Social networks among communities of undergraduate mathematics instructors at PhD-granting institutions

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Calculus is typically the first undergraduate mathematics course for science, technology, engineering, and mathematics (STEM) majors in the United States. Internationally as well as domestically, first year mathematics courses are credited with preventing students from continuing along STEM paths. A recent study of the features that characterize exemplary calculus programs from five PhD-granting institutions highlighted several common characteristics, one of which was the existence of a well-established system for coordinating Calculus I. This coordination of courses and instructors seems to engender a community of practice. This study aims to expand on this finding by leveraging social network theory to map the underlying structure of the social ties between instructors of lower-division undergraduate mathematics courses, to compare informal and formal organizational structures in each case, and to compare the communities across the five selected institutions. Here I report on the results from one of the five selected institutions.

Key words: Social Network Analysis, Communities of Practice, Calculus, Social Capital

Calculus is typically the first undergraduate mathematics course for science, technology, engineering, and mathematics (STEM) majors in the United States. Internationally as well as domestically, first year mathematics courses are credited with preventing students from continuing along STEM paths (Seymour & Hewitt, 1997) a fact which has led to increased research and attention by professional societies. Complicating an understanding of the situation in Calculus I is the fact that most PhD-granting universities offer many sections of calculus each semester. These sections tend to be taught by a wide range of instructors including visiting faculty, postdocs, adjunct lecturers, graduate students, as well as ladder rank faculty. The tremendous variation in who is teaching calculus makes for a situation where different students taking calculus the same semester at the same university may not be taught the same core material. This is particularly problematic for calculus since it is a fundamental prerequisite for subsequent STEM courses. Moreover, the quality of instruction may vary considerably, which can affect what students actually learn, even if the same content is being covered and assessed.

As part of a large national study of Calculus I programs, the Characteristics of Successful Calculus Programs (CSPCC) conducted case studies at five PhD-granting institutions selected for having a relatively more successful Calculus I program. At each of the five selected institutions, there was a central individual, the calculus Coordinator, who organized and led the enactment of the uniform aspects of calculus instruction. While the background of the Coordinator varied, what was common among the five Coordinators was their disposition toward their role. Each of the five Coordinators viewed themselves as a resource and facilitator rather than as the owner of the calculus program or the authority on how to teach. This finding suggests that further research needs to examine the extent to which faculty involved in teaching the calculus sequence communicate and interact with each other. Accordingly, the study reported is a first step in addressing the following goals:

1. To map and characterize the social network (informal structure) that exists among the actors within each community.
2. To compare the informal structure derived from the social network with the formal structure of the departmental hierarchy.
3. To compare and contrast the social networks across the five selected institutions.

The first goal aims to fill a gap in the research literature. Social network analysis admits quantitative measures to the description of a community of practitioners in a way that has not been seen at the undergraduate level, although it has been used extensively with K-12 communities (Daly, 2010). Such analyses will enable us to say more about *how* these communities support the successful calculus programs at the selected institutions. The second goal, comparing formal and informal structures, will be used to determine whether the instructors actually interact in the ways implied by the case studies. Specifically, I wish to discover whether the Coordinators are truly central actors who function as hubs for the dissemination of social capital, and if they are other brokers in the community. The third goal, which is beyond the scope of the current analysis, aims to describe differences between the communities at each of the five selected institutions.

Theoretical Perspective

This research is grounded in two complementary perspectives, the first of which draws on the *community of practice* perspective put forth by Wenger and colleagues (Lave & Wenger, 1991; Wenger, 2000). A community of practice is a collective construct in which the joint enterprise of achieving particular goals evolves and is sustained within the social connections of that particular group. In achieving a particular joint enterprise, such as the teaching and learning of calculus, a community of practice point of view highlights the role of brokers and boundary objects. A broker is someone who has membership status in more than one community and is in a position to infuse some element of one practice into another. The act of doing so is referred to as brokering (Wenger, 2000).

The community of practice perspective is well aligned with the perspective of *social capital theory*. This theory, which places value on social connections, has been leveraged in a wide variety of contexts, informing studies of "families, youth behavior problems, schooling and education, public health, community life, democracy and governance, economic development, and general problems of collective action" (Adler & Kwon, 2002, p. 17). The concept of social capital has also gained traction in organization studies, and it is in this area that our contribution falls. As social capital has been used in a wide variety of concepts, it has been conceptualized of in a wide variety of ways. However, common to all definitions is the notion that social capital consists of "resources embedded in social relations and social structure, which can be mobilized when an actor wishes to increase the likelihood of success in purposive actions" (Lin, 2002, p. 24). In a sense, social capital refers to the human capital that an actor can access through his or her social ties. In some cases, central actors, referred to as *hubs*, facilitate the flow of capital between otherwise unconnected actors. In these cases the hub functions in a way similar to that of a broker. I believe that the overlap in characteristics will help to identify potential brokers in the observed networks.

