Winter 2019

The Push and Pull of Social Gravity: How Peer Relationships Form Around an Undergraduate Science Lecture

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Disciplines

Curriculum and Instruction | Curriculum and Social Inquiry | Educational Assessment, Evaluation, and Research | Educational Psychology | Social and Philosophical Foundations of Education

Comments

This article is published as Brown, M. The Push and Pull of Social Gravity: How Peer Relationships Form Around an Undergraduate Science Lecture., *Review of Higher Education,* Winter 2019, 43(2); 603-632. Doi: 10.1353/rhe.2019.0112. Posted with permission.

The Push and Pull of Social Gravity:

How peer relationships form around an undergraduate science lecture

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Abstract

Undergraduate students benefit from academic-centered peer interactions, especially in large lecture courses. However, little is known about how students come together and form relationships around a course. I conduct a mixed-methods study of students' peer networks to explore how students choose peers for academic-focused interactions. The network of connections among students in a large undergraduate physics class decreases over time, leaving students looking for study partners later in the course at a disadvantage. While community structure might limit relationship formation late in the semester, students who connected across campus capitalized on network internalities that facilitated opportunities for collaboration.

A small number of social connections, perhaps as few as two or three, can positively impact a student's campus engagement (Chamblis & Takacs, 2014) and performance in a course (Rizzuto, LeDoux, & Hatala, 2009). The importance of interaction among peers for learning is especially apparent in math and science where work is often completed in pairs or small groups (Callahan, 2008; Deslauriers, Schelew, & Wieman, 2011). When students interact to complete course tasks, they exhibit significant learning gains in comparison to students who work independently, especially in undergraduate courses like mathematics (Callahan, 2008) and physics (Brewe, Kramer, & Sawtelle, 2012) where the material is provided in an ordered progression of complexity. As such, it would be useful for scholars and instructors to understand the factors that foster student participation in academic-centered interactions.

However, very little is known about the mechanisms that facilitate students' academic interactions. Researchers advocate for the importance of peer interactions focused around academic work (e.g. Brewe, Kramer, & Sawtelle, 2012; Tinto, 2003), but they have yet to account for the ways that classroom connections are "developed, composed, maintained, and abandoned" (Dawson, 2010, p. 739). Instead, research on social learning in large lecture halls tends to examine the number of connections students have in isolation from the larger classroom network that shapes and structures their interactions (e.g. Rizzuto et al., 2009). Focusing on the number of connections rather than the nature and arrangement of those connections may overlook the ways that the structure of connections (the network and its organization) can limit the agency of individuals to participate in social opportunities and access different informational and social support resources (Lin, 2002).

This is particularly true in postsecondary contexts where tightly connected undergraduate peer networks can restrict access to individual and institutional informational resources (McCabe, 2016). Tightly knit networks result in configurations where students have fewer contacts on campus and the majority of their contacts are connected to each other. There are few loose ties that provide diverse informational resources or opportunities. Few connections mean fewer friends of friends to connect with to form study groups. As a consequence, the structure of the network of peers that forms around a course may impact students' ability to participate in crucial academic activities like out-of-class study groups. The purpose of this exploratory study is to identify some patterns in the ways that students formed and made changes to socio-academic peer relationships connected through a large undergraduate science lecture course.

Background: Connecting with Peers

The impact of undergraduate experiences is mediated and informed by "the extent and content of one's interactions with major agents of socialization on campus" like peers and instructors (Pascarella & Terenzini, 1991, p. 620), especially when these interactions involve academics (Anaya & Cole, 2001; Deil-Amen, 2011; Kuh & Hu, 2001; Tinto, 1993). Peer interactions where academic and social worlds collide, or what Deil-Amen (2011) refers to as "socio-academic integrative moments," can enhance social and academic integration by providing students spaces and times in which their social and academic worlds align.

For undergraduate students, academic and social groups overlap (Nespor, 1994), an effect even more pronounced for students in STEM fields like physics where those

without significant overlap among their academic and social worlds are less likely to persist in their undergraduate major (Forsman, Linder, Moll, Fraser, & Andersson, 2012; Forsman, Moll, & Linder, 2014). Network structures may influence the kinds of interactions students experience on campus. For example, through close personal relationships (what network researchers call "strong ties"), students are able to access emotional support, while those with lots of loosely connected peers (weak ties) are able to access more diverse informational resources through peer interaction on campus (McCabe, 2016). Peer interactions may even motivate students to focus on academic performance (Summers, 2006).

