A Fringe Topic in a Fragile Network: How Digital Literacy and Computer Science Instruction Is Supported (or Not) by Teacher Ties

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In this NSF CSforALL funded research study, the authors sought to understand the extent to which an urban district's teacher instructional support network enabled or constrained capacity to implement and diffuse Digital Literacy and Computer Science (DLCS) instructional practices throughout the K-12 curriculum. Social network analysis was used to investigate informal teacher advice-seeking and advice-giving patterns of DLCS support. Network measures of cohesion and centrality were computed. Findings revealed that DLCS-focused teacher support networks tend to exhibit very low density, have relatively few ties, include a high number of isolates (teachers with no connections), and centralize around a particular actor. In addition, a low level of overlap was found between DLCS networks and primary instructional networks. Overall, study findings suggest that teacher networks are not well-structured to support the flow of DLCS advice and support. The authors conclude that examining and strengthening teacher networks of instructional support may be a crucial step for educational leaders concerned with school improvement and the diffusion of DLCS curricula in US schools.

CCS Concepts: • **Human-centered computing → Social network analysis**; • **Social and professional topics → K-12 education**;

Additional Key Words and Phrases: Social network analysis, digital literacy, computer science

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1 INTRODUCTION

For the past several decades, schools across the United States have faced increasing demands to attend to "21st century skills"—those skills which will equip students for success in the largely information- and knowledge-based economy that has emerged in the post-industrial manufacturing era [40]. Among teachers, widespread confusion has persisted about what, precisely, "21st

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century skills" are, and how instructional practices might be adjusted to imbue students with them [13]. Collaboration, creativity, critical thinking, and flexible problem-solving are often referenced as requirements of a 21st century workforce, as is digital or information literacy. While some progress toward incorporating more instruction around digital literacy and digital citizenship into schools is being made, it is still an emerging concept for many teachers [25]. Moreover, the lack of curricula around computer coding and programming, arguably the most "21st century" skills that exist, is "astonishing" [36]. By some estimates, only one in four U.S. schools offers computer science courses that include programming and coding [63]. As of 2015, only 22 states allowed such courses to count toward high school graduation requirements [63]. Overall, it is clear that there exists a strong need to increase student opportunity to learn digital literacy and computer science (DLCS) in K-12 schools across the country.

Computers and computer science are not new to education; since the advent of the personal computer in the 1970s, educators have looked for ways to use computing technology to aid the work of teaching and learning [37]. Especially in the past decade, however, schools have struggled to keep up with the pace and complexity of ever-evolving digital technologies [52]. From how to police (or not) the use of personal devices to the expense involved with equipping schools with robust internet networks and up-to-date computers, the promise of computing technologies comes with a score of concomitant problems. Arguably, most pressing is the problem of how to provide students with the type of high-level digital literacy/computer science (referred to as DLCS in this article) skills that are a requirement for most jobs; various reports have found the United States to lag in science, technology, engineering, and math (STEM) subjects including computer science [30]. Another issue is how to define the end-goals for technology integration in schools. Teachers often feel pressure to use technology in their classrooms without a clear idea why, or sometimes even how [1]. It is only recently that high-quality curriculum standards regarding DLCS have been available for teachers. In the state where this study took place, a new curriculum framework for K-12 DLCS was introduced during the 2016-2017 school year.

Reports from government and private sector agencies show a compelling need for more high school graduates who are skilled at both the technical/design (computer coding, programming, and computational thinking) and user/consumer (digital and information literacy) side of computing, yet numerous obstacles persist to integrating this type of instruction into the K-12 environment [31, 37, 39, 56, 58] and most research suggests that computing technology is being largely underused in schools [1, 53, 66]. In response to these circumstances, various private and public initiatives have been launched to address the growing need for more high-quality instruction about computers in schools; in 2016, President Barack Obama called for an investment of more than $4 billion to augment schools' ability to offer computer science opportunities to students. President Donald Trump's FY 2018 budget request proposes $6.6 billion for NSF, including a proposal of $839 million for the Directorate for Computer and Information Science and Engineering (CISE). NSF CISE looks to sustain investments in fundamental research, education, and research infrastructure, and cross-cutting activities that support national priorities such as Computer Science for All, or CSforAll [44]. NSF CSforALL funds research and development projects that build the infrastructure necessary for implementing rigorous and engaging computer science curriculum in all U.S. schools. The program has two primary goals: (1) to expose all students at the elementary and middle grades to the ideas, possibilities, skills and dispositions of computer science and digital literacy; and (2) to expand computer science course offerings at the high school level while continuing to educate all students in the computer skills and dispositions necessary for success in the workplace [73].

Simply providing funding, however, will likely not be sufficient to significantly improve K-12 student access to high quality curriculum in computer science and digital literacy. As with all innovations, schools will need to negotiate a host of environmental- and individual-level factors that will influence implementation of any curricular initiative. Success will, in large part, be predicated on two types of capacity: individual and organizational [32]. In schools, teachers' self-efficacy (how confident they feel about their ability to carry out high quality teaching practices) is often used as a proxy for individual capacity. Especially for incipient initiatives, however, schools' potential for instructional innovation is greatly determined not only by the number of individual teachers in a school who have knowledge of or expertise in a particular reform (individual capacity), but by the ability of the existing network of professional relationships to support the acquisition, flow, and sharing of critical resources (organizational capacity) [32].

1.1 Context of the Study

The current study was funded through an NSF-CSforALL grant intended to help public school districts understand and address the barriers that exist to improved DLCS instruction. The primary goal of this study is to empirically examine the extent and ways in which school-based teacher instructional support networks are organized to constrain or advance the implementation and diffusion of DLCS throughout K-12 classrooms. The district studied serves more than 25,000 students from preschool to grade 12 in 32 elementary schools, 12 middle schools, 3 schools serving grades 6 to 12, and 8 alternative schools. The district also includes magnet schools, vocational schools, and a variety of other specialized educational settings. During the 2015-2016 school year, nearly 20% of the district's students were African American, 65% were Hispanic, 12% were white, and 3% were Asian. More than 67% of the district's children were classified as economically disadvantaged (among the highest in the state), and more than 26% did not speak English as a first language. Nearly 20% of the district's students are classified as having disabilities, and 78% are considered "high needs." There are roughly 2,040 teachers in the district [71]. Overall, the district is rated by its state as one that is in need of substantial assistance.

