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Operationalizing Centerness and Measuring It in Professional Development Teams

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Abstract

Centerness is defined as a quality of multi-agent systems (groups) where agents share a common set of system goals and interact so the system will achieve those goals. A pair of measures is identified to capture the two dimensions of centerness: distance-weighted fragmentation and average goal centerness. As a case study, the measures of centerness are applied to six teacher professional development groups within the Information Technology in Science Center for Teaching and Learning. The calculated measures of centerness of these groups generally conform to the expectations. Insights on using this measure of centerness to evaluate centerness in other professional development programs are included.

Keywords: *centerness, social networks, professional development, multi-agent systems, teams*

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Introduction

> *If you can not measure it, you can not improve it.*
>
> —Lord Kelvin, attributed

Measuring how well team members work together to achieve a common purpose is important to teams and organizations in many different domains where a diverse group of people must be brought together to work on a common set of problems. This is the situation for many K–12 Science, Technology, Engineering, and Math (STEM) professional development programs. Many of these programs have been created with an intensive cohort model, based around the concept of communities of practice. In these models, K–12 teachers learn from and collaborate with STEM research faculty to develop curriculum and materials that can be used to

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integrate STEM in their schools (Christian et al., 2021; Hardré et al., 2014; Schielack, 2012). Bringing these groups of K–12 teachers from diverse settings, along with education and STEM faculty, for a common purpose is a key component of the learning experience (Stuessy et al., 2012). Collaboration among teachers has consistently been an effective means to instructional improvement (Weddle, 2022). However, there are many obstacles in bringing these groups together, including the need to establish common vocabulary and ways of thinking. To make these professional development programs function, personnel from diverse fields must also come together to organize, plan, and execute these programs (Wu et al., 2012).

Units such as the Centers for Learning and Teaching established by the National Science Foundation are examples of professional development organizations that desire this quality among center leadership and cohorts. In these centers, diverse groups of researchers had to come together from physics, biology, chemistry, mathematics, engineering, education, and other fields to achieve center goals. These researchers were often at different institutions and may have been geographically separated. Also, many of these centers had professional development programs where teachers from different schools and subject areas came together to work within a group.

A team's ability to function together can be inferred from the quality of its products; however, besides being an inference, this excludes the ability to formatively judge a team's functioning until products are available for analysis. If a team's functioning can be measured formatively, its actions can be changed in process to improve that functioning. This is the case in units such as Centers for Learning and Teaching, where outcomes of the impact on K–12 students may take years to produce. Thus, process measures are needed that can examine the current state and functioning of that team. If one or more measures can be developed that will predict the effectiveness of the team, they can be used by intensive professional development programs using the communities of practice model to determine if the team is working effectively and so predict positive outcomes for their classrooms.

This paper examines team functioning through the concept of centerness. Centerness may be colloquially defined as "structured synergy brought together for a purpose." It is used to capture the concept of a group of people who have come together and are effectively collaborating to achieve specific goals. This paper proposes an operational definition of centerness and a quantitative measure of a team's current state of centerness. This measure is then validated against artificial and real groups. It is hoped that such a measure could be used to evaluate professional development team effectiveness.

Defining Centerness

Centerness is operationally defined as a quality of multi-agent systems where agents share a common set of system goals and all interact so the system will achieve those goals. Hayes's definition of agent is used here: "an agent is an entity (either computer, or human) that is capable of carrying out goals, and is part of a larger community of agents that have mutual influence on each other" (1999, p. 127).

The term group throughout this paper refers to multi-agent systems. The formal definition of centerness identifies two major dimensions: agents sharing a common set of goals and agents working together. Sharing a common set of goals shows that the system's agents are all pursuing and motivated by the same object, i.e. the overall objectives of the system. Rather than a simple binary state, there are degrees to which agents can share a set of goals; some agents may pursue certain goals while other agents pursue others, with the possibility that no single agent pursues all of the system goals. Also, some fraction of the agents in a system may not be pursuing the system's goals, but through their efforts and those agents who are pursuing the systems' goals the goals may still be accomplished. For example, in an undergraduate course, the students might not consciously pursue the stated course objective. While the course goals may be accomplished by the

efforts of both the students and the instructor, the instructor is focused on achieving the goals and may design a course to encourage students to engage in behavior that will achieve the goals.

The second dimension of centerness is interactions between agents. Two issues can be raised about these interactions. First, what defines these interactions? It is not possible to give a general answer as the nature and mode of the interactions will vary across groups. The essential, identifiable interactions are different even across educational settings, such as a traditional classroom, a design studio, a blended in-person and Web-enhanced course, a fully on-line course with synchronous video-based sessions, and an asynchronous course held largely via pre-recorded videos and discussion boards. This question must be resolved for the individual team context by the researcher. Also, this question must be addressed not just by the mode but by the content and nature of the interactions. If a fully online course has synchronous lectures with little interaction and a great deal of discussion on asynchronous discussion boards, the discussion boards are the most likely candidate for identifying channels for interactions between people.

The second issue with respect to interactions is to identify what pattern of interactions among the agents indicates a high level of centerness. Generally, the more interactions among the team, the better the centerness as the team is drawing on each other's expertise and skill in pursuit of their goals. A recent review of the literature on team effectiveness found interaction factors including interdependence and collective information sharing result in greater effectiveness (Mathieu et al., 2019). Both interdependence and information sharing imply interactions among team members and both should be positively related to numbers of interactions. In literature that examines teams of researchers, measures (such as co-authorship) are used to construct sets of interactions based on more co-authorships indicating more collaboration (Youtie et al., 2013). It should be noted that interacting with every other member in a team may not be feasible in a given group size. The influence of one member may be mediated through a web of relationships. Many agents may only influence other agents through intermediary relationships or not at all if the network is fractured (i.e., not all agents are reachable by relationships with other agents) or has clusters where only a few members of individual clusters interact across those clusters. This issue will be addressed practically below when describing a measure of centerness.

It should be made clear that centerness is a quality of a network or group, not of individual agents. The definition above makes no claims about the nature of the agents or their specific roles, only that there are multiple agents in the system. Also, this paper does not examine the conditions that may lead to and/or sustain high centerness within a group, though that is an important topic for study. A system's agents may be homogeneous or heterogeneous and still achieve a high level of centerness, though it is conjectured that a group of heterogeneous agents would require more effort (Ledford, 2015). Further, there can be a continuum of centerness, where a system may have more or less depending on the levels of the two dimensions. To have a high level of centerness a system must have high measures of agents sharing common goals and a high number of interactions to achieve the goals.

It is our contention that centerness is an emergent property of the system. It is not a quality that proximally results from specific system inputs. Rather, it emerges from the interactions of the network and their respective efforts toward the system goal.

