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Who Dunnit: The Party Mystery Game for Analyzing Network Structure and Information Flow

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Abstract

The activity facilitates students' understanding of network measures, including different types of node centrality, shortest paths, cliques, and communities, and their implications for information flow in groups or organizations. The goal of the game is for students (a minimum of 10 and maximum of 28 participants in a network; a larger class can be divided into two or more networks) to solve a company mystery by exchanging information clues with other students based on an imposed communication network configuration. The activity can be debriefed by discussing the game outcomes, analyzing the network structure (using a software to input data and calculate key network measures), and evaluating the practicality of the game. Examples of network configuration, data sets, and a script which uses the igraph package in R are included.

Keywords

Network structure, Information flow, Centrality, Class activity, Organizational networks.

Network theory and methods contribute prominently to understandings of how the structure of communication and interactions among people impact various organizational processes and outcomes (Monge and Contractor, 2003; Borgatti and Halgin, 2011). This mystery game (see Appendix 1 for game setup instructions) offers an engaging way to help students experience and understand how their position in a network brings opportunities and constraints in accessing information and facilitating information flow. Like in existing network simulation activities (e.g., Trefalt, 2014), players exchange resources within an imposed networks structure. However, this activity uniquely provides a cognitive puzzle of 'Who Dunnit' that can be solved via dyadic information exchange between players whose designated positions in the communication network vary in four measures of centrality. In addition, as an option, the communication network used in the game can be utilized as a simple and effective data set for analyzing network measures and practicing network visualizations.

Both formal hierarchy and informal relationships constitute patterns of communication in organizations (Krackhardt and Hanson, 1993; Rank et al., 2010; Lee and Lee, 2015). The extent to which nodes occupy various central positions is a key structural aspect influencing how quickly and extensively one can access information (Borgatti, 2005). Popular measures of centrality include degree, closeness, betweenness, and eigenvector centrality (Wasserman and Faust, 1994; Borgatti, 2005). At the broader network level, network diameter, mean geodesic distance, and the existence of subgroup structures, like cliques, impact the patterns and efficiency of information flow (e.g., Yamaguchi, 1994). A summary of these measures including their definition, implications, and key references is provided in Table 1.

The communication network given in this activity is designed to highlight the differences between four centrality measures and underscore unique aspects of structure that impact information flow. The activity can be utilized in undergraduate and graduate level courses on network analysis or on various topics in the fields of

Table 1. Summary of network measures used in the proposed activity.

	Measure	Definition and implications	Key references
Node-level	Degree centrality	• Considers a given node's number of direct connections • Nodes high in degree centrality have a large number of immediate exchanges of information	Borgatti (2005)
	Closeness centrality	• Considers the average shortest path from a given node to all other nodes in the network • Nodes high in closeness centrality can reach all the other nodes in the network in a short number of steps and, therefore, can be efficient in accessing or sharing information	Wasserman and Faust (1994)
	Betweenness centrality	• Considers the extent to which a given node is positioned between other nodes on their shortest paths, or geodesics • Nodes high in betweenness centrality can serve as a bridge to transport information or control the interactions between other nodes	Freeman (1977), Wasserman and Faust (1994)
	Eigenvector centrality	• Considers the centralities of a given node's neighbors (in contrast to degree centrality which exclusively relies on the number of connections) • Nodes high in eigenvector centrality are more influential than nodes which have a large number of connections to less central nodes	Bonacich (2007)
Overall network-level	Diameter	• Measures the distance between the two nodes furthest apart in the network, or the largest geodesic distance across the entire network • Represents the maximum distance a piece of information needs to travel in a network	Yamaguchi (1994)
	Mean geodesic distance	• Measures the average number of shortest steps between pairs of nodes • Reflects the overall connectivity of a network and impacts the extent to which information can be shared among nodes in few steps	Hanneman and Riddle (2005)
	Clique	• A cohesive subgroup of nodes that are all directly connected to all others in the group • Members in a clique have constraints in accessing non-redundant information if they do not have ties to nodes outside of the clique	Haythornthwaite (1996), Hanneman and Riddle (2005)
	Community structure	• Structures of densely connected subsets of nodes • Represents social groupings, impacting the flow of information within and across those boundaries	Girvan and Newman (2002)

Note: The information provided in this table can be used to teach students about network concepts prior to playing the game.

management, communication, sociology, and others. This activity has several learning objectives:

- describe the implications of network position and structure for information accessibility;
- differentiate between four measures of network centrality (degree, closeness, betweenness, and eigenvector centralities) and understand how central positions can facilitate or constrain information flow;
- compare a fictitious game scenario to real-word communication contexts; and
- conduct network analysis and visualization using computer software.

The following sections give instructions for the activity, including preparation, materials, introducing the game, playing the game, and debriefing the game. Suggestions for appraising the learning outcomes follow. Two examples of communication networks, for varying class sizes, are displayed in the figures. Data sets for the networks, as well as an R script for inputting the data, computing network measures, and creating plots, are included.

Who Dunnit activity

The activity suits a 50 to 85 minutes and can be adjusted for 10 or more players. Students will first be introduced to the concepts of centrality, shortest paths, and subgroups and will then play a mystery game. The activity, described in more detail below, is meant to be like party murder mystery games that people play in social settings. But instead of solving a murder, players will attempt to discover who stole secrets from the company they work at. This activity revolves around clue exchange between players across several rounds, where players meet in dyads to exchange one clue each per round.

This mystery game is particularly well suited for conveying the network concept of centrality, in addition to other subgroup and global level measures, because it (i) plays upon an innate desire to solve a mystery which increases student engagement and (ii) controls the structure of interaction such that students can examine the relationship between network positions and returned outcomes. In this scenario, one of the main outcomes is whether a player successfully identifies the person who stole secrets from their company.

Preparation

To prepare students to learn about network concepts, introductory readings on measures of network centrality and subgroups (e.g., Monge and Contractor, 2003, Chapter 2; Hanneman and Riddle, 2005, Chapters 10 and 11) can be assigned. Instructors may also assign an overview reading of social network analysis (e.g., Borgatti et al., 2009), especially for students without background in the field.