Over the past several years, an increased focus on student engagement with technology has led to a variety of interventions. A one-to-one laptop program provided every student from the 3rd to 12th grade with a dedicated computer for use in school. In the 2016-2017 school year, a district-wide campaign sought to raise teachers' awareness about the importance of digital literacy/computer science skills to student readiness for school and work life. By the year 2022, the district plans to have DLCS skills embedded throughout the curriculum, at all grade spans, including a required computer science course for high schoolers, and a professional development track for teachers that focuses on DLCS integration in the classroom. However, at the time of this study, the district offered no professional development opportunities specifically for DLCS instruction.

The district operates in a Northeastern state where new DLCS standards emphasize four major areas of importance: computing and society, digital tools and collaboration, computing systems, and computational thinking. In the elementary and middle schools, DLCS integration will occur at all grade levels and involve all teachers, including those with specialized expertise in technology. At the high school level, the district's plan is that all subject-area teachers would continue to incorporate digital literacy into their instruction, while optional specialized courses would be offered for those students looking to advance their computational thinking and computing systems skills.

In this study, we sought to understand the extent to which the District's instructional support networks enabled or constrained teacher access to social capital and their capacity to implement and diffuse DLCS instructional practice throughout the K-12 curriculum. Our primary analytic method was social network analysis and we addressed the following research questions:

(1) To what extent do district teachers believe they are capable of delivering DLCS instruction? (self-efficacy)

(2) How cohesive and centralized are the district's instructional support networks (i.e., isolates, density, connectedness, and average degree)?
(3) To what extent is knowledge of DLCS instruction able to flow through schools' support networks?

1.2 Network Theory and Social Capital

There are numerous difficulties surrounding the integration of computer science into public schooling which generally are either "environmental" or "individual" in nature [52]. Environmental, or school-level, obstacles include: lack of resources such as time, technology, or technical support; lack of support from leadership; lack of standardized or state-wide assessments for computer science; and a subject culture that resists changes to longstanding practices in distinct areas of study [37]. Individual, or teacher-level, obstacles include lack of knowledge and skills about using and/or teaching technology, and teachers' attitudes and beliefs about the value of or place of computers in instruction, or about their own ability to effectively teach or use technology [52]. Second only to lack of hardware in schools, teachers' lack of knowledge and skills about computers and digital literacy is one of the most prevalent barriers to DLCS instruction [58], suggesting a strong need for job-embedded professional development for teachers in this area.

Teachers' relationships to each other are acknowledged as meaningful components of school improvement [14, 45, 48]; thus, creating and supporting the professional networks that facilitate those relationships is seen as "a critical way to sustain the work of teaching and learning and ultimately of change" [26, 1]. Teachers develop knowledge and skills in part through informal exchanges with colleagues [57], and teachers with close collegial relationships are more likely to experience higher job satisfaction and exhibit greater commitment to remaining at their schools [42, 62]. Informal interactions that take place in teachers' lounges, mail rooms, and after-hours gathering spots are widely recognized as powerful transmissions of advice and information [29: 4]. Furthermore, studies have shown that regarding technology use, specifically, frequent informal contact between teachers has been shown to impact teacher behavior [7, 69].

Underlying these assertions is the concept of social capital, the idea that individuals are embedded in social structures, that relational ties between individuals in those structures serve as conduits for the exchange of resources, and that such resources can be accessed to advance individual or institutional goals [55]. It has long been understood that rather than being located *in* individual actors, social capital is located in the ties *between* actors [21]. In schools, social capital is often conceptualized as "an investment in social relations by individuals though which they gain access to embedded resources to enhance expected returns of instrumental or expressive actions" [46:39]. Collegial relationships within schools are teachers' primary source of social capital [24], and it is often accepted that some teachers, given the nature of their embeddedness in the infrastructure of their schools and the demands of their workdays, have limited and inequitable access to social capital [12, 29]. In other words, since the sources of social capital are understood to lie in the structure of relational ties in which an actor is embedded [2:19], an individual's position relative to a larger network may have profound implications both for the actor and for the network as a whole.

It is theorized that denser (teacher support) networks are associated with resource exchange and complex curricular implementation, while sparser networks of ties may provide access to different types of information and resources [28]. Because DLCS implementation is a complex endeavor that will require teachers to have or acquire various types of knowledge, it is important to understand the nature of the instructional support network (ISN) in which teachers are already embedded, and the potential of those networks to generate and transmit different types of resources related to DLCS implementation.

2 METHODS

Primarily, social network analysis methods were used to address the research questions to understand the extent to which the district's ISN enabled or constrained teacher access to supportive professional relationships and their capacity to implement and diffuse DLCS instructional practice throughout the K-12 curriculum.

2.1 Primary Analytic Approach—Social Network Analysis

This study's approach, both methodologically and philosophically, is grounded in network theory and social network analysis (SNA). At base, SNA is a way of using matrix algebra to describe, measure, analyze, and visualize relationships between actors in a social system. While often referred to as a method, SNA is in fact a "set of theories, models, and applications that are expressed in terms of relational concepts and processes" [16:4]. Social network analysis is, in some respects, a way of measuring a person's access to communal resources, as it assumes that "an actor's position in a network determines in part the constraints and opportunities that he or she will encounter" [10:1]. Moreover, it treats individuals in a network as independent actors, their behavior at least in part determined by the position they occupy in the network [29].

Social network analysis offers explanations for, and provides a new way of describing, a myriad of social phenomena. It has been used recently to explain globalization and international trade patterns [43], the spread of obesity [17], and social isolation in children [35], to name just a few. SNA holds that relationships or connections between people in a network are critical conduits through which all types of resources—knowledge, information, advice, materials, and so on—may flow [26]. Moreover, the sharing of such resources is not simply transactional; in many cases it helps people coordinate work, nurture collective expertise, and develop shared understandings [18].

Network structure refers to the patterns of ties between a defined group of individuals. In education, social network analysis has often been used to help visualize and understand how resources and knowledge flow to and from educators in a school or district [32]. Typically, network researchers look both at the overall characteristics of networks (generally referred to as measures of cohesion) and at the positions of nodes within a network (generally referred to as measures of centrality). Educational researchers often use these measures to investigate organizational factors such as social capital, capacity for reform, and organizational learning [4, 27, 28]. In this case, SNA allowed both for the inspection of overall instructional support networks and an examination of the teachers' positions within them.