Centeredness may be a desirable quality in some systems and not others. For example, an interdisciplinary research center, such as one of the Centers for Learning and Teaching, may desire centerness among its teams. Other systems where centerness may be desirable include a sports team, a business division, and an orchestra. However, in a system like a public park, it is not necessary for the various users of the park to share the same goals or to work together for the park to be a success.

As with many measures, centerness takes a "snapshot" of a system at a particular window of time. With centerness measurable on two continuous dimensions, an analysis could be made of the change in the

measures over time, either at fixed intervals or before and after major events in the system. Showing the change over time of centerness may assist in identifying events that contributed to or disrupted the centerness of a team.

Benefits of Centerness

There are benefits to having high levels of either dimension of centerness, as both are related to indicators of effectively performing groups. Logically, the more members of a group who are pursuing the same set of goals, the more focused and directed they will be. A shared set of goals among a group leads to increases in productivity (Pritchard et al., 1988), including when interactions between people while performing the task are removed (Weingart & Weldon, 1991). Hersey et al. state that "when the needs of individuals within a group and the group goals are harmonious, the group is probably effective. When they are not, the group is probably ineffective" (1996, p. 363). In addition, a lack of shared goals among a group can contribute to organizational problems (Hare & O'Neill, 2000). A review of team effectiveness found that the activities of mission analysis, goal specification, and strategy formulation contribute to team effectiveness (Mathieu et al., 2019).

Complex problems require strong interactions among a group to be resolved effectively. When the group's tasks cannot be done by a single person and skills and knowledge are distributed among the group, the group's goals will not be met unless the individuals work together. Bradbury and Lichtenstein (2000) argue for the importance of focusing on relationships between individuals when studying organizations and lists many methods that can be used to examine them.

The two dimensions of centerness are mentioned together in some descriptions of effective groups. Johnson and Johnson (1991) list three qualities of effective groups: (1) meeting their goals, (2) members that keep up good relations with each other, and (3) adapting to change while improving effectiveness. The first two qualities map directly to the two dimensions of centerness. Creamer (2003) concludes—based on studying collaborative research teams—that such groups "can be created through strong personal relationships, a commitment to a common inquiry goal, respect for each other's knowledge or expertise, and willingness to work through differences of opinion" (2003, p. 464). Again, the first two qualities map to the two dimensions of centerness, while the other two qualities would likely be reflected in the strong personal relationships.

These two dimensions are also seen as valuable by other intensive, cohort-based professional development programs for teachers. Brownell et al. (2017) compared two professional development models, noting that the more effective design included greater facilitation of collaboration among the participants. The researchers also noted the need for coherence in the design of professional development that is focused on standards and current work practices; in other words, having a common set of goals for the cohort. Moore et al. (2016) also found their design emphases on coherence and community were key elements in the success of their professional development program. In their program, researchers found that sense of community was fostered even through hybrid communication modes and contributed to a stronger sense of preparation to apply the content. Mouza et al. (2022) found in their professional development for computer science teachers that the most valued aspects of the program were related to collaboration such as exchanging ideas and networking. Their participants also considered the focus on learning newer content valuable to their practice.

Trabona et al. (2019) provide a negative example that shows the value of the two dimensions. These researchers created a professional development community to develop leadership among science teachers. They found participants tended to engage in superficial affirmation rather than develop deeper interactions among the cohort's teams. However, the participants engaged more in practical application and authentic implementation issues in the classroom. It appeared that collaboration and focus were not as strong in the original conception of the program as when teachers were able to focus and collaborate on problems that were meaningful to that team.

Related Concepts

Centerness is similar in some ways to the sociological concept of solidarity. Defining solidarity has been problematic due to differences in conceptions of the term (Fararo & Doreian, 1998). Though differing, all definitions require a relationship of some sort to exist between people, whether physical (Collins, 1981), of some value and frequency (Homans, 1974), or of some other nature. Also, many definitions indicate a purpose or reason for membership in the group. Both criteria are similar to the two dimensions of centerness. Others have explicitly modeled solidarity as having two major components: an ideational component, referring to agents' identification with a network of agents, and a relational component, referring to the relationships in the network of agents (Moody & White, 2003). Moody & White also note that the two dimensions of solidarity are separate concepts and must be measured separately. While similar in some respects, the concern of centerness with a task/activity sets it apart from the more socially focused construct of solidarity.

Another closely related concept is task cohesion, which describes members of a team working together to accomplish a task (American Psychological Association, n.d.). In contrast, centerness is about achieving certain goals, not specific tasks. Task cohesion is considered an emergent state of teams, coming from many factors internal and external to the team (Rapp et al., 2021). Similarly, centeredness emerges from the interactions of agents and their focus on a set of goals. One review of the literature on cohesion notes that there is a mix of definitions in the literature around the concept of cohesion; however, it seems to be a multi-dimensional construct (Salas et al., 2015). This review suggests that measuring both the relational/social dimension and the task-oriented dimension are best. In addition, the reviewers suggest measuring this quality may be more effective in a small team, as there are practical limitations on measuring this construct for a large organization (Salas et al., 2015).

A recent study examining team collaboration is congruent with the construct of centerness. Kelly et al. (2020) examined collaborative research teams comparing the social network of co-authorship on articles and team members perceptions of frequency of collaboration with team output. The study indicated that certain social network measures may correlate with higher team performance. This indicates that the interactions component has a relationship to team output, possibly through the emergent property of centerness.

A Measure of Centerness

Having defined centerness, the following sections describe a measure of this construct, followed by application of this measure to artificial and real groups. Consonant with the epigram at the beginning of this paper, if centerness is desired we must be able to measure it. As there are two dimensions of centerness, two separate measures are required to examine each dimension independently. Such measures are identified below.

Measuring Centerness of Agent Interactions

As the definition of centerness indicates a network of agents that interact, several measures already developed by social network analysis are considered for this dimension. As discussed previously, the exact nature of a meaningful interaction must be determined for each domain. For example, in a system of scholarly interaction, the meaningful interaction may be co-authorship on a journal article, co-membership on a committee, or a citation in one's work to the other. While the nature of the interaction is specific to the system under study, the network of meaningful interactions is what must be measured to examine centerness.

Several social network analysis measures are considered here to determine one that is most suitable to examine centerness. How each measure accounts for the connectedness of the agents, fragmentation in the network, and the influence between agents that are not immediately connected are considered major criteria

for selecting between the measures. Fragmentation in a network means that not all agents are reachable by other agents through network paths, and it is conjectured that a fractured network would be a hindrance to centerness. As centerness can exist in degrees, fragmentation may not completely remove this quality from the system, but it would seriously weaken it. Also, in considering the interaction aspect of centerness, the influence of an agent in the system likely does not stop with the other agents with are immediately connected. The influence can spread through a system beyond their immediate connections, and this influence would support centerness, though to a diminished degree.