The clearest evidence of benefits from academic interactions in peer networks can be found in the classroom. Undergraduate students in classrooms that are organized to support interaction post greater learning gains than their peers in traditional 'sage on the stage' lecture courses (Baepler & Walker, 2014; Ge & Land, 2003). Peer networks in a course can provide important informational support, which is crucial for academic success (Canche, D'Amico, Rios-Aguilar, & Salas, 2014; Carolan, 2013). Peer interaction has been linked to "cognitive development, identity development, self-confidence, self-efficacy, and social and academic integration into the university" (Callahan, 2008, p. 361). Cooperative classroom environments, which facilitate collaboration on academic tasks, are associated with gains in student achievement as well as increased motivation and persistence in undergraduate education (Pascarella & Terenzini, 2005). The benefits of peer interaction to learning appear to be contingent upon high levels of interaction and the dynamics of student groups (which facilitate engagement and feedback; Webb & Farivar, 1999).

Individuals who participate in a social network benefit from network externalities, where the more participants there are a network, the easier it becomes to access different types of resources through that network (because of its increasing size and potential diversity; Christakis & Fowler, 2009). Individuals who do the work of networking around a class and who create relationships that span socio-academic realms may also benefit from what Tufekci (2017) terms "network internalities." According to Tufekci,

> [network internalities encompass] the benefits and collective capabilities attained during the process of forming durable networks which occur regardless of what the task is, or how trivial it may seem, as long as it poses challenges that must be overcome collectively and require decision making, building of trust, and delegation among a semi-durable network of people who interact over time. (p. 75)

As individuals build their networks—as they go about the work of networking and relationship formation—they develop capacities beyond the resources and opportunities that flow from social capital exchange (Tufekci, 2017).

Network internalities are produced through the ongoing work of interaction required to make relationships functional and connections among relations durable (Tufecki, 2017). Network internalities may be valuable beyond the social capital resources that individuals within the network possess. In addition to social capital exchange, network participants benefit from the trust and understanding that results from sharing time and energy—the process of networking that builds a reliable and durable interpersonal social structure. As

Tufecki (2017) notes, “sometimes doing seemingly pointless or unimportant work gives groups the capacity to do more meaningful things” (p. 76).

Working with others to address a task or negotiate conflict makes the network stronger and better prepares individuals to take on future collaborative tasks. The process of networking around coursework may help students develop stronger multi-dimensional ties that provide social, informational, and instrumental academic support. There is an increasing body of evidence that shows that networking around other campus activities strengthens students’ relationships and their campus engagement (Mayhew et al., 2016). The internalities that come from networking around coursework can help students identify social and academic resources in their network, potentially making them more effective at capitalizing on their social ties. In this way, networks and networking might play a crucial role in helping students navigate campus life and academic work.

Forming Social Ties around Coursework

The nature of classroom peer interactions results in contextual and dynamic influences on student learning. Positive interactions (like providing social and informational support) might spur student success while negative interactions (like distracting a peer) might deter engagement (Carolan, 2013. During class time, peers can distract other students or help keep them on task, especially in classrooms where the space is conducive to interaction (Baepler & Walker, 2014).

Competition between peers in a course may prevent students from sharing knowledge or ideas with others. Seymour and Hewitt (1997) observed that competitive classroom environments like those found in undergraduate math and science courses can warp peer interactions, resulting in suspicion between peers and isolation. In-class

collaborations can also result in dysfunctional groups when students do not share equally the burden of work (Aggarwal & O'Brien, 2008; Hall & Buzwell, 2012; Li & Campbell, 2008). Anxiety about working with peers who are better prepared can also deter peer collaborations and reduce the efficacy of peer academic interactions (Dijkstra, Lindenberg, & Veenstra, 2008; Micari & Drane, 2011). This may explain why, in many cases, students tend to sort into in-class groups on the basis of shared socio-demographics and similar perceived levels of academic ability (e.g. Callahan, 2008; Freeman, Theobald, Crowe, & Wenderoth, 2017). This tendency may carry over to out-of-class academic interactions as well.