Network theory and analysis can help explain patterns that are critical for resource exchange between individuals and groups within an organization [11, 16]. Social network theory and analysis is increasingly applied to a variety of educational research questions, especially those that are concerned with educator collaboration and the implementation and sustainability of innovation and reform initiatives [4, 19]. Leana and Pil [45] found that attending to the overall structure of a school's collaboration network could facilitate information sharing and exchange of knowledge among individuals. Working in the Netherlands, Moolenaar and Sleegers found that teachers in "dense" instruction-focused collaborative teams perceived their working climate to be more innovative than teachers in schools where fewer such relational ties existed. They emphasized the importance of links that "nurture and stimulate the growth of a schoolwide innovation-supportive climate in which risk taking can occur in a safe environment" [50:111]. Coburn et al., looked at network structure in four US elementary schools, and found that collaboration between teachers can be heavily influenced by existing organizational norms, structures, and practices, and that "the tie formation process is amenable to policy intervention" [19:48]. Social network theory, then, grounds educational research in the following ideas: that relational ties are an important consideration for schools concerned with educator collaboration and looking to break down the proverbial "eggcrate"; that networks are the vehicles through which knowledge and information flow; and that networks can be fostered through policy interventions and changes to organizational structure.

2.2 Conceptualization of School Networks

The term "network" can be problematic when it is assumed to reify what is simply a concept. Patterns of relationships exist all around us, and network theory can help us conceptualize those patterns as a single entity that can be operationalized and visualized [68]. A central challenge to designing this study was making decisions about how to conceptualize the patterns of different types of relationships that exist within schools. To do so, assumptions were made based on prior research and existing knowledge of how schools typically function.

First, it was assumed that most teachers seek out certain colleagues for advice and support regarding instruction. This is both intuitively sound and borne out by numerous empirical reports [12, 27, 32, 64]. In this study, these relationships of general instructional advice and support were conceptualized as one network, which we call the Instructional Support Network (ISN). If "capacity" is understood to mean organizational conditions that enable or constrain the flow of instruction-related advice and support, then the ISN can be seen as a reflection of a school's capacity for instructional improvement via collegial interactions.

Second, it was assumed that when teachers need advice about something that is subject-specific or particular to a certain skill, they may need to reach out beyond their usual advice-seeking patterns. Again, this is both an intuitive assumption and one that is supported by prior research [32]. Therefore, the second network was conceptualized to represent the patterns of advice seeking and support around DLCS—this network is referred to as the Computer Science Support Network (CSSN). Similar to the ISN, the structure of the CSSN, and its attributes in relation to the ISN, can be seen as a reflection of a school's capacity for DLCS instructional improvement through professional relationships.

Third, it was assumed that ISNs were schools' *primary* advice networks (in other words, that they are the ones being accessed daily about a myriad of instructional issues), and that CSSNs were contingent networks, mobilized only when specific information about DLCS is required. Therefore, Cross and Parker's [23] understanding of *access* and *awareness* was used to conceptualize each network. ISNs are access networks that capture who teachers go to for advice/support, and how often; CSSNs function as both access and awareness networks, capturing teachers' perceptions of who they believe to be knowledgeable about DLCS and the extent to which they interact with those people. To that end, the sociometric survey discussed in the next section asked questions about each of these networks in slightly different ways. In theory, this approach permitted a comparison between the two networks while allowing for the possibility that people who are known to have expertise in DLCS instruction are nevertheless not accessed by their peers.

2.3 Data Collection

Data for this study were collected through a survey instrument that included items in three categories: demographic information, self-efficacy, and sociometric data.

Demographic Information. Teachers were asked to indicate their gender, length of time served in district (seniority), and role in school (content-area or classroom teacher, computer science teacher, counselor, library media specialist, instructional technology specialist, other specialist teacher, instructional coach, administrator, etc.).

Self-efficacy. Twelve of the 15 self-efficacy items on the survey came from the widely used *Teachers' Sense of Self Efficacy Scale* [67]. That scale measures teacher self-efficacy using three sub-constructs: efficacy for instructional strategies, efficacy for classroom management, and efficacy for student engagement. Respectively, they are collected through questions such as, *How much can you do to motivate students who show low interest in school work?* (student engagement)*; To what extent can you craft good questions for your student?* (instructional strategies)*; How much can you do to control disruptive behavior in the classroom?* (classroom management). Constructs are measured on a likert-type scale ranging from 1 (low self-efficacy) to 9 (high self-efficacy). In addition to strong construct validity, this measure has a demonstrated full-scale reliability score of $\alpha = .90$ [67].

The remaining 3 of the 15 total items on the survey used in this study were related specifically to a teacher's sense of self-efficacy in DLCS instruction. Subject matter experts, teachers in the studied district, and teachers at a district unassociated with this study assisted in the development of the three DLCS oriented efficacy items. Ultimately, survey participants were asked: *To what extent do you believe that you are able to increase your students' digital literacy? (e.g., use of digital tools, website evaluation, online safety); To what extent do you believe that you are able to increase your students' computational thinking? (e.g., breaking down large problems into sub-problems, organizing data, logical reasoning);* and *To what extent do you believe that you are able to motivate your students to engage in computer science?* A scale reliability test returned an alpha of .832; for most social science research a co-efficient of at least .7 is considered acceptable.

Self-efficacy is defined as the "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments" [5:3]. Teacher self-efficacy has been linked to behaviors in the classroom and the implementation of instructional changes [41]. High levels of teacher self-efficacy have been shown to positively influence teachers' ambition and teaching behaviors, and influence receptiveness to the acquisition and implementation of new instructional techniques [3]. Level of self-efficacy was important to this study because of the relationship between efficacy and social capital, and because of how efficacy is theorized to influence patterns of advice-seeking among teachers.

Sociometric Data. It is typical for sociometric data to be collected as part of a standard survey, either directly by the researcher or through computer-assisted means [16]. To elicit such data, researchers may use one of two name-generation methods: nomination (in which respondents are asked to recall some number of network actors with whom they share ties) or roster (in which respondents are given a complete list of network actors and asked to report about the existence or extent of a tie to each). In this study, the large number of schools in the district made it infeasible to construct the necessary number of rosters and unique survey files that they would have required. Therefore, the survey relied on the nomination method. They survey was electronically distributed to all teachers in the district via email.