Density

One measure that could be applicable is density, the ratio of actual relationships between agents to all possible relationships in the network. Although this measure does indicate connectedness, it is a simple measure of immediate connections, not of information or influence that propagates through the network. Further, the measure of density does not identify fragmentation in the network, where some subset of agents are inaccessible by any relational path from other agents. Though density can still be calculated in a fragmented network, it does not penalize specifically due to fragmentation.

Degree Centrality

Another measure of connectedness among agents in a network is degree centrality. This is an agent-level measure that captures the number of immediate relationships in which an agent participates. A system-level measure can be generated by averaging the degree centrality for all agents in the network. Degree centrality has the same disadvantages for measuring centerness as density; it only examines the immediate relationships between agents and does not assign a penalty for fragmentation. Also, when normalized, average degree centrality is essentially the same measure as density.

Closeness Centrality

Closeness centrality is based on the measure of farness, that is the sum of the shortest distances from an agent to all other agents in the network. The inverse of farness is the measure of closeness centrality for an agent. Like degree centrality, closeness centrality is an agent-level measure, so that a system-level measure can be calculated by averaging closeness values for all agents. While this measure succeeds in capturing the extended influence of an agent, it cannot be calculated when the network is fragmented. Similar measures, such as the average geodesic distance, must also be eliminated for this reason.

Distance-Weighted Fragmentation

Borgatti (2006) proposed a different measure of social networks: distance-weighted fragmentation (^{D}F). This measure accounts for the extended influence an agent can have on other agents through relationships and penalizes fragmentation. The formula for ^{D}F is seen in Equation 1, where d_{ij} is the distance of the shortest path between agents i and j, and n is the total number of agents. Borgatti (2006) describes this measure in greater detail.

$$^{D}F = 1 - \frac{2\sum_{i>j}\frac{1}{d_{ij}}}{n(n-1)} \quad (1)$$

^{D}F accounts for the influence an agent has on other agents that do not share an immediate relationship by assigning a penalty for the weaker level of influence—the reciprocal of the distance (or number of connections apart). In addition, this measure can handle a fragmented network and penalizes for the lack of connection. The distance between two agents that are not connected by any path is considered infinite, resulting in the inverse distance being $1/\infty$, which is taken to be zero.

Since it meets the two major criteria discussed and measures the connectedness of the network, it is favored as the centerness measure of agent interaction. It should be noted that the measure ranges from 0, indicating a network where all agents are immediately connected to each other (a density of 100%), to 1, indicating a network completely free of relationships between agents (complete fragmentation, density of 0%). To adjust this to the concept of "low" and "high" centerness, the scale of ${}^{D}F$ is inverted so that 0 indicates a network completely free of relationships between agents, to 1, where all agents are immediately connected to each other. Thus, from here on the measure used is distance-weighted fragmentation with scale inverted or ${}^{D}F_{si}$ and is calculated as seen in Equation 2.

$$ {}^{D}F_{si} = \frac{2\sum_{i>j}\frac{1}{d_{ij}}}{n(n-1)} \tag{2} $$

Measuring Centerness of Agent Goals

The intention of this measure is to capture how many agents in the system being studied have system goals as their own overall goals within the system. While the agents may have other goals as part of their participation in the system, it is the presence or absence of system goals that is important to centerness.

One way to quantify this is to determine the fractions of system agents pursuing each system goal, that is on average how many agents pursue a system goal. Thus, for a given system goal g, the centerness on that goal is the number of agents who pursue that system goal (a_g) divided by the total number of agents (n). Assuming there is more than one system goal, this quantity can be averaged across all system goals (g total), giving the average centerness on goals (CG). This formula can be seen in Equation 3. Thus, when CG is 0, there are no agents pursuing any system goals, and when CG is 1, all agents are pursuing all system goals.

$$ CG = \frac{\sum_{g=1}^{g_{total}}\frac{a_g}{n}}{g_{total}} = \frac{\sum_{g=1}^{g_{total}} a_g}{ng_{total}} \tag{3} $$

There is no weighting of individual goals or agents, implying that each is of equal significance in centerness. While this assumption is arguable, it may be quite difficult to determine weights for agents and goals in practice if all are essential to the system's successful operation. Also, major stakeholders in the system may not be able to reach a consensus over the weighting scheme. Thus, this formula is adopted in the interests of parsimony, though recognizing this as a potential area for further research and improvement. It should also be noted that this formula does not account for goals agents are pursuing outside the identified system goals.

The number of goals in the system and the number of agents depends largely on how the system under study is defined. Whether an agent is explicitly attempting to achieve a particular goal can be determined in one of at least two ways. First, self-report: the agent is queried in some way and identifies the overall system goals that they are pursuing, either by identifying the goal in a free response manner or by selecting goals from a provided set. Second, modeling: the system is modeled (which admittedly may involve the former method), and the model reveals which agents are pursuing which goals.

It is possible that a system is defined such that there are no clear system goals. In such an unstructured system, CG can be calculated by assuming that all goals that are self-reported by agents in the system are the system's goal set.

Applying Centerness Measures to Distinguish Artificial Systems

Four artificial systems are presented here to show how these two measures can be used to measure centerness at the extremes of its two dimensions. For the sake of comparison, each system has the same number of agents (n = 20). All network analysis values are calculated using UCINET (Borgatti et al., 2002), and the figures were generated using NetDraw. We provide additional detail on the first example to demonstrate how to calculate the measures of centerness.

University Research Laboratory

Faculty, graduate students, and technicians work together in a university research laboratory to pursue one or a small set of research questions. Typically, all (or nearly all) lab members will interact in some way with each other, though there may be subgroups dedicated to specific lines of research. Given a laboratory of n = 20, assume there are three professors, one lab technician, and three groups of graduate students (one of six students and two of five), with each group concentrating on a particular project. The meaningful measure of interaction, in this case, may be working together on a research project. Assume the three professors are on all students' thesis committees, that the technician is acknowledged in every paper, and that the students in each research group collaborate on papers. Also assume that for each pair of groups there are two students in each group that collaborate with two other students in the other group.

In order to calculate the distance-weighted fragmentation using UCINET, a spreadsheet that indicates connections between individuals in the network must be constructed. This spreadsheet can be seen in Figure 1 that describes the situation described above. A connection between two individuals is indicated by a 1 in that cell, otherwise the cell is zero. Figure 2 shows this network in diagram form.

