Tested Studies for Laboratory Teaching
Proceedings of the Association for Biology Laboratory Education
Volume 39, Article 26, 2018

Using Social Network Analysis to Better Understand Student Connections and Learning

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In laboratories and other active learning environments, learning is embedded in a social context: students learn with and from the students with whom they interact. According to social capital theory, students with more social connections to other students have greater access to the information and skills of their peers, which promotes learning and academic success. Instructors who can monitor social connections among their students can better understand how information flows through a classroom and whether all students have access to that flow of information. However, identifying and quantifying student social connections can be difficult without the proper tools. Social Network Analysis is a set of techniques and statistical methods that quantify and visualize connections between students. In this workshop, participants will learn how to collect and interpret social network data. Participants will learn the basics of social network theory as well as methods for surveying students to collect meaningful social network data. Additionally, participants will work in small groups with sample classroom networks to practice interpreting network graphs and statistics. Interested participants will be provided with resources to help them learn how to use the necessary applications to perform the analyses on their own.

Keywords: social network analysis, social capital, diffusion of innovations, student learning

Introduction

In a biology laboratory, learning takes place in a social context. Students may learn socially by watching instructor demonstrations, observing their peers, receiving feedback from instructors, and collaborative problem solving with peers. If we are to study how students learn in a laboratory setting in order to improve pedagogical methodology, we must understand this social context. Social network analysis is a quantitative tool that can be used to provide the social context to inform pedagogical research (Carolan, 2014).

Social networks are graphical representations of individual entities (actors) and the social connections between them (ties; Figure 1). Actors are represented in a network graph as vertices and ties are represented as edges between vertices. Color, size, and shape of vertices are often used to represent actor attributes (e.g., demographic attributes, academic performance, etc.). Line thickness, color, or dashing of edges may be used to represent tie attributes (e.g., strength of relationship, positive or negative relationships). Edges imply a reciprocal or mutual relationship between actors, while arrows can be used to show directionality of relationship. Networks that represent ties that are not necessarily reciprocal (e.g., advice seeking) with single or double-headed arrows are referred to as directed, while those that represent obligately mutual ties (e.g., studying together) with lines are referred to as undirected.

The position of individuals within the network structure, the patterns of ties between dyads and triads of actors within the network, and the structural patterns of parts or the whole network can all be quantified in numerous ways. Social network analysis consists of both the methods for quantifying network structure and actor position, and a set of statistical models that allow rigorous comparisons of network properties and relationships between individual attributes while controlling for the non-independence of actors within a network (Carolan, 2014; Grunspan *et al.*, 2014; Luke, 2015; Prell, 2012; Wasserman & Faust, 1994).

Theoretical Framework

Social network analysis is both the quantitative and statistical methodology of studying interdependent actors and a theoretical framework that gives meaning to and justifies the use of those methods. According to Wasserman & Faust (1994), social network theory is founded on four main assertions. Individuals and their

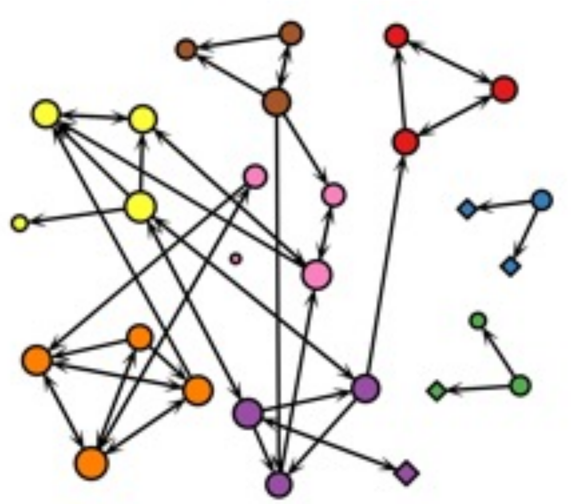

Figure 1. Example directed network graph of students in an introductory biology laboratory. Colors indicate lab group membership of actors, shapes indicate actor attributes, and size of actor vertex indicates degree centrality.

actions are interdependent, resources may be exchanged through relational ties, the structure of the network can provide or constrain opportunities for individual action, and network structure represents enduring patterns of relations among actors. Taken together, networks are viewed as entities emergent from the patterns of interaction among a set of actors that simultaneously affect actor behavior and are shaped by the behavior of actors.