The game will work with a minimum of 10 and a maximum of unlimited players. Figures 1 and 3 provide examples of network configurations and corresponding nodelists for 14 players and 28 players, respectively. The size of the group of students playing the game dictates the number of nodes that will be in the network and the network configuration. If the group is smaller than the network to be used, nodes (i.e., each player in the game) should be removed from the nodelist – starting from the highest numbered nodes (e.g., node ID 14 in a 14-player network, then node ID 13, etc.) – until the number of nodes matches the number of players. In both 14-player and 28-player networks, the highest numbered nodes are located on the periphery of the network to assist with such adaptation. For class sizes ranging from 15 to 27, nodes should be removed from the 28-player network. The 28-player network is built upon the 14-player network so that, if node IDs 15 to 28 are removed, the network will become identical to the 14-player network. If the number of players exceeds beyond 28, the instructor should split the class into two groups of a smaller number of players in each. In this case, having multiple networks of similar size is recommended in order to allow discussing the players' shared experiences of how information exchange unfolded in each network, and comparing them against each other. For instance, for a class of 30 students, two 15-player networks can be set up. For a class of 35 students,

1	2	4	6	13		
2	1	4	5	7		
3	9					
4	1	2	5	6	7	8
5	2	4	7			
6	1	4	8			
7	2	4	5	8		
8	4	6	7	9		
9	3	8	10			
10	9	11	12	14		
11	10	12				
12	10	11	14			
13	1					
14	10	12				

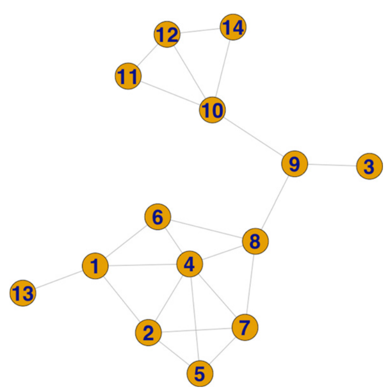

Figure 1: Nodelist and plot of a 14-player network. The plot should be displayed during debriefing.

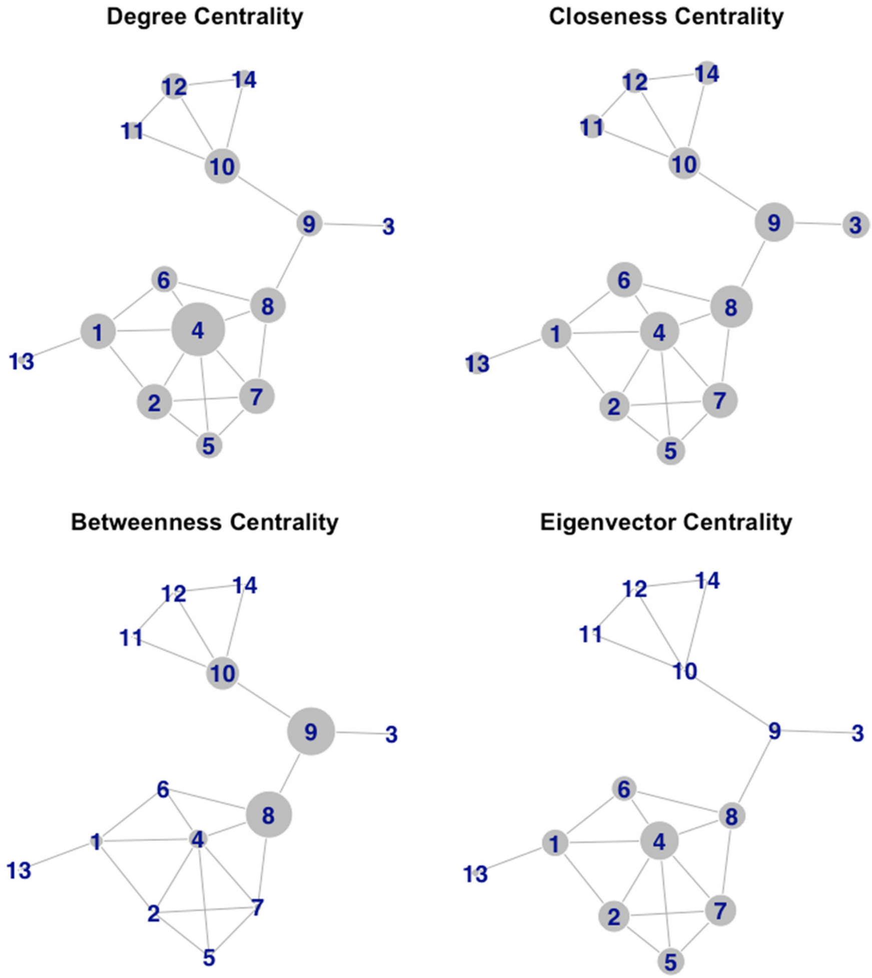

Figure 2: Plots with centrality measures for the 14-player network. Node size is adjusted by each of the four centrality measures. Instructors can show these figures to students after analyzing the network structure.

one 17-player and one 18-player network can be set up. A class of 70 students can be divided into one 24-player and two 23-player networks. Edges (i.e., ties that indicate which players can communicate with which others) should be modified accordingly. For example, for a 12-player game, remove 13 and 14 from other players' rows in the nodelist.

The network structure is designed to show communities and bridges in both versions of the network. In class sizes that do not consist of exactly 14 or 28 players, the recommendation for using the larger network and cutting nodes, rather than using the smaller network and adding nodes, is because the provided networks have been designed such that nodes may be removed while preserving the overall integrity of the exercise. In the proposed 14-player and 28-player networks, nodes that are high in each of the four centrality measures are differentiated. For instance, in the 14-player network (see Table 2, Figure 2), nodes 4, 8, and 9 are the highest in degree, closeness, and betweenness centrality, respectively. Node 7 is the second highest in eigenvector centrality other than node 4, which is noticeably the highest due to its high degree. These differentiations between node centralities are preserved when the network is adapted to a different number of players. In addition, there will always be peripheral nodes that have constraints in their number of communication partners. For example, if nodes 11 through 14 and associated edges are removed for a 10-player game, these differentiations are still maintained: node 4 has the highest degree centrality; node 8 has the highest betweenness centrality; nodes 4 and 8 are the top two highest in closeness centrality; and node 7 is the second highest in eigenvector centrality other than node 4, which remains the highest.