Figure 1. *Spreadsheet of Network Connections for Laboratory Example*

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		Prof 1	Prof 2	Prof 3	Tech	Stu1	Stu2	Stu3	Stu4	Stu5	Stu6	Stu7	Stu8	Stu9	Stu10	Stu11	Stu12	Stu13	Stu14	Stu15	Stu16
1	Prof 1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Prof 2	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	Prof 3	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	Tech	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	Stu1	1	1	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1
6	Stu2	1	1	1	1	1	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1
7	Stu3	1	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0
8	Stu4	1	1	1	1	1	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0
9	Stu5	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	0	0	0	0
10	Stu6	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	0	0	0	0	0
11	Stu7	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0
12	Stu8	1	1	1	1	0	0	0	0	0	1	1	0	1	1	1	0	0	0	0	0
13	Stu9	1	1	1	1	0	0	0	0	1	1	1	1	0	1	1	0	0	0	0	0
14	Stu10	1	1	1	1	0	0	0	0	0	0	1	1	1	0	1	1	1	0	0	0
15	Stu11	1	1	1	1	0	0	0	0	0	0	1	1	1	1	0	1	1	0	0	0
16	Stu12	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1
17	Stu13	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1
18	Stu14	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1
19	Stu15	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	0	1
20	Stu16	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	0

To the calculate centeredness on goals, we would also use data from a survey that lists the overall goals of the research laboratory and have each individual indicate if they believe they are pursuing that goal. Assuming the ideal case, all individuals in the laboratory are pursuing all goals for the lab. For the sake of the example, we assume there are three major goals for the laboratory. Using Equation 3, we would sum the number of agents pursuing each goal, which for each of the three goals is 20 agents resulting in 60 for the numerator. For the denominator, we multiply the total goals (3) by total agents (20), also obtaining 60. This reduces to a *CD* of 1.

Given this situation, ${}^{D}F_{si}$ = 0.81 and *CD* = 1, which indicate a high level of centerness based on high levels of the two measures. We expect this given the extensive connections between individuals in the laboratory and that every agent is pursuing the stated goals of the laboratory.

Movie Theater

In a movie theater, a group of people gather for the purpose of watching a movie. However, except for groups of people that come together, they are not likely to interact with others in the theater. For example, assume one group of four people, two groups of three people, and five groups of two people are in a theater watching a movie. Further assume that they are all there to see the movie (the only system goal), that the meaningful interaction is communication between agents, and that they will only interact with other agents in their own group. The network in Figure 3 illustrates this situation. In this system, ${}^{D}F_{si}$ = 0.09 and *CD* = 1. In terms of centerness, this shows a high level of agents pursuing the system goal, but low interaction.

Kindergarten Class

An example system with high interaction but low pursuit of common goals is difficult to identify; however, one is a kindergarten class. The main system objective will involve student learning and/or preparation for first grade. However, few kindergarten students may share this goal. We assume a class of one teacher, one teacher's aid, and 18 students. Also assume that the teacher, the aid, and two students are pursuing the system objective. Further assume that the teacher, the teacher's aid, and all students interact with each other. In this system, ${}^{D}F_{si}$ = 1 and *CD* = 0.2 This indicates a low level of agents pursuing system goals, but high interaction. Figure 4 represents this network.

Public Park

In a public park, people come to and use the park for a variety of reasons, and indeed parks are set up and maintained to achieve a variety of goals. Also, like the movie theater, agents who go to a park are not likely to interact with others outside their personal group and may not even interact with anyone. Assume there is a park with one group of four socializing, two groups of three playing organized games, two groups of two who are walking, four individuals who are exercising, and two individuals who are resting. Further assume that all of these purposes are valid system goals (for the sake of this example) and that the meaningful relationship is a social connection. Thus, ${}^{D}F_{si}$ = 0.07 and *CD* = 0.17, indicating a low level of centerness for this system. Figure 5 is an illustration of this system.

Figure 2. *Network for a University Research Group*

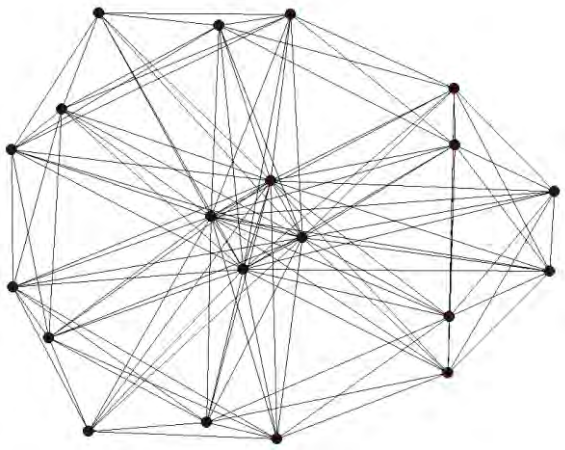


Figure 3. *Network for a Set of Movie Theater Attendees*

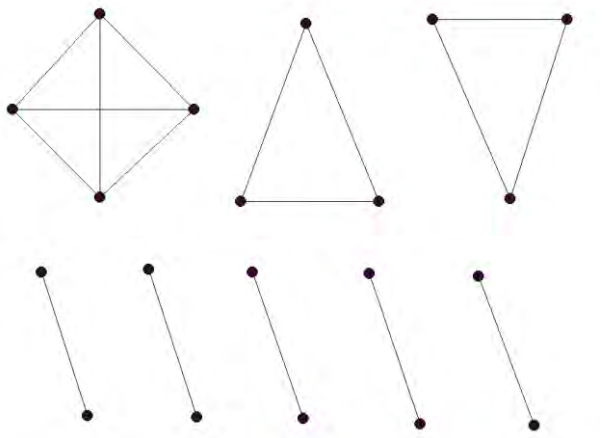


Figure 4. *Network for a Kindergarten Class*

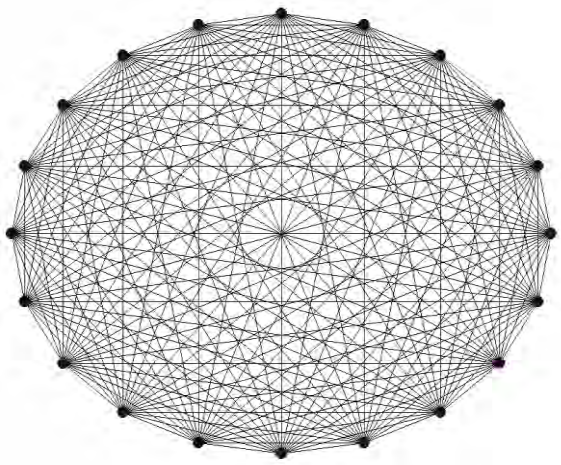
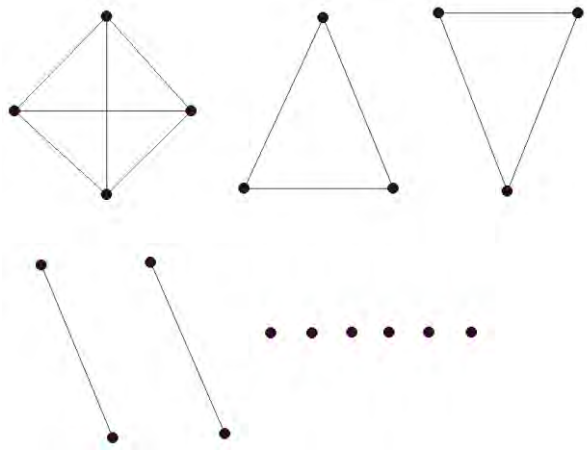