To collect data about the presence or absence of supportive ties, teachers were asked two sets of questions. In the first, teachers were asked to identify up to 10 close professional colleagues in their school, and then to rate the extent to which they interact with each on a five-point scale from *daily* to *yearly/none.* This customary way of collecting one-mode data (actors' direct relationships to each other) is a variation of Moreno's [51] basic sociometric test, which simply asks each actor in a network to identify the alters (others in the network) with whom the respondent has some relationship, along with "interpreter questions" about the particulars of each relationship [49]. In this case, the limit of 10 alter nominations was based partly on a desire to limit the burden on respondents [70]. Prior studies confirm that this type of bounding is appropriate since respondents tend to name closer ties sooner [15]. To mitigate the possibility of imprecise responses (i.e., the use of nicknames), the survey items asked for both first and last names [49]. For each alter nominated by a respondent, the frequency with which the respondent interacted with the alter was also collected.

2.4 Data Analysis

Self-Efficacy. Self-efficacy data were analyzed through basic descriptive statistics, and with a paired *t*-test to compare teachers general instructional level of efficacy to their DLCS level of efficacy.

Network Analysis. One mode (or adjacency) matrices were created, in which both x and y axes were populated with the identity codes of each respondent, and adjacent cells indicated the presence or lack of a tie. To construct matrices, the complete list of names at each school provided by the district was consulted first. The complete school roster was critical, because it allowed for ties to be established even to people who did not complete the survey. For example, because this study is about *teacher* support networks, principals were not surveyed. However, principals are often primary support-givers to teachers. Omitting principals because they were not survey participants, then, would substantially impact results and bias the data. The same principle held true for others who were nominated by respondents but did not participate in the survey themselves. Because complete network data is often difficult to get, it is generally accepted that some level of missingness is tolerable [61], and the general "rule of thumb" is that accurate networks can be constructed with responses from between 70% to 80% of actors; lower response rates seriously damage network validity. For this study, the higher threshold was chosen, and only district schools with at least an 80% response rate were included in the final sample. Ultimately, six schools with the highest response rates were chosen for inclusion in the current study. All were elementary schools serving children in kindergarten through grade five.

For each school included in the network analysis, two matrices were constructed. The first matrix captured the ISN that was generated by asking teachers: *Who in your school do you turn to for advice about your instructional practice?* The second matrix captured the digital literacy/CSSN and was generated by asking teachers: *Who do you know in your school who is knowledgeable about the practices and principles of digital literacy and computer science?*

In addition to the matrices, attribute files were created for the network actors in each school. Attributes listed in this file included role in school (content-area or classroom teacher, computer science teacher, counselor, library media specialist, instructional technology specialist, other specialist teacher, instructional coach, administrator, etc.), gender, and mean self-efficacy scores.

Each matrix was imported into UCINET [9] and NetDraw [8] for mathematical analysis and visual inspection. Sociograms (maps) were created for each network to visually represent their structure. The following network-level structural measures were calculated: ties, isolates, density, connectedness, average degree, and centralization. The next sections will briefly explain each of these measures, their relevance to this study, and how they were interpreted.

Ties. Ties are the reported relationships that exist in each network. Because the primary matrices in this study are directional (teacher A seeks out teacher B, but teacher B may not seek out teacher A) the ties are not necessarily reciprocal. In the sociograms presented in the results section, lines indicate that a tie between two people exists when at least one person has nominated the other as a supportive colleague.

Isolates. In any network, there may be some isolates—nodes that have no ties. In this case, isolates will be those actors (teachers) who are part of the school but to whom no one goes to for support and they don't seek out support for themselves (i.e., they have no in-degree and no out-degree centralization).

Density. Density refers to the actual proportion of ties that exist between people, as a proportion of the total number of ties possible, and can indicate the amount of social cohesion in a network (i.e., higher density can indicate greater cohesion).

Connectedness refers to the proportion of pairs of people who can reach each other through the formal network even if they are connected through multiple other actors. Connectedness is often an important consideration, as it is neither possible nor efficient for every actor in a network to have direct access to every other—rather, it is more important that channels exist for expertise, information, and resources to flow.

Centralization is an indicator of the overall cohesion or integration of a network and the degree to which ties tends to cluster around more prominent actors. Communication networks are often characterized as either centralized, decentralized, or distributed [6]. The more centralized a network is, the more its ties converge around one or a few nodes. The more distributed a network is, the less convergence there is around any actor, and the less vulnerable it may be to the loss of any particular tie.

Degree refers to an individual's number of ties with others. This is often expressed as *in-degree* (the number of times a person is nominated as a tie by alters) and *out-degree* (the number of alters that a person herself nominates).

3 RESULTS

In this study, two different types of teacher networks in an urban school district were examined; network-specific results are drawn mainly from a sample of six elementary schools from that district; results related to self-efficacy were also drawn in part from a larger sample that included teachers from across the district at all levels of schooling. Results are presented in relation to the three research questions.

3.1 Teacher Beliefs about Their Ability to Implement Effective DLCS Instruction (RQ 1)

Teacher self-efficacy findings were aggregated from the results of the survey that had a total of 1,106 responses from employees with instructional responsibility in the school district including teachers, counselors, librarians, paraprofessionals, and others; this represents approximately 44% of school-based (non-central office) instructional employees. General self-efficacy about instruction was measured with a widely used instrument [67] that captures three indicators of the construct: student engagement, instructional strategies, and classroom management. Self-efficacy about DLCS was measured using a scale of the authors' devising that demonstrated a sufficient level of reliability. Results are shown in Figure 1.

A test of statistical significance revealed that DLCS self-efficacy scores were significantly lower ($p = <.001$) than general instructional efficacy scores. In other words, teachers in our sample reported significantly higher levels of self-efficacy about their ability to (for example) craft good questions for their students than they did for their ability to (for example) increase students' digital literacy. These results should be interpreted with caution. The widely used self-efficacy scale from Tschannen-Moran and Hoy [67] captures teachers' feelings of efficacy around broad constructs related to the work of teaching; the DLCS scale, by design, asks about a much narrower domain of instruction specifically relating to DLCS. Therefore, a comparison of means across these constructs may be misleading (perhaps *any* question about a specific area of instruction might have yielded similarly low means).