1	2	4	6	13	19			
2	1	4	5	7	17	26	27	28
3	9							
4	1	2	5	6	7	8		
5	2	4	7					
6	1	4	8	21				
7	2	4	5	8				
8	4	6	7	9	25			
9	3	8	10					
10	9	11	12	14	16	22		
11	10	12	15	18				
12	10	11	14	22				
13	10	19						
14	1	12						
15	11	20	23					
16	10							
17	2	25						
18	11	20						
19	1	13	21					
20	15	18	23	24				
21	6	19						
22	10	12						
23	15	20						
24	20							
25	8	17						
26	2							
27	2	28						
28	2	27						

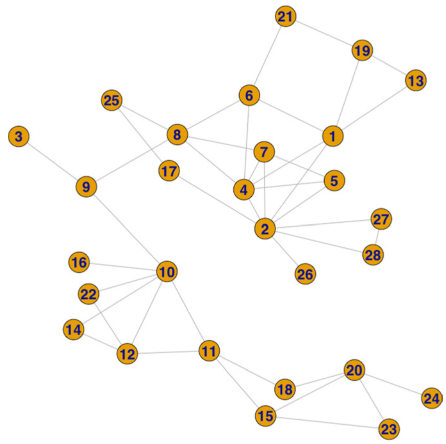

Figure 3: Nodelist and plot of a 28-player network. The plot should be displayed during debriefing.

See Table 3 and Figure 4 for nodes that occupy positions of four different types of centrality in the 28-player network. The manners in which the centrality measures are distinguished from each other will vary slightly by network sizes (e.g., in some networks, a similar set of nodes occupy high closeness and betweenness centrality positions; in other networks, a similar set of nodes occupy high degree and eigenvector centrality positions). Yet, in all possible network sizes ranging from 10 to 28, the structure is configured to show differences when nodes that rank top 2 in each centrality measure are compared. Overall, the larger the network, the more nuanced the discussions could be around the intricate differences between the measures. For instance, in the 28-player network, node 10 ranks among top 4 in all three measures of degree, betweenness, and closeness centralities, despite lacking connections to other well-connected nodes (i.e., low eigenvector centrality). This node is in stark contrast to node 4, which has the same number of direct contacts (i.e., degree centrality) but to other higher degree nodes (i.e., high eigenvector centrality) that are connected with each other (i.e., low betweenness centrality).

Clues (i.e., the 28 pieces of information regarding the five suspects) are included in Appendix 2. Prior to class, the clues should be printed and cut out individually (see Online Appendix: Clue List), and players can use the blank side of the strips of paper their clue(s) are on to block other clues when exchanging information with their classmates. Please note that the clue number corresponds to the node ID (i.e. clue No. 1 is given to the student assigned to node ID 1). There are five pieces of information about Lisa and Jake and six about Brandon, Adam, and Erica. There is one piece of key information about each of the four suspects that is crucial for exonerating them, and four pieces of information that make the correct suspect suspicious. All players should be given the same number of clues to start, receiving two clues in network size 14 or smaller. Note that key pieces of information are distributed in various locations of the network, all within nodes 1 to 10, so the game will work with a minimum of 10 players. The rest of the clues can be distributed to corresponding node

Table 2. Node centrality measures in the 14-player network.

Node ID	Degree centrality	Closeness centrality	Betweenness centrality	Eigenvector centrality
1	4	0.0278	12.5	0.6244
2	4	0.0278	2	0.7589
3	1	0.025	0	0.0472
4	***6***	0.0357	18	***1***
5	3	0.0263	0	0.6335
6	3	0.0323	7	0.5674
7	4	0.0323	7	***0.7605***
8	4	***0.0385***	42.5	0.6325
9	3	0.0357	***44***	0.1876
10	4	0.0294	30.5	0.0664
11	2	0.0222	0	0.0239
12	3	0.0227	0.5	0.0287
13	1	0.0208	0	0.157
14	2	0.0222	0	0.0239

Notes: This table can be shown to students instead of analyzing the network or after analyzing the network as an answer key. Nodes with the highest centrality in each measure are indicated with bold italic. For eigenvector centrality, the two highest centrality nodes are indicated with italic.

numbers. For instance, in a class of 14 students (Figure 1), node ID 1 can be given clues number 1 and 15, node ID 2 can be given clues number 2 and 16, and so on. To account for unexpected student absences, the highest numbers are assigned to positions in the network which are not necessary to be filled. The instructor can easily take out all the highest numbers until the number of nodes matches the number of students in class on the day of the activity.

Materials

Below is a list of materials that are needed for the activity, as presented in the figures, tables and Appendices that are included at the end of the paper. In addition, as an extra set of Online Appendices, we provided Appendices 2, 4, 5, and 9 where page arrangements are configured so that they can be directly printed and cut to be used for the activity:

1. Node ID tags, in an envelope, cup, or bag to be randomly picked by each player (Appendix 4).
2. One paperclip or binder clip for each player to attach their node ID tag to their clothing.
3. Piece(s) of information for each player (Appendix 2).
4. One clue track sheet for each player (Appendix 5).
5. Slideshow (with information desired by the instructor). Suggested information for a 14-player network, in the order to be displayed, includes:
   - Appendix 1: Game setup information.
   - Figure 1: Nodelist (only table).
   - Appendix 3: Rules of the game.
   - Appendix 6: Guess record (alternatively, on black/whiteboard).
   - Appendix 2: Guilty party and clues.
   - Figure 1: Network plot.
   - Figure 2: Plots with centrality measures.
   - Table 2: Node centrality measures.
6. Optional worksheet for each student for analysis and reflection (Appendix 9).

Introducing the game (10–15 minutes)

After students are introduced to the game setup (Appendix 1), they will pick the tag of a random number ('node ID'; Appendix 4) that represents their position in the network. Ask them to attach the tag

Table 3. Node centrality measures in the 28-player network.