Figure 5. *Network for a Set of Public Park Users*



Confirming a Measure of Agent Interactions

All four cases of agent interactions above are given in Table 1. Generally, these measures match the expected pattern of the examples. The table also shows that some are less suited than others as a measure of centerness. Closeness centrality, as expected, could not be calculated in fractured networks (the movie theater and the public park). Density (and the equivalent degree centrality) and ${}^{D}F_{si}$ both seem promising as candidate measures as they track the expected pattern and give equivalent results on three groups. However, there is nearly a .20 difference in their indication of the connectedness of the research group. A generally high value is expected for this group as, while all agents are not immediately connected, no agent is more than two steps from any other agent.

While density and degree centrality may be strong candidates, Distance-weighted fragmentation is preferred as the measure of agent interactions, both because it is designed to measure a concept that is logically close to centerness and is closer to the expected level of connectedness in these examples.

Table 1. *Potential Measures of Agent Interactions from Hypothetical Cases*

	Density	Degree Centrality	Closeness Centrality	Distance-Weighted Fragmentation (scale inverted)	Expected Interaction Level
Research Laboratory	0.62	61.58	74.10	0.81	High
Movie Theater	0.09	8.95	Unable to calculate	0.09	Low
Kindergarten Class	1.00	100.00	100.00	1.00	High
Public Park	0.07	7.37	Unable to calculate	0.07	Low
Interpretation	1 = Max 0 = Min	100 = Max 0 = Min	100 = Max 0 = Min	1 = Max 0 = Min	

Applying Centerness Measures to Distinguish Actual Systems

Having established that the measure of centerness proposed here can identify the expected levels of centerness in the extremes of the artificial systems above, the following six actual groups are examined. Five groups are teams of teachers involved in a professional development program in the Information Technology in Science (ITS) Center for Teaching and Learning. These teams were measured for their centerness twice, once in each summer they were in the ITS program. The sixth team is the ITS Center's management team, which oversaw the center's activities and was measured once.

The research question addressed is whether the proposed measure of centerness can discern the quality of centerness between the teams. The nature of these teams and how they were examined are described in greater detail below. It was expected that the five teams of teachers would have very similar levels of centerness as they have a very similar structure and makeup. Also as the five teams are measured twice, their centerness was expected to increase from the 1st to the 2nd year. It was also expected that the management team would have a higher level of centerness on both dimensions than any of the project teams. To compare the calculated level of centerness with qualitative assessments, the perceived centerness of the teams was collected from the external evaluators for the management team and the graduate students that mentored the project teams.

ITS Center

The ITS Center existed to improve science and math education in the middle and high school grades through inquiry-based methods and authentic information technology. The main means to accomplish this were through a 2-year professional development program for teachers. This program was designed around project teams, groups of teachers, STEM faculty, and K–12 education graduate students. These worked together in the summers to collaboratively develop classroom interventions and then implement them with support during the school year.

Team Makeup

Five groups examined here are project teams in Cohort III of the ITS Center's professional development program. The five teams examined one of five scientific topics indicated by their titles: Landscape Ecology and Conservation, Molecular View of the Environment, Plant Genomics and Time-Lapse Imaging, Science and Technology at the Nanoscale, and The Water Environment. These teams are made of two to five scientists, two or three education specialists (graduate students), and seven to 14 participants who are a mixture of teachers and graduate students.

The sixth team is the ITS Center's management team. The management team is responsible for setting the overall goals and plans for the center, especially the professional development program, and evaluating progress toward those goals. At the time of measurement, this team consisted of the center's director, principal investigators, faculty from the sciences and science education who were partially supported by the center and have an interest in directing its activities, the center's funded post-docs, the internal and external evaluators, and one graduate student to represent the funded graduate assistants.

Data Collection

To collect the data necessary to calculate the centerness measures, two surveys were designed, one for each type of team studied. Judgments on the centerness of the teams by knowledgeable personnel were also collected.

Surveys of Centerness

A survey was developed to examine the project team participants' goals and interactions. It contained one question to address goals: "What are your personal goals for your participation in the ITS Center?" The section to address connections between participants asked: "List the people with which you have had a significant interaction as part of your participation in the ITS Center (both Center personnel and participants). [For each individual,] Rate how frequently you interact with each person." The rating scale ranged from 1 (very infrequent) to 5 (very frequent). This survey was administered on paper to all project team members on the last week of each summer session of the program. Response rates among the teams in the initial administration ranged from 88% to 100% per team; in the final administration response rates among the teams ranged from 67% to 100% per team.

A similar survey was designed to capture data from the management team. The main difference is that on the question addressing interactions, the table was filled with the names of the management team members, funded graduate students, and other key personnel within the ITS Center. Blank spaces were also left for any who were not on the list. This survey was administered on paper at a fall planning meeting of the ITS Center coinciding with the initial administration to project teams, where the management team and other personnel were expected to attend. The survey also had questions addressing depth of understanding of the center's functioning, but these were for internal evaluation purposes and are not part of this study. The response rate was 64%.

Perceptions of Centerness

To compare with the centerness data collected from the surveys, evaluations of each teams' centerness were collected from knowledgeable personnel. For the five project teams, the mentoring graduate students were consulted as to how much centerness was in the team at that time. In an emailed survey, each graduate student assigned to a team was presented with the formal definition of centerness given above and asked the following questions:

1. How much do you think your team had centerness this past summer? (Respond with low, moderate, or high.)
2. Rate your agreement with the following two statements on a scale of zero to 10:
    a. Team members shared a single common set of goals.
    b. Team members had strong interactions with all other members of the team.
3. Provide any comments related to the centerness of your team.