Organizing emerging social relations around shared identities potentially creates unequal access to the kinds of opportunities and social resources that academic peer interaction is intended to afford. For example, if students are underrepresented in the classroom—that is, if they are unlikely to share identities and experiences with their peers—they may be excluded from out-of-class study groups that coalesce around shared identities. A substantial body of empirical literature on social network formation suggests that connections are generally guided by homophily, or similarity along dimensions of shared identity and/or experiences (Goodreau, Kitts, & Morris, 2009).

Social Forces and Learning Network Formation

Students in postsecondary classrooms appear to engage in homophilous sorting just like students in other environments. Students in a large active learning lecture course had high odds of sorting into in-class study pairs by race and gender (Freeman, Theobald, Crowe, & Wenderoth, 2017). In a longitudinal study of campus peer networks, McCabe (2016) also observed students sorting into groups around shared identities, a tendency

that was most pronounced among the networks of African American and Latina women. The participants in McCabe's study attributed this to a need to connect with other students who shared similar personal pre-college experiences, racial identities, and communal perceptions of the campus environment. In this way, homophily serves as a social good, by providing students connection and a sense of belonging to a community on campus.

However, a potential negative consequence of homophilous sorting is that it segregates the exchange of social capital—specifically the exchange of information, influence, social credentials and access to social opportunities (Lin, 2001 p. 20)—within relatively homogenous networks. When social capital exchange extends to power relationships like participation in networks of knowledge and social support organized around classroom experiences, access to social capital shaped by homophily can restrict individuals' ability to participate and form relationships within a network. For example, an individual's ability to 'borrow' information from a friend of a friend to complete a task for a course may be limited by their structural position in the network (who they are tied to, how closely connected their ties are to other individuals who possess resources; Lin, 2002. As such, an accounting of network structure and evolution is needed to understand the relationship between students' agentic decision-making and the social structures that facilitate or deter their network participation.

Conceptual Framework

Large introductory physics courses provide an ideal context for an exploratory study of undergraduate out-of-class study group networking because they require a logic of collaboration for student success (Nespor, 1994). Students in these courses are

expected to work together during class time, as part of completing lab experiments, and on out-of-class work. The approach used in this study, where structural properties are captured through what are called 'socio-metric surveys' and enriched through qualitative interviews, provides insight into the relationship between individual student agency and the classroom opportunity structure (Tinto, 1997).

Drawing upon the prior literature on undergraduate students' social networks, this study focuses on how different aspects of network formation and change may influence students' study group partnerships. Research is needed on undergraduate students' social and academic networks (Biancani & McFarland, 2013) because a growing body of literature suggests that different aspects of social network features, like the number of social connections a student possesses in a course (Rizzuto, LeDoux, & Hatala, 2009) or how central they are to a network of peers in a course (Buchenroth-Martin, DiMartino, & Martin, 2017), are related to end-of-term academic performance. Additionally, research on homophily in peer relationship formation and its relationship to socio-demographic identities is needed to understand how potential inequalities might form in access to the benefits that extend from peer networks. Finally, research on peer networks could contribute to our understanding of undergraduate student engagement by providing insight into the role of network externalities and internalities in affording opportunities to access social and academic support resources through peer networks.

In this study, I aim to advance research on undergraduate peer relationship formation in the context of a large science lecture course by drawing on social network theory and employing social network analysis to (1) identify and characterize the network structure within which students make decisions about whom to work with, if anyone, as

part of out-of-class study preparation, (2) illustrate how changes in the network structure over time might inform students' position in the network, given the potential for homophilous sorting on the basis of gender and race among young adults (McPherson, Smith-Loving & Cook, 2001), and (3) understand how students' decision-making about out-of-class study group participation might be related to the development of network internalities and integrative capacity for accessing social and academic support resources.

Methods

In this study, I employ a mixed-methods approach to the analysis of students' social networks. The data collection strategy involved administering socio-metric surveys twice during the semester concerning students' reported social and academic relationships in a large undergraduate introductory physics course. At the end of the semester, students were interviewed, using network visualizations of their reported study groups as prompts for retrospective interviews about their relationships. The socio-metric survey data provides insight into my first research objective regarding how the larger course network emerged and changed. The interview data addressed my second research objective related to significant influences on relationship formation and my third objective regarding students' decision-making about whom to work with.