Node ID	Degree centrality	Closeness centrality	Betweenness centrality	Eigenvector centrality
1	5	0.0106	48.0833	0.7109
2	***8***	0.011	85.6667	0.9748
3	1	0.0099	0	0.0402
4	6	0.0127	64.8333	***1***
5	3	0.0101	0	0.6345
6	4	0.0118	46.4167	0.5917
7	4	0.0119	35.3333	0.7543
8	5	***0.0137***	190.3333	0.6349
9	3	0.0133	***191***	0.1731
10	6	0.0123	185.5	0.0694
11	4	0.0104	110.5	0.0276
12	4	0.0101	6.5	0.0337
13	2	0.0085	0	0.2267
14	2	0.0094	0	0.024
15	3	0.0086	46	0.0082
16	1	0.0093	0	0.0161
17	2	0.0099	5.25	0.2759
18	2	0.0085	23	0.0075
19	3	0.0085	3.0833	0.2643
20	4	0.0073	27.5	0.0046
21	2	0.0093	5.4167	0.199
22	2	0.0094	0	0.024
23	2	0.0072	0	0.003
24	1	0.0061	0	0.0011
25	2	0.0108	14.5833	0.2118
26	1	0.0085	0	0.2266
27	2	0.0086	0	0.2953
28	2	0.0086	0	0.2953

Notes: This table can be shown to students instead of analyzing the network or after analyzing the network as an answer key. Nodes with the highest centrality in each measure are indicated with bold italic.

to their clothing so that it is visible to other players. Students will each be given a copy of the Who Dunnit Clue Track Sheet (Appendix 5). Next, a nodelist of who can communicate with whom will be shown (Figure 1). Students can be given approximately 2 min to write down the list of node IDs they can communicate with on their Track Sheet, and also use the nodelist data to visually map the network structure on a piece of paper. This process will help them acquire some knowledge of the network structure and make strategies about who they would like to speak with to maximize their access to clues. Yet, as people often do not have a global vision of their network in the real-world, it is suggested that students are not given enough time to completely map the network. Limiting students'

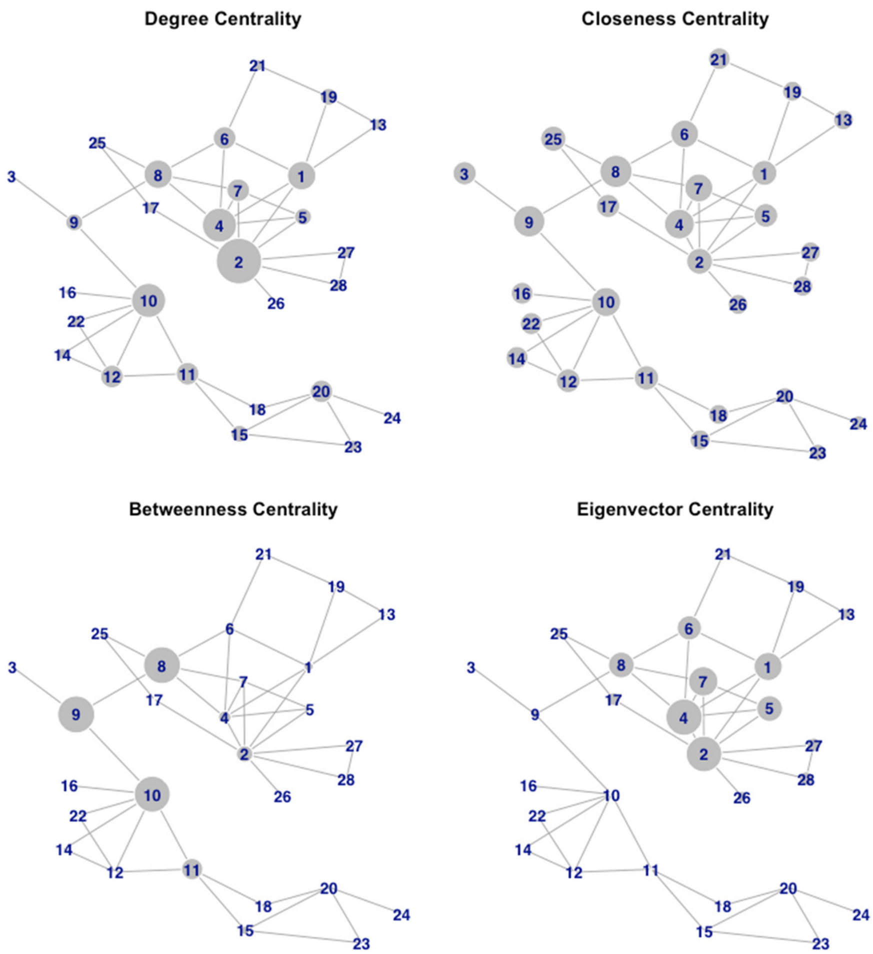

Figure 4: Plots with centrality measures for the 28-player network. Node size is adjusted by each of the four centrality measures. Instructors can show these figures to students after analyzing the network structure.

knowledge of the global network helps to recreate real-world scenarios where they typically have incomplete and differential understandings of existing communication networks. Yet, an adaptation can be made where the instructor elects to provide only a personal nodelist (i.e., who the individual can talk to) to each player, if the goal is to test the extent to which different players actively make efforts to identify the patterns of connections. If this is the case, the instructor can enlarge, print out, and cut apart the nodelist in Figures 1 and 3 and distribute each row to the corresponding player.

Students are then introduced to the rules (Appendix 3) and instructed to use the Track Sheet to record the clues when they receive any (Appendix 5). Next, students will be given a clue, or two clues, to begin with (i.e., a slip of paper with a piece of information on it). Once students become familiar with the rules, the game starts.

Playing the game (25–30 minutes)

Players will exchange information. Players should engage in one-to-one information exchange, which helps to control for possible confounding factors. For example, generosity (Flynn, 2003) and likeability are individual differences that are likely to have effect on how resources are exchanged. By including a stipulation that only one clue is to be exchanged by each person per round, the effects of individual differences unrelated to centrality (e.g., how quickly one writes the clues down, or how outgoing or shy one might be in approaching others) can be minimized, but not completely eliminated. The effects of clues not being accurately or fully communicated are also reduced by this set up. Additionally, this restriction slows the pace at which clues are accumulated by each player, such that a result of almost every player in the network having almost every clue is less likely to be observed.

Students are permitted to ask one additional time for a clue if the clue that they receive is not new to them. They are also not required to have 'new' information to give the person they exchange with in order to get 'new' information from them. However, if a player continues to not have new information to provide, eventually that person will likely no longer be sought as a partner.

