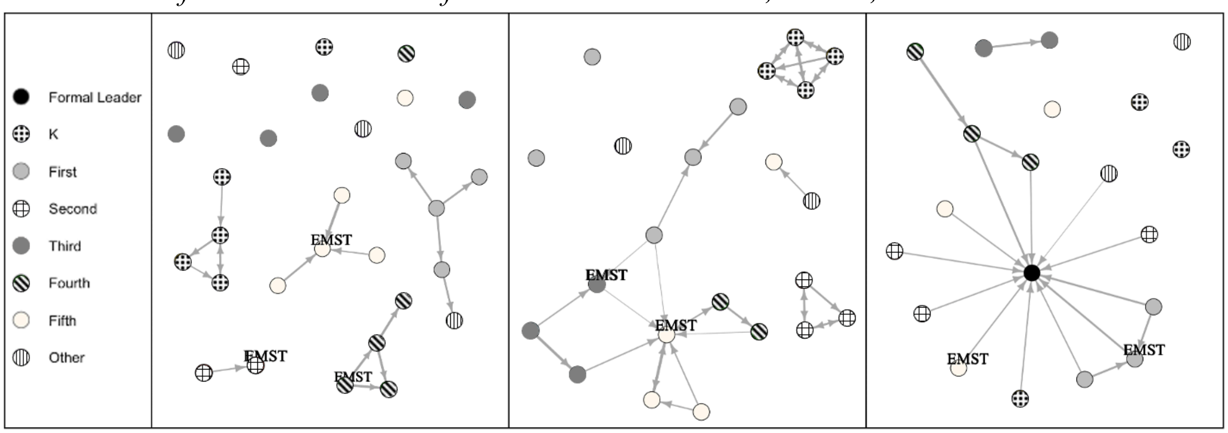


Figure 2

Advice and Information Networks for Mathematics at Briar, Rowan, and Woods



Note: Vertex color represents role and grade. “Other” refers to teachers that taught multiple grades.