Self-efficacy scores as related to teaching in general and DLCS specifically were calculated for each of the six elementary schools. Results are presented in Figure 2. With one exception (School

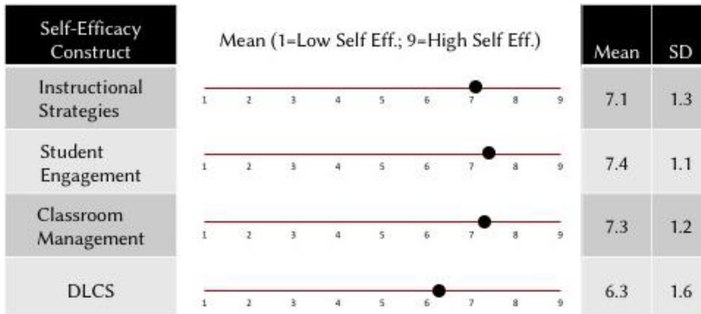

Fig. 1. District-wide self-efficacy results.

	Mean Self-Efficacy, General (SD)	Mean Self-Efficacy, DLCS (SD)
School A	7.4 (1.6)	5.9 (1.4)
School B	7.1 (1.0)	6.2 (1.5)
School C	7.3 (1.6)	6.2 (2.1)
School D	8.0 (0.6)	7.3 (1.0)
School E	7.2 (1.6)	6.5 (1.9)
School F	7.5 (1.1)	6.5 (1.4)

Fig. 2. Self-efficacy results in six elementary schools.

D), the elementary schools appear to be typical of the district in terms of their self-efficacy, both in general and related specifically to DLCS.

3.2 Structure and Attributes of Instructional and DLCS Support Networks (RQ 2)

Sociograms, network cohesion measures, and descriptive statistics were used to analyze the data for the six K-5 schools included in the network analysis portion of the study. Sociograms are depicted in Figure 3. The ISN for each school is shown in the left-hand column and the CSSN is shown in the right-hand column. Nodes are shaped based on individuals' professional role (see sociogram key) and sized by in-degree (those with a higher in-degree—more people seek advice from them—are larger). Isolates, those teachers who do not seek support and that no one seeks advice from, are shown to the top left of each sociogram. No modifications were made to the UCINET outputted sociograms, so representations of geodesic distances (relative levels of connection between actors) are intact.

Visual inspection of the sociograms reveals prominent differences between the district's DLCS support networks (CSSN) as compared to the general ISN. CSSNs are sparse, weakly connected, centralized, and include higher proportion of disconnected teachers who do not have access to support. Overall, teacher capacity to implement and diffuse DLCS science curricular throughout K-12 classrooms appears to be low.

A comparison of ISN and CSSN network cohesion measures is reported in Table 1. In addition to visual inspection of the sociograms, these measures further indicate that teacher networks of professional support may be inadequate to support the implementation and diffusion of DLCS curriculum.

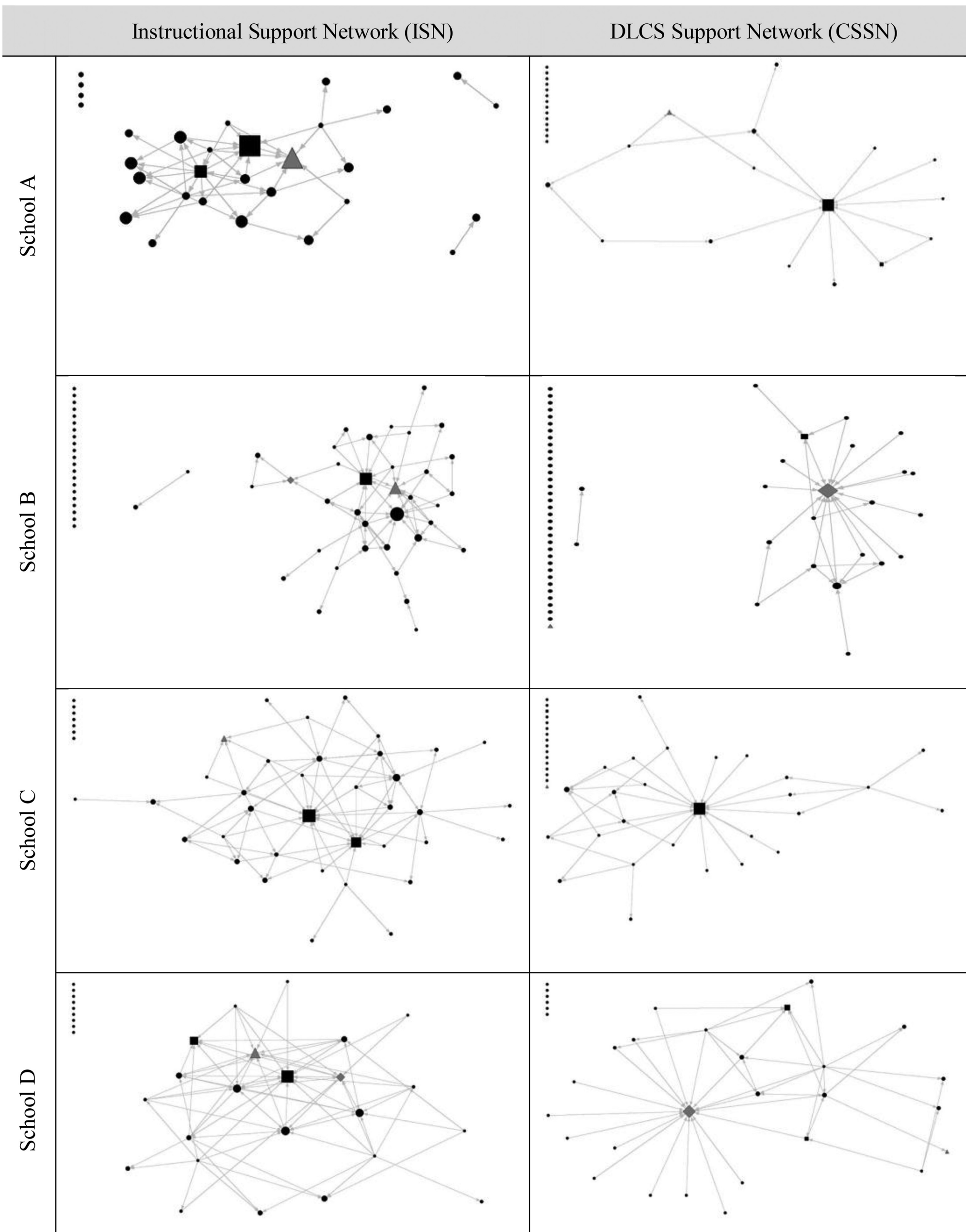

Fig. 3. Sociograms of ISNs (left) and CSSNs (right).