The instructor should remind students to continue trying to solve the mystery to encourage information exchange and reduce distraction. In larger network sizes, as the time it takes for players to access a reasonable number of crucial clues will be lengthened, it is suggested that the game involves more rounds. After 15 to 20 min (i.e., approximately 10 rounds for network sizes 20 or smaller; 15 rounds for network sizes 21–28), players return to their seats. Students will then be asked to guess who the suspect is by evaluating all the clues they acquired, and writing the name of the guilty person on their sheet (Appendix 5). The guesses will then be recorded for the class to see. Ask each student to come to the front to write the suspect they guessed and the total number of information pieces they acquired on a board or input them on a slide (Appendix 6).

Debriefing the game (15–40 minutes)

The instructor will reveal the suspect who stole the company secrets, as well as a complete list of clues. The clues can be displayed on two pages of slideshow. The network map is also shown after students have had a chance to review the complete list of clues. The instructor can also ask students about what they think the overall network looks like before showing the network map. Students are asked to reflect on why they were or were not able to guess the suspect by comparing the full set of clues against the clues they acquired. Draw focus toward the clues with two asterisks in Appendix 2, which are the crucial pieces of information (clue numbers 1, 7, 9, 10), in addition to clues with one asterisk (clue numbers 6, 11, 15, and 21), which illustrate that the suspect had both motive and opportunity. Some players may notice that they received a clue, but the information provided was inaccurate or missing some parts. Instructors can then lead the class in discussions of the outcomes, analyses of the network structure, and evaluations of the practicality of the game.

Discussing the outcomes of the game

Typically, after the finding out the guilty suspect, students chatter amongst themselves about who guessed whom, why they guessed (in)correctly, and which clues were (un)helpful. After a minute or two of students talking freely with each other, facilitate a discussion of the outcomes of the game. Refer to the first discussion question and expected responses to address the relationship between network position and information access:

1. How did you feel about your information accessibility? Did your position give you any opportunities or constraints? How did you use the opportunities afforded to you to access information? How did you make efforts to overcome your constraints?

Expected responses:

- People who are high in degree centrality are likely to report that they were sought after as communication partners, sometimes feeling information overload.
- People who are high in betweenness centrality may report that, although they only had a small number of ties to other nodes, their ties connected them to completely different sides of the network and so new information was not hard to come by. Alternatively, they may report that, after a certain point, they started talking to just one of the two subgroups they were bridging, effectively cutting the other subgroup off from additional clues.
- People who are low in all or most measures of centrality are likely to report that, after a certain point, they had difficulty being able to talk to people they wanted to talk to and only had the choice to talk to someone who they did not find useful. They may also report that they had to skip one or more rounds until their designated contacts chose to talk to them again, whereas they observed central nodes staying occupied with clue exchanges and being sought by others.
- Overall, students are likely to voice that people who were higher in one or more measures of centrality were more likely to be able to find a way to overcome any barriers they encountered while people who were lower in most measures of centrality were less likely to able to do anything to change their situation.
- Yet, players who have a fair number of connections may also report feelings of constraint

due to everyone they could talk to already being in contact with each other, therefore limiting the diversity of information they received. Related to this point, as a subgroup gets played out (i.e., no one in the group has new information to add), they will begin to recognize the importance of the bridge for that subgroup who is high in betweenness centrality. However, the person with high betweenness centrality may prefer not to talk to members of the subgroup as they realize that there is no new information to be collected.

- In case of a large class which was split into multiple network groups, students can discuss if their experiences were similar or different across the groups. Individual behaviors (e.g., a broker who keeps information from being exchanged across communities) may have played a role if there are contrasting outcomes. Overall, individual differences may become more pronounced in small networks. If multiple networks are not of the exact same size, the instructor also needs to draw attention to the structural explanations regarding why the nodes have different experiences (e.g., node 11's experience in a 11-player network and in a 12-player network will be different).

Analyzing the network structure

Students can input the network data into the chosen network analysis software, such as igraph package (Csardi and Nepusz, 2006) or Ucinet 6 (Borgatti et al., 2002). Data sets and a script for igraph package in R with annotations are available (Appendix 7; data sets for 28-player network provided in Appendix 8). Appendix 9 can be used to guide students' analyses of the network measures, either as an in-class worksheet or as a homework. Ask students to calculate measures of centrality. Have them record their own centrality (degree, betweenness, closeness, eigenvector) measures, and reflect on the structure of the network and outcome of the game. Figure 2 displays the 14-player network in which node size is proportional to each of the four node centrality measures, and Table 2 provides the measures. The discussion questions and expected responses below can be used to explain the implications of the different centrality measures, with or without students conducting the network analysis:

2. How did the different types of centrality come into play?

- How did the nodes differ in terms of their degree, closeness, betweenness, and eigenvector centralities? Students can assess the centralities by examining the full network map, and (optionally) confirm this information with output from network analysis.
- Did a relationship exist between different types of centrality and the amount of information accessed (i.e., number of clues) or guessing correctly? Everyone had the same number of turns, but some people will not be sought for information exchange as often or will share information redundantly.

Expected responses:

- Subquestion a. can be effectively discussed with a direct facilitation from the instructor. Key areas to highlight for the 14-player network would be to use nodes 4 and 13 to illustrate a large difference in their number of direct connections (i.e., degree centrality). Nodes 4 and 9 can be used to illustrate differences in betweenness centrality with attention being drawn to how node 4 is very low on this measure, and subsequently in its capability to serve as a connection between otherwise unconnected social groups, despite having high degree centrality. Node 8 can be highlighted with regard to its unique position of having shortest paths to all the other nodes, even though it is not the highest in either degree or betweenness centrality measures. Node 7 can be used to illustrate eigenvector centrality because even though the node has the same number of direct ties as many other nodes do, its connection to node 4 boosts its eigenvector centrality.
- The likeliest response to come out of the activity for Subquestion b. is that players who are high in degree centrality are most likely to be able to surface up a large number of clues because they have more alternatives in the event that certain players become associated with not offering valuable clues. As such, they have a higher likelihood of correctly guessing the suspect, especially if they are able to access information from the other side of the network. Another key point is that the players who are high in betweenness centrality are the players with strategic advantage, in terms of being able to determine if anyone has a chance to correctly guess the suspect. When this activity is run

and no relationship is found between centrality and success, this is usually because at least one of the players who was high in betweenness centrality actively constrained the flow of information between subgroups. In addition, if sufficient time is given for the activity, there is a likelihood that a player with high closeness centrality will get access to a large number of clues, as they have a shorter distance to travel to reach other nodes within the network. Players with high eigenvector centrality may report that they were able to get many pieces of information thanks to their tie to the player(s) with high degree centrality, even though they might not have had a large number of total connections.