Knoke & Yang (2008) recognize three important assumptions of social network theory. Relational ties are assumed to be critically important when attempting to explain the behaviors and attitudes of actors in a network. Position in a network affects the behaviors and attitudes of actors through the set of direct and indirect ties that connect an actor to others. Ties within and between networks are dynamic. The first two assumptions are necessary in order to interpret the quantitative descriptions of social network position and structure in terms of actor behavior and attitude, and vice versa. The third assumption might, at first, seem contradictory to Wasserman & Faust's (1994) assertion that networks represent enduring patterns of ties. However, this contradiction is resolved by analogy when we consider that a river represents an enduring pattern of water flow that is at the same time dynamic and will change course over time. Relational ties that are used to build a social network must be substantial enough to the actors involved to allow exchange of resources or transmission of influence, but might change over time.

Although social network analysis is situated in its own theory, for many research questions it is useful to view social network analyses through another theoretical lens (Carolan, 2014; Prell, 2012). Two such additional theoretical frameworks that allow for richer analyses in a classroom setting are social capital theory and diffusion of innovations theory. Social capital theory asserts that social connections (ties) are a kind of currency in the sense that they imply direct and indirect access to the resources (material and relational) of others (Prell, 2012). Diffusion of innovations theory asserts that innovations (i.e., new knowledge, learning) spreads from actor to actor along pathways of relational ties (Prell, 2012). Both theories have been applied to educational research using social network analyses.

Social Capital Theory

According to social capital theory, relational ties can be interpreted as both a currency, in terms of the access to other actors' material resources and the influence over other actors' behaviors that ties represent, and the means for the exchange of that currency (Prell, 2012). For our purposes in educational research, social capital could represent an understanding of biological concepts or competency in laboratory techniques and the ability to transfer that knowledge and skill to peers. Instructors might be able to increase overall classroom performance by tapping the influence of students with higher social capital by first ensuring they understand concepts and procedures, then asking them to work with students with less social capital.

Based on social capital theory, there are two primary and competing ways by which actors access social capital. First, social capital should be most readily exchanged in cliques, subsets of networks in which actors are more connected to each other than they are to actors outside the clique (Prell, 2012). Individuals situated within cliques, with a greater density of ties, would have greater access to knowledge and skill and should perform better than those with fewer connections. Second, since social capital can only flow through ties in a network, actors that bridge cliques have greater access to a diversity of social capital pools (Prell, 2012). Individuals that bridge two or more cliques should perform better than those with similar numbers of ties due to the structural arrangement of their ties rather than the density.

Research suggests that both structural positions within a network can result in increased academic performance, but only within certain social contexts. Maroulis & Gomez (2008) were interested in whether a student's position in their local social network influenced their academic performance (GPA). They collected relational data from high school students that were part of an experimental "school-within-a-school" reform effort to increase student sense of community. They found an interaction between the effects of local network density and peer social capital on individual student academic performance. In other words, being in a clique (high local network density) increased an actor's GPA, if the other members of the clique were also high performers (high social capital). Conversely, bridging the gap between cliques (low local network density) increased an actor's GPA, if the members of those cliques were low performers (low social capital). Maroulis & Gomez's (2008) research suggests that a student's academic performance depends on both who the student knows and their position in the network.

Diffusion of Innovations Theory

Diffusion of innovations theory describes how innovations are transmitted from actor to actor across networks through relational ties (Prell, 2012). In an education research context, innovations could represent any gain in biological content or conceptual knowledge acquired by students. Prestigious students, those with a great deal of influence based on number of connections or position within the network, could help instructors in disseminating knowledge to peers.