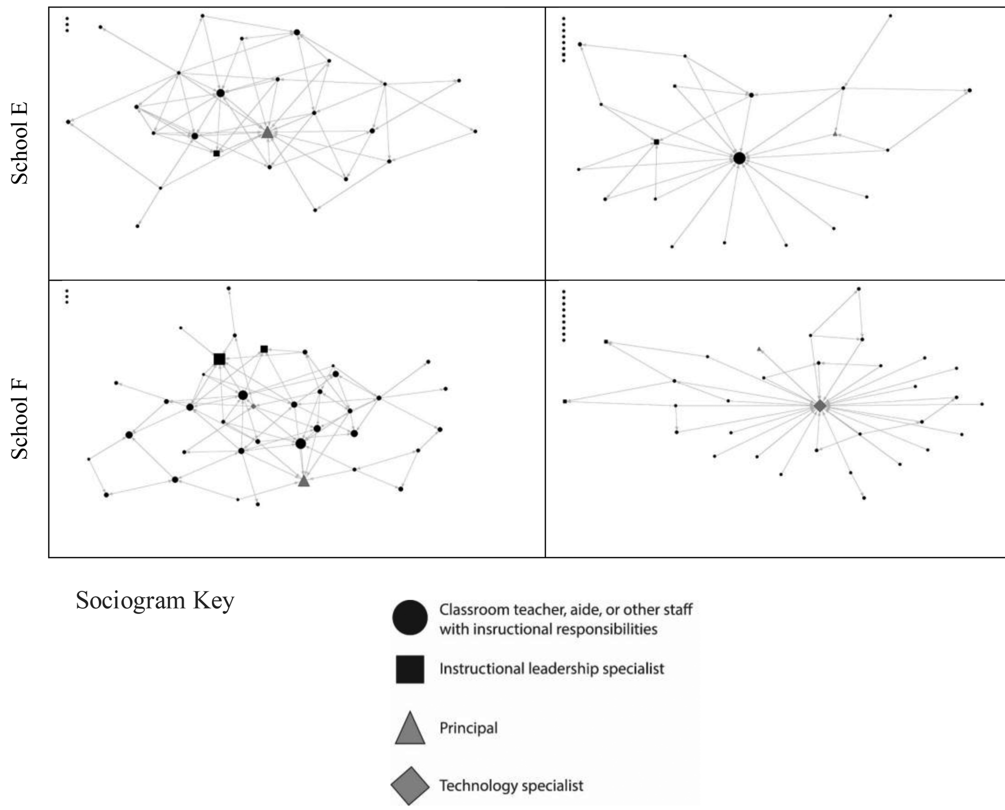

Fig. 3. Continued

Table 1. Density of ISNs and CSSNs

	School A (n = 30)		School B (n = 58)		School C (n = 43)		School D (n = 32)		School E (n = 28)		School F (n = 41)	
	ISN	CSSN	ISN	CSSN	ISN	CSSN	ISN	CSSN	ISN	CSSN	ISN	CSSN
Density	0.11	0.04	0.04	0.02	0.09	0.04	0.15	0.09	0.17	0.08	0.10	0.05
Connectedness	0.54	0.28	0.36	0.13	0.70	0.39	0.51	0.66	0.79	0.50	0.86	0.61
Avg. Degree	3.2	1.2	2.3	1	3.6	1.7	4.5	2.8	4.6	2.2	4	2
% Isolates	13%	47%	36%	60%	16%	37%	28%	19%	11%	29%	7%	22%
Centralization	0.35	0.56	0.15	0.28	0.27	0.39	0.35	0.5	0.4	0.53	0.18	0.64

The density of the ISN across the six schools ranged from a high of 17% (School E) to a low of 4% (School B). Densities of the digital literacy/CSSN across the six schools were markedly lower, ranging from a high of 9% (School D) to a low of 2% (School B). In other words, less than 10% of all possible advice-seeking/giving connections between teachers that could exist, actually exist. Connectedness followed a similar pattern. With the exception of School D, ISNs are more connected that CSSNs. Teachers in the ISN have, on average, a higher degree (more ties to other teachers) than teachers in the CSSN, and the percent of teachers who are isolated from the support network is higher in the CSSN than in ISN. Notably, 60% of teachers in School B are isolates and do not give or receive DLCS collegial support. One outlier is School D, where the proportion of isolates is lower in its CSSN than its ISN. This can be explained by the presence of a strong and widely known technology specialist that was placed in the building at the beginning of the academic year. It is likely that teachers would have been thought of this individual as an obvious person to nominate as a someone they can go to for DLCS support when responding to the survey. CSSNs also tend to be more centralized than ISNs; actors and ties are more distributed in the ISN than in the CSSN. In schools where technology specialists were present (Schools A, D, and F) those people are the most central to their school's DLCS support network. However, the schools without technology specialists exhibit largely the same network cohesion measures, i.e., the CSSNs are more centralized than the DLCS with or without the presence of a DLCS specialist. Possible implications of this result are considered in the discussion section.

3.3 Flow of DLCS Knowledge (RQ 3)

To look at the capacity for DLCS knowledge to flow, we first analyzed two pieces of network data: top support givers in each network and the number of shared relationships between the two networks. Node-level analysis was performed to determine which people (by role) were nominated most frequently as support-givers in the instructional and digital literacy/CSSNs. The results of node-level analysis are shown in Table 2, which illustrates two notable findings: First, while principals are nearly always present in ISNs (with the exception of School C), they are almost never present in CSSNs (with the exception of School A). In general, district teachers see their principal as a person to whom they can and should go to for advice about general instructional practices, but not as someone to seek out for DLCS specific advice. Second, the table shows some limited overlap between support givers in the ISN and CSSN. Persons who are top support givers in both their schools ISN and CSSN are underlined, e.g., Jorge, an instructional leadership specialist (ILS), is a top support giver in his school for general and DLCS instruction.

Because this study conceptualizes ISNs as schools' primary network, it is also useful to know how many relationships within them are shared with CSSNs—in other words, how many of the dyadic ties in the CSSN *also* exist in the ISN. This speaks to the power of the primary advice network to serve needs related to DLCS instruction. Because of the manageable size of these networks, this was accomplished via a side-by-side comparison of each school's ISN and CSSN. Results are presented in Table 3 and indicate that the schools in our sample vary widely in the extent to which their primary instructional networks include ties that can support DLCS instruction.