Instructors may also have students calculate shortest paths between nodes, which helps them examine how many steps it would take for them to reach each crucial clue. After computing network diameter, mean geodesic distance, cliques, and communities discuss how the overall network structure reflected in these measures impacted information flow. When students do not calculate these measures using a software, instructors can instead introduce the concepts of the measures (Table 1) and associated outputs or visualizations in a slideshow. For instance, players in node position 11, 12, and 14 will notice that it takes them six steps to be able to access information possessed by node 13, due to the network diameter being 6. Further, players in a clique (e.g., nodes 2, 4, 5, and 7) may discuss why it took a long time for them to access new information. Lastly, the implications of removing certain nodes or links can be discussed, as suggested in the last section of the R scripts. For instance, removing nodes that occupy different positions in terms of centrality measures and seeing how the structure of the overall network changes (e.g., the extent to which network diameter and mean geodesic distance increase, the extent to which a clique breaks down, whether the network splits into multiple communities) will be helpful.

Evaluating the practicality of the game

Finally, the class can evaluate how the activity resembles real-world phenomena, or any assumptions or rules that were not realistic of what might happen in real life contexts. For instance, rumors might spread in a small group setting (e.g., 'water cooler chat'), not to just one individual at a time. In addition, individuals have differing levels of knowledge about the structure of the network in real life. Subsequently, people will vary in the extent to which they can be strategic about information access. Also, students may find value in applying the take-aways from this activity to workplace environments. In many workplace environments, people who fill secretarial roles are high in centrality, but are often not considered in the same way as a manager who is often lower in the various measures of centrality. The people who typically may have the best grasp of the full picture of the organization may often find themselves in a position where this advantage is underleveraged (Krackhardt and Hanson, 1993) due to the employee's value being considered through a different lens than the social network analysis lens. Refer to the discussion question and expected responses below to explain the comparisons of the game to real-world communication situations:

3. How realistic is this game? What about the activity is similar to or different from communication situations you have been in before?

Expected responses:

- Students may discuss how it shines new light on the role they play in two distinct friend groups that have a minor degree of overlap. They may also think about the implications on their own friendship, especially in a dispute context. How does their position influence their ability to access accurate information or get the 'full picture' from multiple parties?
- Students may also discuss how the concept of centrality changes how they view certain people or positions within an organization and allows them to have a more nuanced understanding of the network overall. For instance, previously they may have considered upper management to be the best people to provide input on the pulse of their company's culture, but now they realize that middle management is typically high in closeness and betweenness centrality and serves as a bridge between upper management and the line workers.
- Another area that may lead to rich discussion is to examine how variations in network structures may lead to different outcomes in problem solving situations. For example, for a project requiring a multidisciplinary approach, different arrangements of relationships (e.g., a microbiologist and computer programmer

could have a direct link or could have someone serving as a bridge between them) would impact information flow. The role of brokers in social networks, the contrasting concepts of structural holes versus network closure, and the corresponding concepts of bridging versus bonding social capital (Burt, 2000) can also be discussed.
- The class can also discuss information flow and diffusion in other social contexts such as the role of opinion leaders on social media platforms and the contagion of viruses through contact networks.
- How information accuracy may deteriorate as information travels through the chain of networks (e.g., the 'grapevine') can be discussed, in relation to examples of the spread of (false) rumors or gossip.

The important point for the instructor to keep in mind during this discussion period is that this time is to be used to further students' understanding of the concepts of centrality and other global level network measures that have been illustrated during the activity by applying them to real life situations in a concrete way. Exactly how that discussion evolves will be dynamic and will depend on the backgrounds that the students bring into the class with them (e.g., work history, social experiences, etc.). The instructor should allow students to guide this time and should only step in if the discussion is moving in a direction that is not conducive toward a better student understanding of the network concepts.

Appraising learning outcomes

This activity provides a productive and enjoyable opportunity to examine the link between network structures and information flow outcomes. The activity has been facilitated by four instructors with knowledge of networks ranging from novice to expert and varying years of teaching experience. Classes with and without prior instruction of network measures and structures have played the game successfully and achieved the learning objectives. The learning outcomes are appraised through instructor observation and direct feedback from students.

Instructors have observed positive learning outcomes after playing the game. Students can easily understand how the overall network configuration impacted information flow. For example, students notice that a player who had many connections but was not able to reach a distant subgroup could not guess the correct suspect. In contrast, a player who occupied a strategic position may have had a higher likelihood of guessing the correct suspect and/or preventing others from being able to guess the correct suspect depending on this player's goals. In some situations, almost everyone may have a wrong guess because they never got a crucial piece of information on the correct suspect or an exonerating piece of information on one of the others. Such situations could happen due to the important clues never leaving the area in which they started. Nodes high in betweenness centrality may have decided to take advantage of their unique position and hold on to key clues to control the flow of information.

Students also leave the activity with a better understanding of what mediates centrality's differential outcomes, such as someone with high degree centrality: (i) getting multiple exposures to the same clue which may reduce the telephone effect where information becomes less likely to be accurate in certain message formats (Brashears and Gladstone, 2016) and the further it travels; and (ii) being valued and sought after for information, which leads to the accrual of more information and increases the player's value in a self-perpetuating cycle. Seeing the network function during the activity via clue exchange and then analyzing the network using a computer program makes the measures of network structure come to life.

Direct student feedback about effective and affective outcomes of the game have been positive. The game was compared to the popular 'telephone game' where information exchanged across a group of people via one-on-one interactions is altered as it moves between people. Many students noted distrust or inaccuracies in information received secondhand from others. Classes have pointed out importance of connections and how a person's social network can provide opportunities or constraints for information access. Classes with more network experience have mentioned bottlenecks in information flow, acknowledged how their success depended on other students' ability to access information and strategize, and described in greater detail how centrality influences how information is exchanged.

Players have affectively evaluated the activity in constructive ways. Students describe the game as fun, thoughtful, educational, interactive, engaging, and informative. Most students report enjoying being able to have enhanced knowledge of network concepts from playing the mystery game. Mixed feedback has been received about whether the activity is representative of real-world organizations and communication patterns. Based on seeing the nodelist before the activity begins, some students quickly realize the opportunities and constraints of their and others' network position and understand how the learning objectives will be met. However, discussing the ways in which the activity is 'unrealistic' and 'predictable' allows classes to dissect assumptions about real life communication contexts and previous and new understandings of network concepts. Regardless of a student's or the classes' ability to solve the mystery, the activity offers a unique way to increase active participation in class and build knowledge. In sum, the mystery game engages students in experiential learning about how network structure influences information flow by solving a cognitive puzzle through dyadic information exchange.