Research Context

The context for this study is an introductory physics course at a university in the American Midwest. According to the 2010 Carnegie Classification, the institution is a high undergraduate enrollment, Doctoral/Research University-Extensive. Most undergraduate students live on campus. The course is the first half of a two-semester introduction to concepts in mechanics. Students attend a one-hour lecture three times a

week as well as a weekly three-hour lab section. Lecture sections ranged in size from 150 to 220 students (see Table 1). Labs enrolled, on average, 25 students. Different instructors lead lecture and lab. This course is a requirement for popular major programs in physics, chemistry, biochemistry, and engineering.

Data Collection

Two phases of data collection took place: surveys were administered during the term and interviews were conducted after the course was completed. First, before the first and third (of four) exams, students were asked to complete two surveys that collected data about their connections in the course. The first and third exams were chosen to provide students sufficient time to form study groups and make potential changes to those relationships during the semester. The survey was administered over the web to students' institutional e-mail address. The survey contained a name generator, where students could type their connections or choose a connection from a list of peers alphabetized by first name. The survey also contained a number of questions about the nature of each relationship, including whether the students knew each other before the course, if they worked together in class on tasks, if they collaborated on out-of-class assignments like homework, and whether they studied together to prepare for exams. This data was used to construct the course-level network as well as the individual networks used in the next phase of data collection. This was a directed network, which means one student could report a study connection and the reported student might (or might not) return that connection on their own survey. Students were not limited in the number of connections they identified.

Network sample. The sample for the descriptive network is composed of students enrolled in an introductory undergraduate physics course designed for engineers (n=510). The course includes three lecture sections, each taught by a different faculty member. Students also enroll in a lab course. Out of the enrolled students, 450 completed both survey instruments. Students received extra credit points on an exam for completing the surveys. The sample was generally representative of institutional enrollment, except for women, who were significantly underrepresented (accounting for less than 30% of students in the course but almost 60% institution-wide; see Table 1).

Table 1. Whole Network Sample (n=451/510)

	Class A (n=138/150)	Class B (n=134/176)	Class C (n=178/221)
Men	69% (106)	73% (129)	70% (156)
Women	31% (47)	27% (47)	30% (65)
API	25% (38)	31% (54)	26% (58)
Black	1% (2)	2% (4)	1.4% (3)
Latinx	7% (11)	4.5% (8)	7.2% (16)
Multi-racial	4% (6)	4% (7)	3.6% (8)
NA/NH	0.7% (1)	0.5% (1)	
Not Indicated	4.6% (7)	1.1% (2)	1.9% (4)
White	58% (88)	56% (100)	59% (132)
International	9.9% (15)	10.2% (18)	5.8% (13)
Survey Response Rate	78%	76%	83%
College of			
Literature, Arts, & Sciences	21% (32)	32% (56)	23% (52)
Engineering	79% (121)	68% (120)	76% (169)

Interviews. Individual students participated in interviews that were conducted a month after the course ended. In this study, the out-of-class study group relationships that a student reported in the course were illustrated using the Statnet network visualization package in R and labeled for the participant's review. Students reflected on their study

groups during the interview and identified relationships they perceived among the other students in a group if relevant. During the interview, students were asked about their social and academic experiences on campus, their study group partners, any observable change in their network over the course of the semester, and their relationships with their study group partners after the course using a semi-structured interview protocol. Interviews lasted between 45 and 75 minutes.

Over 100 students (27%) replied to the initial request for interviews. Before scheduling an interview, students completed a brief demographic survey in order to ensure some demographic balance in the sample. Women, students of color, and women of color were purposefully oversampled in the solicitation for interviews, and in the selection of participants. In total, 68 students were interviewed. Students responded in the following ways to open-ended questions about their social identities:

- Gender: 44 women & 24 men; All participants identified as cisgender.
- Racial/ethnic identity: Afro-Cuban (1), Black or African American (8), Chinese (11), Fillipino (2), Lebanese (1), Latinx/a/o (6), Mexican or Mexican American (3), Middle Eastern (2), Pakistani (2), Pinoy (1), Southeast Asian (2), Taiwanese (1), White/Caucasian (27).