Two attributes of top CSSN support givers were examined: DLCS self-efficacy, and familiarity with the state's DLCS curriculum framework. For each school, teachers were divided into quartiles based on their reported self-efficacy regarding DLCS; those lists were then cross-checked against the known in-degree of all teachers based on the network matrices. Of the 27 top support-givers in the schools' CSSNs (see Table 2 for a complete list), 12 scored in their school's first (highest) quartile for DLCS self-efficacy; 3 scored in the second quartile; 6 scored in the third quartile; and information is unavailable for 6 of them due to missing data (those people did not respond to that part of the survey). Two of the top support givers indicated that they had read the standards and adjusted their classroom instruction as a result, 3 had read it and were thinking about their implications for classroom practice, 10 were aware of the frameworks and planned to read them, 3 were aware of them but indicated that they were uninterested in reading them, 3 had never heard of the standards, and information was unavailable for 6 of the top support givers.

Lastly, for the subset of teachers with the highest DLCS self-efficacy scores, in-degree scores were compared to examine the extent to which the two were related. Across the six schools, there were a total of 45 teachers who were ranked in top quartile of their respective school's self-efficacy

Table 2. Comparison of Top Support Givers (Top 10% In-Degree) in ISNs and CSSNs

School	ISN Top 10% Support Givers	CSSN Top 10% Support Givers
A	Carla, ILS	Michelle, ILS
	Jean, Principal	Rachel, Teacher
	Melanie, Teacher	Damany, Teacher; Jean, Principal♦
B	Barbara, Teacher	Kursten, Tech. Specialist
	Jorge, ILS	Ilana, Teacher
	Marsha, Principal	Jorge, ILS
	Cass, Teacher	Sarah, Teacher
	Sadia, Teacher	Saadia, Teacher; Colleen, Teacher♦
	Bande, Teacher	Frieda, Teacher; Erin, Teacher♦
C	Sue, Teacher	Sue, Teacher
	Tina, ILS	Lena, Teacher
	Rosa, Teacher	Angelina, Teacher
	Emma, Teacher	Taylor, Teacher
D	Marit, ILS	Jacinda, Tech. Specialist
	Jane, Principal	Beatrice, ILS
	Beatrice, ILS	Naila, Teacher
E	Denise, Principal	Portia, Teacher
	Portia, Teacher	Ashley, Teacher
	Danica, Teacher; Kathryn, Teacher	Kathryn, Teacher
F	Lupita, Principal	Elizabeth, Tech. Specialist
	Gwyneth, Teacher	Jocelyne, Teacher
	Courtney, ILS	Paula, ILS
	Beth, Teacher	Amanda, Teacher; Courtney, ILS♦

♦Indicates a tied score between two individuals.
Underlined names indicate top support givers in both ISN and CSSN.
Names are listed in order of in-degree (i.e., names listed first have the highest in-degree, and so on).

Table 3. Shared Relationships between ISNs and CSSNs

	No. of ISN Ties	No. of Shared Ties between ISN and CSSN	Percentage of Ties in ISN That Can Support DLCS Instruction
School A	48	8	17%
School B	72	1	1%
School C	87	21	24%
School D	83	23	28%
School E	67	14	21%
School F	93	8	9%

sores. Of those, 12 were also top support givers (in the top 10% of in-degree scorers in their school); 5 had an in-degree of at least one but were not considered top support-givers in their schools, and 29 had an in-degree of zero (meaning that no one nominated them as knowledgeable regarding DLCS instruction).

4 DISCUSSION AND IMPLICATIONS

The findings of this study raise three important issues about the capacity of school networks to support improved DLCS instruction. First, the constructed sociograms indicate that DLCS advice networks may often be highly centralized around one or two focal nodes. Second, the sociograms show a high number of isolates in both the ISN and CSSN, but in the latter networks most prominently. Third, a comparison of dyadic relationships across ISNs and CSSNs show a low level of overlap, suggesting that the primary network (ISNs) may not be well-structured to support the flow of DLCS advice and support. In addition to the findings related to network structure, this study has implication for how teacher self-efficacy is understood in relation to DLCS instructional improvement.

Though few prior studies have compared networks of general instructional advice with those meant for content-specific purposes, Farely-Ripple and Buttram [32] accomplished something similar by looking both at general instructional networks and networks intended for advice on data usage. They found that the more specific networks were less dense and moderately more centralized (though not to the extent of those reported here) and concluded in part that school leaders may want to find ways for knowledge about data use to become "part of the flow of information within the school" [32:25]. Here, we find a similar instance in which knowledge of a particular topic (DLCS) is not tightly woven into the fabric of schools' primary advice-seeking networks. Indeed, findings suggest that K-12 initiatives that aim to improve and increase the teaching of DLCS can anticipate that the full strength of teacher support networks may not necessarily be at work when it comes to this particular type of innovation.

Notably, results suggest that the centralized structure of CSSNs did not depend on the roles of school employees; whether or not a school employed a technology specialist, a single node provided the bulk of support in schools' CSSNs. The extent to which those actors are in fact skilled at the practices and principles of DLCS is unknown. Digital literacy and computer science are not unidimensional constructs, and the practices of integrating them with general instruction are not widely understood. According to discussions with district teachers and administrators, the non-technology teachers who are currently central nodes in CSSNs may simply be those who are known to be "good with computers" or who have a personal interest in instructional technology. Similarly, technology specialists, who are central CSSN nodes where they exist, may have been pulled from the ranks of general teachers, and may not actually have a level of knowledge and skill that will allow them to be instrumental in implementing DLCS instruction across all classrooms. Some effort is called for to investigate the extent to which teachers who are currently providing technology support (formally or informally) may benefit from additional training. Given the level of centralization that currently exists in the CSSNs, it may be the case that these focal nodes, regardless of whether they have formal education in technology or computers, will also need support as the expectations for DLCS are augmented.