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Appendix 1. Game setup instructions

These are the setup instructions provided to players for the game. Instructors are suggested to put them in a slideshow:

> The boss in your organization has had valuable company secrets stolen from a drawer in his office sometime between when he left the office at 5:00 last night and this morning. You are all in the office now and have seen and heard different things and are trying to figure out who did it. There are five prime suspects and all of you have pieces of critical information that will either draw suspicion to or exonerate one of the suspects. However, because your organization is very hierarchical, you are only allowed to talk with certain people (i.e., the people you directly work with), *as is shown in the next slide*.

Appendix 2. Pieces of information regarding the five suspects

Pieces marked with ** are crucial clues, which suggest that the suspect could not have stolen the secret. Pieces marked with * are an additional set of informative clues, but are not crucial, which suggest the suspect had motive and opportunity. The * and ** marks should be removed from the clues that are given to students for the purpose of executing the activity, but may be displayed in the list that is shown during the debriefing part of the activity. Each piece of information should be cut out separately (see Online Appendix) and distributed to players according to their node ID. Instructors should put the clues distributed in class in a slideshow for after the suspect has been revealed:

Clue List

1. You have been with **Brandon** every moment since the boss left the office yesterday and he rode into work with you today. There is no way he could have snuck out and come back without your knowing.**
2. **Adam** has previously stolen an idea you sent to him for suggestions and passed it off as his own to the boss. He kind of fits the profile.
3. **Lisa** is always the last to leave and the first to arrive at the office. She could have easily taken the documents when no one was there.
4. **Brandon** and **Erica** grew up in the same neighborhood and went to high school together.
5. **Jake** is acting a little off and has been distracted lately. There seems to be some sort of problem bugging him, but he will not tell you anything about it.
6. You remember that **Erica** told you a few months ago that she had started dating someone from a company that is in competition with yours.*
7. **Jake** is a systems administrator. He was given an extensive background check because he works with company secrets and infrastructure every day. With administrator privileges to every single company folder, he already has electronic access to company secrets.**
8. **Brandon** has expressed to you a strong desire to leave the company but has been having trouble finding another company that wants to hire him.
9. You know that **Lisa** is high enough in the company that she has her own copy of the company secrets in question. She would not have needed to steal them from the boss's office to access them.**
10. **Adam** asked you to cover for him yesterday morning and went home sick. You know that he has not been back in the building since then.**
11. **Erica** came to you for advice a few days ago. She told you that she and her boyfriend were not quite working out and that he wanted her to do something for him that she was not ready to do yet.*
12. You had lunch with **Adam** once a few weeks ago and remember how much respect he has for the company and his boss specifically because they were so understanding during his messy divorce.
13. **Lisa** told you in confidence a couple of days ago that the company is going through rough times right now and that it is possible that they might be downsizing.
14. **Jake** is a long-time friend of the boss. They served in Afghanistan together and, when they got back stateside, the boss specifically sought him out to offer him a job with his company.
15. You saw **Erica** enter the boss's office after she left yesterday and emerge with a manila folder. As she is his secretary, it would not necessarily mean that she was stealing the folder.*
16. You noticed that **Adam** was eyeing the boss's office a lot yesterday.
17. **Brandon** told you this morning before the theft was known that he has a new job lined up and will be leaving the company.
18. **Adam** has been expressing a strong desire to move up in the company as he has been there a long time but is still working an entry-level position.

19. **Adam** told you a few days ago that he has a performance review coming up with the boss, and hopes that it means a promotion is on the way for him.
20. You remember that, shortly after **Brandon** started in the company, the HR person let slip that he had been fired from his last job for corporate espionage.
21. **Erica** does the best she can and is very eager to please the people that are important to her. She finds it really hard to say no to those people.*
22. **Lisa** is well-liked throughout the office. She has always tried to help anyone who has ever asked her for help and you are not sure where you would be without her.
23. You overheard **Lisa** having an animated conversation with the boss yesterday in his office. They seemed to be angry.
24. **Brandon** has been submitting sloppy work to you lately and you know he can do better. You are wondering if he might have been putting his brainpower into other tasks.
25. **Jake** strongly believes in the company's mission and routinely will vent to you about how other companies that do the same thing as yours are just trying to screw over other people.
26. **Erica** is the boss's daughter and you suspect that this may be the primary reason that she is employed at all.
27. **Jake** and **Lisa** went out for dinner together the other day and seem to be getting along well.
28. **Lisa** has never missed a day of work or been late.

Appendix 3. Rules of the game

These are the rules of the game that should be provided to players before they start. Instructors can put them in a slideshow:

- The suspects are Adam, Brandon, Erica, Jake, and Lisa. The suspects are not in the room. Nobody here is guilty.
- Write down any clues you receive on the Clue Track Sheet, including those you started with. Make sure to note the person they came from (i.e., the person's node ID) and the clue number.
- In each round, you can give one piece of information to one other person and receive one piece of information from the same person you have given one piece of information to (that is, two clues will be exchanged per round, but it must occur with the same person). Talk can only occur in dyads (pairs). Make sure your information exchange is only heard by one person at a time and not overheard by anyone else.
- The clue you give can be a clue you received from the instructor, or a clue from someone else.
- Each round will last 1 to 1.5 min. The instructor will signal when it is time to find a new person to exchange information with. If no one in your nodelist is available to talk, you must sit out that round and wait for the next round to begin.
- The clues can be conveyed either verbally, or by showing your Who Dunnit Clue Track Sheet to the other person. Be sure to cover up the other clues you have recorded on this sheet. If a person gives you information you already have, you may ask them to give you a different clue only once during each round. You do not have to have 'new' information to give the person you exchange with in order to get 'new' information from them.

Appendix 4. 'Node ID' tags for individuals in 14-player network

Slips of paper ranging from 1 to the total number of people who will be playing the game in the class should be brought to class (see Online Appendix). The tags, resembling those below, represent players' node ID numbers and should be attached to players' clothing.