Methods

Following up from the CSPCC study, data collection for this study has commenced at the five selected institutions identified as having more successful Calculus I programs, with all data collection to be completed this spring. Data from one institution has been collected at the level required for network analysis (Daly, 2010). Social network surveys are being distributed to individuals at the selected institutions who have recently taught lower-division undergraduate courses, including Pre-Calculus, Calculus I, II, III, Linear Algebra, and Differential Equations. Network questions are used to ascertain the ties that exist between members of the community of calculus instructors, as well as the strength of those ties, and a variety of Likert scale and demographic questions are being used to characterize the actors between whom ties do or do not exist (Coburn & Russell, 2008).

Since this study aims to map the social network of a community of practice, I embarked on a *whole network analysis*. This type of analysis is performed by selecting a set of actors and measuring the ties between them. The standard approach for whole network analysis is to collect information regarding a few types of ties between many pairs of nodes (Daly, 2010). This study encompasses two types of group level analyses, those concerning *network structuring* and *group social capital*. That is, I am looking both to determine the structure of these communities and how they compare, as well as to see how social capital flows through each network (Daly, 2010).

In this case, the actors selected are instructors of lower-division undergraduate mathematics courses, gleaned from course catalogs, as well as all members of the department who have administrative roles relating to undergraduate students and courses. The CSPCC results hinted that a community of practice might exist within this larger community. The network ties being measured in this survey relate to advice, influence, and friendship. The survey also includes Likert scales designed to characterize the individuals, subgroups, and the larger community in terms of trust, innovative climate, professional learning community collaboration and involvement, as well as mathematical affect and beliefs. The general design of the study has been used widely, with success, for this type of analysis, though not among this type of community (Adler & Kwon, 2002; Coburn & Russell, 2008; Daly, 2010; Tichy, Tushman, & Fombrun, 1979). The questions themselves have also been adapted from the K-12 literature, reworded to reflect the difference in the institution type (Antonakis, Avolio, & Sivasubramaniam, 2003; Daly, Der-Martirosian, Moolenaar, & Liou, 2014; Daly, Moolenaar, Bolivar, & Burke, 2010; Daly, 2010; Moolenaar, 2012).

Preliminary Results

Based on the case study analyses from the CSPCC study, which identified coordination as a key feature across the five selected institutions, Rasmussen and Ellis (2014) argued that an important part of the story is the role that calculus Coordinator, among others, plays in creating and sustaining a community of practice around the joint enterprise of teaching and learning of calculus. In other words, the conjecture is that calculus is *not* seen as being under the purview of one person, such as the Coordinator, but rather that at these institutions, calculus is viewed as community property.

To explore this conjecture, I have begun to analyze the social networks that exist within the posited communities of practice at one of the selected institutions, using *social network analysis* methodology. The data collection for this project is ongoing, in part because high response rates are required for conclusive social network analysis (Daly, 2010). Toward research goal 1, as data is collected each participant becomes a node on a graph, and each connection becomes an edge. The frequency of communication, as well as the variety of connections between two actors, are used to weight these edges. Graph theoretic approaches can then be leveraged to analyze network density and centrality, in order to characterize the community as a whole. It is also possible to identify central actors in the network by locating hubs, which will allow the identification of those members of the community who act ask brokers. Of further interest are any existent subgroups within the community, located by identifying cliques in the graph. At the first institution, we already see the emergence of subgroups characterized by experience level.

Data collection at the first institution to be investigated has begun to yield hints for research goal 2. It appears that the hypotheses from Phases I and II regarding Coordinators are being supported. Preliminary analysis reveals that the official calculus Coordinator is in fact a central actor in the network, a main conduit for social capital, and therefore appears to be a hub – matching his formal job description.

Questions for Audience

1. To what extent might the general culture of mathematics departments foster or inhibit the existence of social networks revolving around issues of teaching and learning?
2. This study analyzes the existence and structure of social networks, but does not provide insight into *how* existing social networks came to be. What follow-up studies are needed to address this goal?
3. In what ways do these social networks provide informal professional development opportunities for mathematicians?

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