Of the 11 mentoring graduate students (campus resource persons or CRPs) from the second session of the team, eight responded, and at least one from each team responded. In only two instances did CRPs from the same team gave different ratings in Question 2, and in both cases the ratings were different by a single point. For this analysis, the ratings were averaged. None disagreed on rating Question 1.

For the management team, it has been examined each year by our external evaluators in their annual report. These reports have made specific reference to the centerness (sometimes referred to as "centeredness") of the management team and how well it has functioned. While the external evaluators are members of the team and are funded by the center's grant, they remain intentionally independent of most decisions by the management team.

Identifying System Goals

The normative goals of the project teams and the management team must be identified to determine if the personnel in those teams are explicitly attempting to meet the goals. These were identified from discussions with the project principal investigators (PIs) and from documentation of the center's grant proposal, reports,

and publications. The three main goals of the professional development program are for participants to learn how information technology used in scientific research can be implemented in the classroom, to learn about inquiry based methods of teaching science, and to develop a community with each other and ITS Center personnel. These are considered the goals of the teams for the purposes of this analysis.

Identifying the Social Networks

Data from the interaction questions of the survey were recorded in matrix form in a spreadsheet. To identify the significant relationships between project team members, a relationship is considered to exist when the frequency is rated three or higher. Based on this threshold, the data were transformed into a binary matrix of relationships. All relationships are treated as undirected; that is, if one person claims a relationship with another, the relationship is assumed to exist even if the other person does not claim the relationship on their survey (or if that person was not surveyed).

A network was constructed for each project team. As noted above, only the participants and CRPs were surveyed. This was to establish the core of each network as the participants and CRPs assigned to that team. Relations to personnel outside the participants or immediately related center personnel are not considered part of the network. Otherwise, the network would not be bounded and could grow to encompass all personnel in the ITS system. The focus of this analysis is on the participants in the individual teams, not an attempt to map all actors that may be marginally affiliated to this team. In light of this, one exception was made to the above rules. If one participant, in one team, claimed to have a significant relationship with all the members of another team, and no other participant in the original team also had a relationship to a member in the other team, those relationships were ignored. This rule was applied to one instance in the first survey administration and twice in second (where an individual claimed relationships with two other entire teams).

When constructing the network of the management team, it was recognized that there are some personnel who were officially members of the management team but were typically unable to attend regular management team meetings or be involved in the decision-making process of the center. In light of this, the core of the management team was identified that did regularly attend and participate; this group is considered to be the management team for this study. All official members of the management team that attended at least one of the two management team meetings that coincided with the initial project team summer are considered to be in the core. As with the project teams above, the network was constructed starting with this core and including other official members of the management team that a core member has identified, along with that relationship and any relationships between the non-core actors.

Expectations

While the teachers typically remain in the same project team for the entire 2 years and interact a great deal during the summer, each teacher is designing an individual intervention for their own classroom. Thus, we expect to see a moderate level of centerness in the five project teams. Also, while each project team develops its own character and examines different scientific topics, it is expected that the level of centerness between these teams will be very similar. As the teams have worked together before (though with some CRP changes and individual dropout), it is expected that centerness will rise from the first to the second summer session. Further, it is expected that the CRP ratings of the teams' centerness will be close to the calculated values from the second summer. Finally, it is expected that the management team will have a higher level of centerness than the project teams and will reflect the sense of the external evaluators.

Results and Discussion

The values of the calculated *CG* and ${}^{D}F_{si}$ for all teams, along with their rated values, are given in Table 2. The calculated values for the management team are *CG* = 0.52, ${}^{D}F_{si}$ = 0.78. Diagrams of the social networks of individual project teams from the second summer can be found in Figures 6 through 10. The social network diagram for the management team is in Figure 10. The solid dark nodes in the figures represent the team's assigned participants, while the nodes in grey represent other ITS personnel. Project teams have been deidentified to ensure confidentiality due to the small numbers. Figure 11 plots the centerness scores for the project teams in the second summer with the management team.

Table 2. *Centerness Measures Results for Project Teams*

Team	Session	Calculated CG	CG Rated by CRPs	Calculated ${}^{D}F_{si}$	${}^{D}F_{si}$ Rated by CRPs
1	1st	0.31	-	0.69	-
	2nd	0.22	0.95	0.68	1.00
2	1st	0.33	-	0.65	-
	2nd	0.44	0.80	0.71	0.80
3	1st	0.21	-	0.69	-
	2nd	0.22	0.80	0.75	0.90
4	1st	0.38	-	0.66	-
	2nd	0.29	0.70	0.69	0.70
5	1st	0.30	-	0.77	-
	2nd	0.36	0.85	0.72	1.00