1	2	3	4
5	6	7	8
9	10	11	12
13	14		
15	16	17	18
19	20	21	22
23	24	25	26
27	28		

Appendix 5. Who Dunnit Clue Track Sheet

The information below should be printed on a handout and distributed to students when introducing the game (see Online Appendix). Adjust the number of rows so that it corresponds to the number of rounds.

This sheet is designed to assist you as you search for clues to determine which suspect stole company secrets. Write down the clue(s) you initially received in the first row(s). Then, write down one clue per round, specifying who (node ID) gave which clue (clue #). **Place an asterisk next to the spot where you believe you have enough information to determine who the guilty suspect is and specify the name of who you suspect.** Continue gathering clues to determine if your answer changes. *Remember: suspects are Adam, Brandon, Erica, Jake, and Lisa.*

Your Name: ___________________ Your Node #: _______________

The people I can communicate with are (node IDs): __________________

Round	Node ID	Clue #	Suspect the clue pertains to and what the clue is:	Place an asterisk
0				
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

The total number of clues I acquired is: __________________
The person I suspect of stealing company secrets is: __________________

Appendix 6. Guess record

This table should be used in a slide or on the board when recording information about players' guesses. The total number of information pieces should include the clues students had to start.

Node ID	Suspect guessed	Total number of information pieces
1		
2		
…	…	…

Appendix 7. Data sets for a 14-player network and R script

The instructor can decide whether to have students use this information on individual computers or as a class with the instructor demonstrating on their computer.

Edgelist: Save the following two columns of information as 'rumor_edgelist14.csv,' which will then be imported into R.

1	2
1	4
1	6
1	13
2	4
2	5
2	7
3	9
4	5
4	6
4	7

4	8
5	7
6	8
7	8
8	9
9	10
10	11
10	12
10	14
11	12
12	14

Attribute: Save the following two columns of information as 'rumor_attribute14.csv,' which will then be imported into R.

id	important
1	yes
2	no
3	no
4	no
5	no
6	no
7	yes
8	no
9	yes
10	yes
11	no
12	no
13	no
14	no

R script: Below is the R script for analysis of the network structure, using igraph package.

```
# Set working directory at: [Session]-[Set Working Directory]

# Install and load package
install.packages("igraph")
library(igraph)

# Import data
rumor <- read.csv("rumor_edgelist14.csv", header=F)
# Create an igraph object
rumornet <- graph.data.frame(rumor, directed=F)
# Plot network
plot(rumornet)

# Calculate degree centrality
deg <- degree(rumornet)
# Plot network, using degree centrality to adjust node size
plot(rumornet, vertex.size=deg*5)
# Calculate closeness centrality
close <- closeness(rumornet)
# Plot network, using closeness centrality to adjust node size
plot(rumornet, vertex.size=close*500)
# Calculate betweenness centrality
between <- betweenness(rumornet, directed=F)
# Plot network, using betweenness centrality to adjust node size
plot(rumornet, vertex.size=between*0.6)
# Calculate eigenvector centrality
eigen <- eigen_centrality(rumornet, directed=F)
# Plot network, using eigenvector centrality to adjust node size
plot(rumornet, vertex.size=log(eigen$vector+1)*30)

# Create a csv file with results
write.csv(cbind(deg, close, between, eigen$vector),
 file="rumor_centrality14.csv")

# Import vertex attribute data, indicating whether each node possessed important
 clue or not
important <- read.csv("rumor_attribute14.csv", header=T)
# Create an igraph object with node attributes
rumornet2 <- graph.data.frame(d=rumor, vertices=important, directed=F)
# Plot network, using node attribute to adjust node colors
plot(rumornet2, vertex.color=ifelse((V(rumornet2)$important=="yes"), "red",
 "grey"))

# Calculate the length of shortest paths between nodes
distances(rumornet)
# Calculate longest geodesic distance of the graph
diameter(rumornet, directed=F)
# Calculate mean distance
mean_distance(rumornet, directed=F)
# Find cliques of minimum size 3
cliques(rumornet, min=3)
# Display and plot largest cliques
largest_cliques(rumornet)
vcol <- rep("grey80", vcount(rumornet))
vcol[unlist(largest_cliques(rumornet))] <- "gold"
plot(rumornet, vertex.color=vcol)
# Detect and plot communities
rumorcluster <- cluster_edge_betweenness(rumornet)
plot(rumorcluster, rumornet)

# Remove an edge
rumornet3 <- rumornet - edge("8|9")
plot(rumornet3)

# Remove a node
rumornet4 <- rumornet - c("9")
plot(rumornet4)
```

Appendix 8. Data sets for a 28-player network

Edgelist:

1	2
1	4
1	6
1	13
1	19
2	4
2	5
2	7
2	17
2	26
2	27
2	28
3	9
4	5
4	6
4	7
4	8
5	7
6	8
6	21
7	8
8	9
8	25
9	10
10	11
10	12
10	14
10	16
10	22
11	12
11	15
11	18
12	14
12	22
13	19
15	20
15	23
17	25
18	20
19	21
20	23
20	24
27	28

Attribute:

id	important
1	yes
2	no
3	no
4	no
5	no
6	no
7	yes
8	no
9	yes
10	yes
11	no
12	no
13	no
14	no
15	no
16	no
17	no
18	no
19	no
20	no
21	no
22	no
23	no
24	no
25	no
26	no
27	no
28	no

Appendix 9. Worksheet for analysis and reflection

The worksheet below can be used to guide students' network analysis and reflection on the game (see Online Appendix).

Name: ___________________________ Date: ___________

1. Your node #_____
2. How many pieces of clues did you acquire? _____
3. What is your:
   - Degree centrality? _____
   - Closeness centrality? _____
   - Betweenness centrality? _____
   - Eigenvector centrality? _____
   - What do you notice about your centrality of these four types, compared to those of other nodes? Were you high or low in any specific centrality measures?
4. How many of the important clues were you able to access? _____
   - Which ones did you access? What was your distance to those clue(s)?
   - Which ones were you not able to access? What was your distance to those clue(s)?
   - How did you feel about your information accessibility? Did your position give you any constraints?
5. What is the diameter and mean distance of the network? _____ _____
6. How many cliques exist in the network? _____
7. How many communities exist, based on edge betweenness? _____
8. Which real life situations you have been in before does the exercise remind you of?