Decentralized network structure is typically preferred to centralized network structure to facilitate the rapid flow of innovations (Prell, 2012). A centralized network is one in which ties are unequally distributed among actors such that a small number of core actors possess many ties and a large number of peripheral actors possess few ties. The peripheral actors are primary connected to each other indirectly through the core actors. The core actors, therefore, exert influence over more of the network and restrict the flow of innovations through the network (Prell 2012). A decentralized network is one in which ties are more equally distributed and there are many pathways for the flow of innovations.

Daly & Finnigan (2010) used a mixed method design to study the flow of information on educational reform (the innovations) through a network of school administrators. They found that over time the network became more centralized because core district administrators tended to strengthen or maintain ties while peripheral site administrators tended to weaken or lose ties. In interviews with the administrators, Daly & Finnigan (2010) found that peripheral administrators felt that core administrators monopolized conversations on education reform and limited creativity. Thus, the interview data support the diffusion of innovation theory prediction that core members of a centralized network exert more influence and limit innovation. The combination of interview and social network data in Daly & Finnigan's (2010) study was critical to demonstrate the connection between network structure and the behaviors and attitudes of the actors.

Mini Workshop

In this mini workshop we discussed types of network-level and actor-level metrics that can be used to describe network structure and actor position and influence. We then discussed how to match research questions to data collection and ensure validity and repeatability of the data (Carolan, 2014; Grunspan *et al.*, 2014). Participants worked in groups to draw conclusions from hypothetical case studies.

At the end of the workshop, each participant answered two questions: "Who did you know prior to coming to this workshop?" and "Who helped you interpret the social network analyses during the case study exercise?" Responses to these questions were used to create a social network for the mini-workshop and, as an informal demonstration of the utility of social network analysis, to determine whether influential members of the mini-workshop were most helpful to others in completing the case study exercises.

Although the research question was impromptu in nature and not rigorously formalized, we can predict from social capital theory that influential ABLE members (those with many relational ties prior to attending this mini-workshop) have the greatest access to social capital, and might be able to draw on that social capital to aid their peers during a group exercise. Alternatively, the relevant social capital for evaluating social network case studies might not be professional connections, but rather experience with graphical analysis or a particular way of analytical problem solving (which in this informal situation we did not measure). Despite experimental limitations, we can test the hypothesis that ABLE connections (degree centrality of the social network) is correlated with helpfulness (indegree centrality of the help network).

Methods

Responses to survey questions were collected from 9 of 14 mini-workshop participants. The author used responses to construct two networks: an undirected network representing the prior social connections among ABLE members (social network; Figure 2) and a directed network representing helpful interactions among workshop participants (helpful network; Figure 3). Directed ties reported for the social network were assumed to be reciprocal and were symmetrized to produce an undirected network. Therefore, missing data is less likely to affect network structure and analyses of the undirected social network than the directed helpful network.

The author did not calculate the typical network descriptive statistics (e.g., density, diameter, etc.) due to the limited nature of the analysis.

To determine if helpful interactions were dependent on ABLE social connections, the author fit two exponential random graph models (ERGMs) to the helpful network data: a null model and a model with social network ties. ERGM analysis is analogous to generalized linear modeling of statistical relationships between independent and dependent variables, accounting for the non-independence of network data (Luke, 2015). The dependent variable of ERGM analysis is always the probability of a tie between two actors.

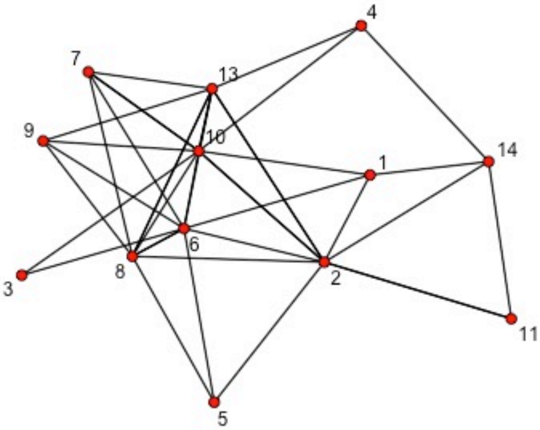

Figure 2. Undirected social network of mini-workshop participants.