Figure 6. *Team 1 Network*

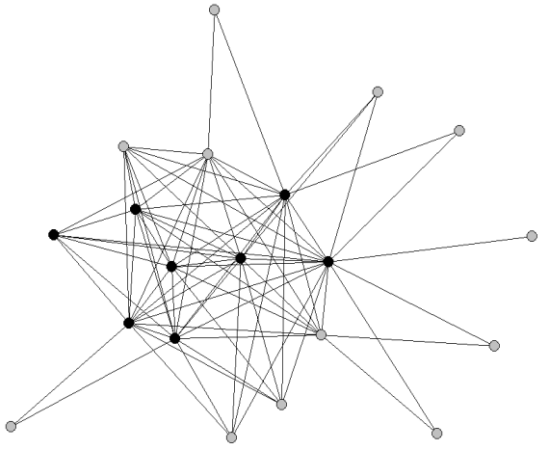


Figure 7. *Team 2 Network*

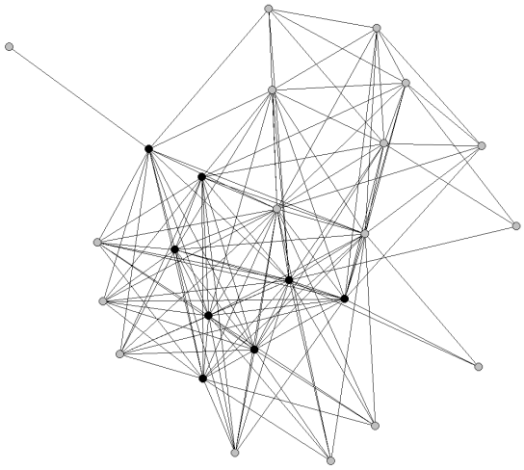


Figure 8. *Team 3 Network*

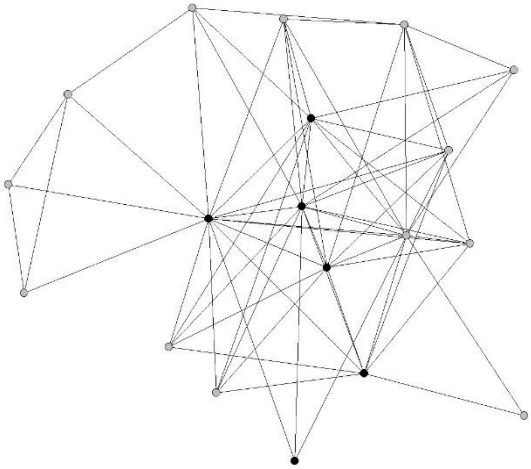


Figure 9. *Team 4 Network*

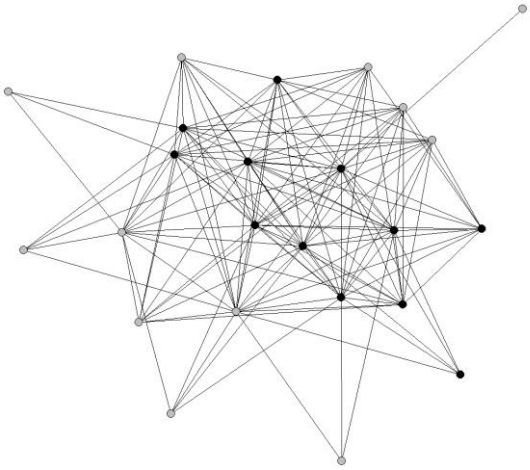


Figure 10. *Team 5 Network*

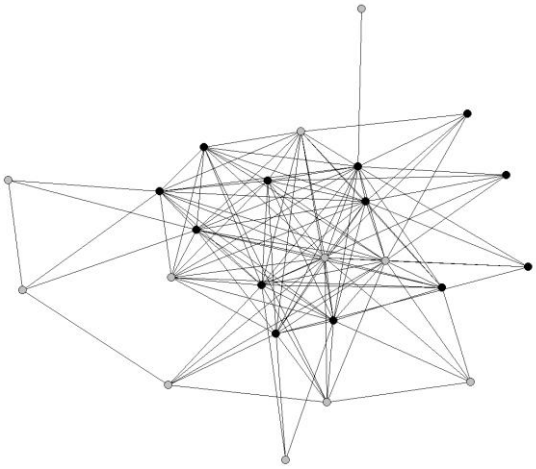


Figure 11. *Management Team Network*

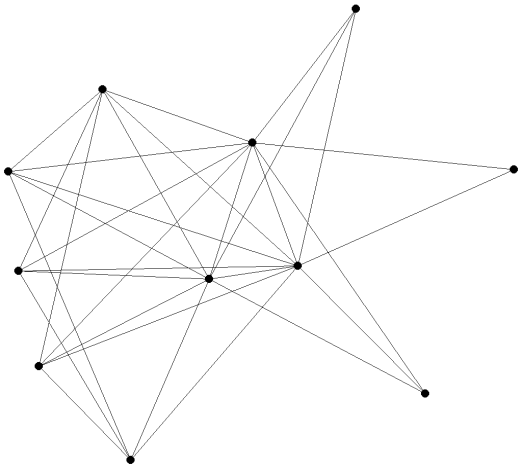
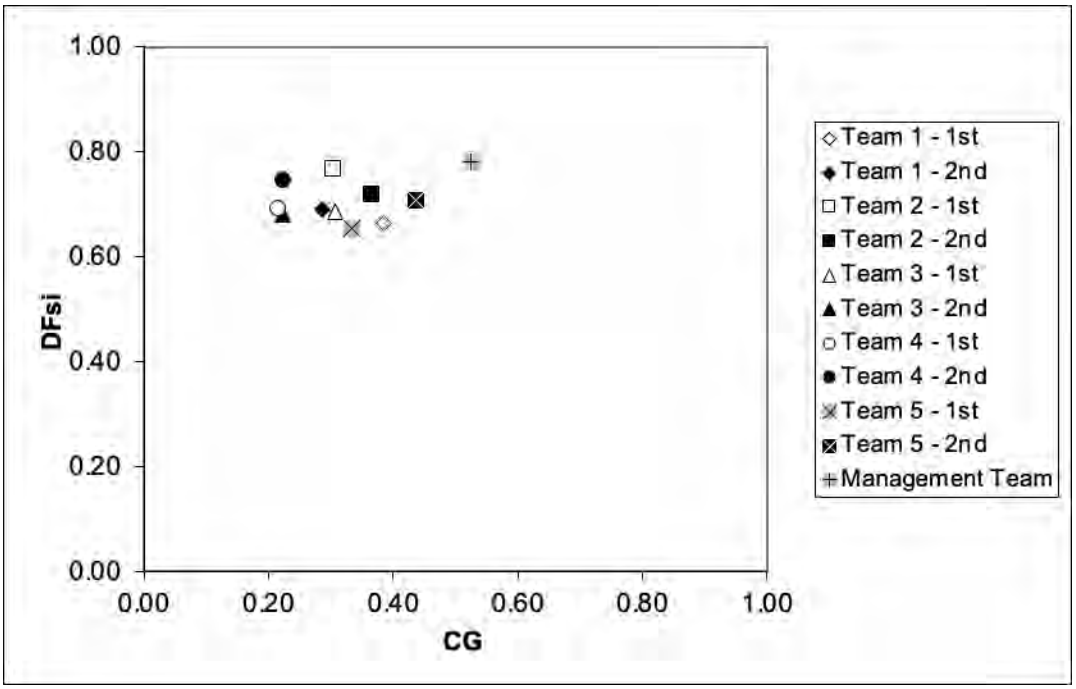


Figure 12. *Graph of Centerness of Project Teams and Management Team*



The first expectation, that the five project teams would have very similar levels of centerness, is generally accurate. The project teams in both years have similar ${}^{D}F_{si}$ scores, with a range of only .11 from lowest to highest across all project teams and both years. The *CG* values are more widely spread, with a range of .22 from lowest to highest across all project teams and both years. As can be seen in Figure 11, the project teams are generally clustered in one region of the graph.

The expectation that the five project teams would generally increase in centerness from one year to the next did not prove uniformly true. As seen in Table 2, two teams increased in centerness on both dimensions, two teams increased on one and decreased on another, and one team decreased on both.

While increases were expected, that does not mean that the teams could not have experienced setbacks that could decrease their centerness. Disruptions in personnel may have played a role. Of the two teams that increased on both dimensions of centerness, one lost a single participant while the other lost none from the first to second summer. The teams that decreased on at least one measure lost two participants each, and the team that decreased on both measures lost three participants between the 2 years. Given the myriad of other factors that could play a role, it is not possible to conclusively determine a cause for gains or losses in centerness. However, if centerness is an emergent property of a team, then loss of team members may suppress the emergence of centerness. Although the expectation that team centeredness would generally increase was not met, it was based on the assumption that centerness in a group is dominated by time and that greater time spent as a group necessarily increases centerness. The data show that this assumption is not true.