Findings related to self-efficacy also imply a mismatch between network structures and the goal of DLCS diffusion. When compared against in-degree, results demonstrated little discernable relationship between teachers' DLCS-related self-efficacy and the extent to which they were seen as knowledgeable by their peers. Indeed, many of the teachers with the highest reported self-efficacy had an in-degree score of zero, and some who served as top support-givers in their network had self-efficacy scores in the second or third quartile for their schools. Putting aside the possibility of measurement error, this finding can be interpreted in a number of ways. Because the CSSNs were conceptualized as access *and* awareness networks, we can possibly infer that (a) many people who believe themselves to be knowledgeable about DLCS are not perceived that way by others, (b) the network is not set up to support the awareness of others' expertise, or (c) DLCS is not treated as enough of a curricular priority, and therefore teachers rarely have the opportunity to publicize their expertise, even if the network supports such sharing. All three of these phenomena may, in fact, be at work here, along with myriad others. Our initial thought that some of the limitations of the CSSNs might be mitigated by the relatively more robust ISNs was tempered by the results of research question 3, which indicated that there is fairly little overlap between the two networks—in other words, most of the relationships that support DLCS instruction do not exist in the ISNs, which we see as the "primary" networks in the schools. This may be problematic, because it suggests that knowledge of DLCS is still seen as a specialized "fringe" topic, not a core competency that all teachers should be responsible for [54].

There are no accepted theories about what optimal teacher networks should or do look like, however, it would be more ideal for DLCS networks to be more distributed (i.e., less centralized), to have far fewer isolates, and to have more overlap with schools' primary instructional networks. School and district leaders might move in this direction by looking at the overall structures of the school's sharing and communication networks, and taking steps to ensure that those people with DLCS expertise are distributed (rather than concentrated) on teams. They might also look at those people with high DLCs self-efficacy, and low CSSN in-degree, to see if they can be mobilized to be another source of DLCS support in the building. Moreover, educational leaders may seek to target professional development and DLCS training to specific teachers who are well-connected to the overall advice-seeking structures.

Findings related to self-efficacy were less conclusive. Both DLCS and general self-efficacy were relatively high. One computer science teacher (who also helped develop the survey items) noted,

> "I talk to a lot of teachers about computer science and digital literacy and, believe me, many should not be as confident as these numbers reflect. But maybe it's a good thing? Maybe if people are feeling like they know something about these concepts, we can build on that sense of familiarity as we think about how to ask them to learn even more about it. I think what worries me is that some people might think they know enough already, and they don't."

Though the district's high levels of self-confidence are likely inflated, they are not necessarily unexpected. During the time this study was conducted, no interventions or DLCS-related professional development had been introduced, hence teachers may have an inaccurate sense of efficacy. A dip in efficacy is to be expected in the future, after participants are faced with new knowledge and the task of acquiring new skills. The implementation dip is "characterized by a sense of anxiety and feelings of incompetence associated with relearning and meaningful change" [33, 38]. A reduction in confidence/efficacy is to be anticipated when teachers in the district encounter an innovation such as DLCS that requires the acquisition of novel skills and understandings [33].

When considering the implications of all the above findings, it is important to note that this study compares networks of general instruction (ISNs) with those that are content-specific (CSSNs); it stands to reason, then, that the first would be more robust than the second. It was infeasible for us to collect similar information on a separate, unrelated yet equally specific advice-seeking network (such as algebra or reading comprehension), yet doing so would have allowed us to contextualize our findings in a valuable way. Since, other than the works cited earlier, we are unaware of a study that has done such a comparison between general and specific school networks, we are unable to make any claims about the relative strength or weakness of DLCS support. A promising direction for future research would be to look at digital literacy and/or computer science advice networks as compared with those of another core subject.

Similarly, results related to self-efficacy should be interpreted with caution. Though the 12-item scale that we used to measure self-efficacy in general is a validated instrument, the 3 items that we designed to measure DLCS self-efficacy were only field-tested, and more consideration may be needed to design questions that more precisely get at this particular self-perception.

Moreover, all of the study's findings are complicated and limited by the fact that, guided by the frameworks in use by the state in which it was conducted, this study took digital literacy *and* computer science as its organizing principles. While related, those two concepts are distinct, though recent data [72] suggests that educators do not properly distinguish computer science (the study of how computers are designed, and how to get them to perform specific functions) from digital literacy (the ethical, legal, and critical use of computer programs and the information accessed through them). It was beyond the scope of this study to look at the type of advice sought from the central nodes in these schools' DLCS networks, but future researchers might take up this issue more seriously and examine in more detail how questions about DLCS instruction are being asked and answered. Finally, the content and quality of what is flowing between existing ties in the ISNs and CSSNs has not been established, and we do not have fine-grained information about the extent to which any of these reported relationships result in changes to instruction.

5 CONCLUSION

It is widely understood that continuous access to professional collegial feedback is a key factor in teachers' capacities to improve their instructional practice; further, it is understood that teachers' access to valuable information from peers has historically been determined largely by accidents of personal affiliation or in-building proximity rather than organizational design. Yet scholars from a variety of traditions support the idea that organizational conditions can be tailored to encourage or restrict a wide range of professional behaviors. Research suggests that strong school networks enable the sharing of professional knowledge, improve teaching practice, and facilitate school- and district-wide change [26, 34, 59, 60]. Cultivation of what Cohen and Moffitt [20] call "infrastructure" for teaching and learning is thought to be uniquely promising as a means to instructional improvement. As Croft et al. [22:5] explain,

> "Teachers' professional development is largely a product of formal and informal social interactions among the teachers, situated in the context of their school and the classrooms in which they teach and distributed across the entire staff. If implemented and supported effectively, [these interactions] have the potential to contribute to the development of all teachers within a team or school by generating conversations among teachers about concrete acts of teaching and student learning."

Despite this growing awareness, however, organizational infrastructure to support formal and informal social interactions and access to social capital is often left unattended to by school administrators [65], and school leaders may feel powerless to influence communication ties between teachers or hamstrung by an invisible web of personal affiliations through which flows critical knowledge, information, and opinions [29]. Studies such as the one we have conducted can help make the fragile nature of these webs visible, and show school leaders the underlying network of relationships that may have a significant impact on everything from school culture to classroom instruction.

In the 21st century, improved DLCS instruction has become a pressing priority for the U.S. school system. Facility with technology, and coding in particular, is "the lingua franca of the modern economy" [47]. While school leaders and teachers often recognize the urgency of addressing this need, attempts to affect large-scale improvements are often met with a variety of challenges, including lack of effective support structures for teachers, many of whom may feel unsure of how to create DLCS-focused learning opportunities for their students. Examining and strengthening teacher access to social capital and networks of instructional support may be a crucial step for K-12 school leaders concerned with the diffusion of DLCS curricula.

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