Next, the author used the null ERGM to simulate 10,000 helpful networks and calculate a null distribution of correlation coefficients between indegree centralities of the simulated helpful networks and the degree centralities of the social network. To determine if there was a correlation between actor helpfulness and social connection, the author compared the correlation coefficient of the observed correlation between indegree centralities of the helpful network to the degree centralities of the social network to the expected distribution of simulated correlation coefficients. Although probably unnecessary for this particular limited analysis, simulation-based, permutation tests are often preferred over traditional statistical tests due to the non-independence of many network variables (Luke, 2015).

The author used the statnet package in R to construct networks and calculate centralities (Butts, 2008). The author used the ergm package in R to model and simulate networks (Hunter *et al.*, 2008). All other calculations, simulations and analyses were conducted in the R environment (R Core Team, 2016).

Results

AIC comparisons of null and alternative ERGMs show that a model including social ties, does not improve the fit of the null model (ΔAIC = 1.99). A permutation test revealed no significant correlation between helpfulness indegree centrality and social degree centrality (p = 0.089).

Conclusions

The data were collected in an informal manner without a rigorous *a priori* theoretical framework for

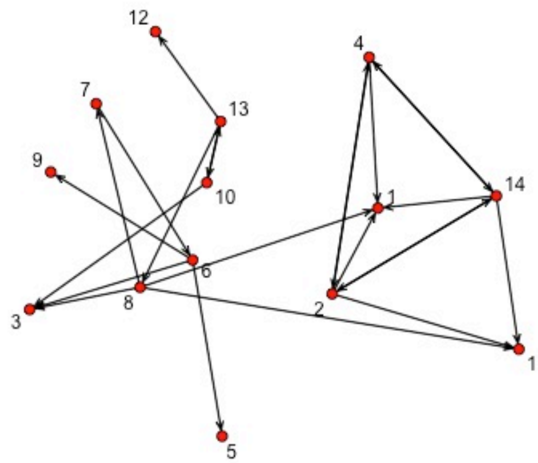

Figure 3. Directed helpfulness network of mini-workshop participants. Arrows point from the actor who was helped to the actor who was helpful.

interpretation of results. Data collection and statistical analysis was intended as a means of providing a simplistic example of social network analysis in the context of educational research, rather than a means of producing generalizable knowledge or testing theory.

Despite the obvious limitations, we can draw some simple conclusions without any intent at making generalizations. Including social ties did not improve ERGM fit for predicting the probability of helpful ties. This result suggests that mini-workshop attendees were not more likely to nominate well-known or influential ABLE members as being helpful for understanding social network case studies. There was a non-significant correlation between indegree centrality in the help network and degree centrality in the social network. This suggests that the number of contacts made prior to attending the mini-workshop did not having any bearing on how many peers nominated a participant as helpful.

Taken together, it appears that the social capital associated with being well connected in the ABLE community was not particularly relevant to helping others understand the content of this mini-workshop. Limitations notwithstanding, this does not necessarily rule out some kind social capital being important to learning new material at a mini-workshop. If repeated, it would be important to assess the level of prior experience with social network analysis and graphical skills, as these are likely important currencies of social capital.

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Acknowledgments

I would like to thank the participants of this mini-workshop for contributing their relational data to this manuscript as well as valuable feedback about the scope of this mini-workshop. I hope to be invited to present similar content at ABLE 2018 as a major workshop.

About the Authors

Dylan Dittrich-Reed has been an assistant professor at Clemson University since 2013, where he teaches a large introductory biology course for majors and a small introductory biology course for honors students. His research interests include how social context affects student learning and how students form and change groups for collaborative assignments.

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Citing This Article

Dittrich-Reed DR. 2018. Using Social Network Analysis to Better Understand Student Connections and Learning. Article 26 In: McMahon K, editor. Tested studies for laboratory teaching. Volume 39. Proceedings of the 39th Conference of the Association for Biology Laboratory Education (ABLE). **http://www.ableweb.org/volumes/vol-39/?art=26**