The management team did prove to have a higher level of centerness on both dimensions than any project team in either year, as expected. While the ${}^{D}F_{si}$ measures of some other teams were comparable, the *CG* measure is 0.08 higher than the highest *CG* measure of any project team and is more than double that of three teams. Considering the plot of the teams' centerness measures in Figure 11, the project teams are generally in a cluster, while the management team is somewhat removed toward the upper right corner.

In addition to the numerical analysis, the perceptions of centerness were collected from knowledgeable personnel. The external evaluators of the center considered the management team to have a high level of

centerness as of the report prior to this study. The management team had been working together for over 5 years prior to being measured, and, while personnel have come and gone, at the time of the survey the group had been generally stable. In this case, the perceptions of the evaluators align with the relatively high level of centerness as calculated. Even with this high perception by the evaluators, *CG* for the management team is only about half of its maximum possible value. This suggests that this dimension may be more difficult to increase than that of increased interaction.

Campus resource persons (CRPs) for four of the five project teams rated their team on Question 1 as having high centerness. The other, Team 4, is rated as having only moderate centerness. While ratings of ${}^{D}F_{si}$ are somewhat close to their calculated values, calculated and perceived values of *CG* are very different. The CRPs were highly involved in their teams, and the summer program was successful in many ways. These factors may have led CRPs to have a higher perception of centerness in their teams than is warranted. Another possibility is that in light of the management team achieving a *CG* of only 0.52 and the discrepancy in calculation and perception for project teams, the *CG* dimension may have a low threshold for "high" values of centerness.

Conclusions

This paper has given an operational definition of centerness and presented a quantitative measure of it. As formulated here, centerness has two dimensions: the level of shared goals among agents in the group and the level of interaction among the same agents. The higher both measures are, the higher the total centerness. The artificial systems examined show that the measure can identify groups at the extremes of centerness, and the groups in the ITS Center show that the measure can distinguish real-world systems as well. The calculated centerness measures did distinguish the management team from the project teams. Also, the project teams were generally clustered. While the project teams did not uniformly increase in centerness from one year to the other as expected, this expectation was likely not valid. The measure of centerness was able to distinguish these real-world groups in spite of many limitations, particularly that the relationship measure used is subjective.

The resources required to measure centerness are relatively low with this method. The main system goals and the key modes of interaction must be identified. Based on these, a survey can be created and administered to the group. Once the results are collected, *CG* can be calculated by hand, and ${}^{D}F_{si}$ can be calculated with UCINET. The primary benefit of this analysis is awareness of the current state of centerness in a group. Assuming the key modes of interaction in relationships can be identified early on, centerness could be measured from the beginning of a group onward, providing regular feedback to the manager(s) as to any changes over time in the centerness of the group. Use of this measure of centerness may also support activities within a group that encourage regular reflection on the goals of the group and increasing the number and strength of interactions among group members.

This measure is applicable to any group that desires centerness among its members, and thus needs to measure it. One such group includes intensive, cohort-based professional development programs for K–12 STEM teachers. These programs involve extensive collaboration between K–12 teachers from various grade and subject areas and faculty in education and STEM fields to create curricular materials. This measure can examine the change over time of centerness within the program leadership and within cohorts of participants and faculty as a measure of growth. If the centerness of these groups can be measured and improved early in its life, then the benefits of centerness will be realized sooner in the work of the program. The ITS Center was measured as having a high level of centerness among the leadership team after approximately 5 years of effort, culminating in a successful third cohort of participants in the professional development program. We can only speculate on the trajectory of centerness of the leadership team over time. Would improved centerness early

on have led to more positive impacts in the program structures for earlier cohorts? The cohorts and subgroups of teachers need to achieve centerness to reap the full benefits of a professional development program.

The major benefit in these cases is awareness for those leading the professional development program. If a cohort or subgroup of a cohort is showing very low centerness over time, an intervention can be applied before time passes and the quality of team efforts suffer. The same can apply to the leadership team. If that time is highly diverse in subject areas represented, measuring centerness gives a quantifiable method of demonstrating if progress is being made on the group coming together to produce high-quality professional development with a unified purpose.

It must be noted that the concept of centerness is most applicable to professional development programs that take place over a long time and are designed around extensive collaboration among participants and supporting personnel. Centerness is not meaningful for a 2-hour workshop focused on dissemination of information. Centerness is more useful for programs that are establishing communities of practice where teachers are gaining new knowledge and skill through collaboration. While centerness is not the sole quality required for success, we contend it is a necessary quality, and thus is necessary to measure so it can be improved.

One insight into centerness revealed by the measure presented here is based on the fact that the number of agents in the system impacts both dimensions. Adding a new member to a group who is not currently connected to other members and not pursuing the system goals has an immediate negative impact; this impact is inversely proportional to the size of the group. Also, losing a member can impact both measures depending on their connections and pursuit of the goals. If teachers join or leave a cohort once it has begun its work, they are less likely to have internalized pursuit of the goals and to have connections with the rest of the group, bringing down the group's centerness. Likewise, if faculty or other personnel supporting the cohort must step aside or join later in the process, this may also negatively impact centerness of the group.

There are several limitations to the measure of centerness presented here, which may be improved with further study. Perceived strengths of relationships between individuals is a subjective measure, so it was not considered in this case. If a more objective measure is used, such as observed times a pair of group members collaborated, then the strength of the relationship can be considered in the measure of interactions. Even in a group where nearly all personnel are immediately connected, if the strength of the connections is weak, the measure of centerness should be low on this dimension. Also, if a more objective measure is used, a measure of interactions could take into account directionality of those relations. If information tends to flow only one direction between a pair rather than both ways, this would negatively impact centerness and the measure of this dimension should reflect that fact. Finally, the personal priorities assigned to goals identified by participants were not considered in this analysis. Strength of importance of a goal may also play a role in the level of centerness.

It should be noted that this study is not a full attempt to establish validity or reliability. This is an attempt to operationalize the concept of centerness and propose a method for measurement. The four examples of artificial groups plus the real groups from the ITS Center are resented as a preliminary attempt to examine construct validity. Additional study will be required to establish anything beyond face validity.

A major issue for further study is to identify the factors that contribute to centerness. The measure reveals the current state of centerness and variables that indicate that, but not what conditions must exist for it to develop within a group. If centerness is to be improved and not just measured, these factors must be discovered.

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