Students received a $25 gift card for participating in the interview. Interviews were conducted in the month after the course ended.

Classroom Context. In addition to the surveys and interviews, I also conducted observations of instruction in each of the three sections of the course as well as in each lab section to identify variations in teaching approaches among the three instructors. During class time, each instructor provided students with multiple choice questions and

encouraged them to discuss their answers with their partner before submitting responses using an i-clicker system. All three instructors engaged in this practice, although two of the instructors did this, on average, four times per class while the other instructor only provided one question per period. Students were able to make connections in the classroom through this process, although their ability to network was limited by the physical space. The classroom was arranged in a traditional lecture style, with 250 fixed seats facing chalkboards and a projector screen. I never observed a student get up and move to work with a partner, although students were free to work with whomever they chose. In the labs, students were required to work with a new partner each week, which resulted in a great deal of meeting and greeting contacts but may have prevented relationship development through interaction during lab time.

Data Analysis

Survey Data Analysis. Two phases of social network analysis were employed as part of this study. The first phase involved the calculation of basic network statistics and the visualization of networks, including information about students in the network to identify potential trends in collaboration. Survey data was used to identify network structure at the time of each survey administration and changes in network structure that had occurred between survey administrations (e.g., changes to partners a student identified at each survey administration) were based on both waves of data collection. Data about student connections from the survey instrument were used to develop social network visualizations. Visualizations and network statistics were produced using the Statnet package for R (Handcock, Hunter, Butts, Goodreau, & Morris, 2008). Survey data

was compiled in adjacency matrices, where for each possible pair of students, a binary value indicates the presence or absence of a study partner relationship.

Three network statistics were calculated as part of these analyses to characterize network structure, explore changes in the structure and features of the network, and understand how students were positioned in the network given different socio-demographics. First, a density measure for the network was calculated (see Handcock et al., 2008 for a description). A density measure is a proportion where the total number of observed connections in the network is divided by the total possible number of connections in a network. In this study, any student enrolled in the course could nominate any other student in the course. There is the potential then, in the network, for every student to be connected to every other student (which would result in over 33,000 connections). As the findings will illustrate, this was far from the case. Density measures range from zero (no observed connections) to one (all possible connections are present).

Second, a measure of in-degree (the number of people who identify a student as their study partner) and a measure of out-degree (the number of people whom a student identifies as their study partner(s)) was calculated. For example, if Student A is identified by six other students as a partner and only identifies three students as their partners, they would have an in-degree of six and an out-degree of three.

Finally, a measure of betweenness centrality was calculated for each student in the network who identified at least one study partner on at least one survey. A betweenness centrality measure indicates the number of times an individual acts as a bridge (or connection) along the shortest path between two other individuals in the network (Wasserman & Faust, 1996). If a student has a high betweenness centrality, they

are likely to be serving as the bridge connecting many other (unconnected) students (for a technical discussion of the approach I used, see Newman, 2005).

Interview Data Analysis. Qualitative findings draw upon the data collected during the interview phase of the study. Each interview was transcribed by the researcher. After transcribing the interviews, I open coded each interview to identify initial themes in the data (Miles & Huberman, 1994) using the Dedoose software package. I focused on relationships connected to the focal course and generated an initial list of codes. After generating the first cycle of codes, I placed each excerpt into a meta-matrix as described by Miles, Huberman, and Saldaña (2014) where each row is a respondent, each column a code, and each cell an excerpt from the transcript. Code examples include: nature of relationship, timing of change, impetus for change. I also cross-referenced the emergent themes with prior findings in the literature on undergraduate peer relationships as a way to challenge my initial assumption (Saldaña, 2015).

A set of broader themes emerged, suggesting patterns in how students formed, maintained, and abandoned out-of-class study partner relationships. I then re-analyzed the data with the new codebook. While coding with the new emergent themes in mind, I also referenced the visualization of a student's study group (which had been used as a prompt during the interview) to observe similarities in the structure of groups that students reported relative to the kind of social forces they identified as significant influences on changes in their relationships. After finalizing a set of themes, I conducted member checks with participants to ensure that my interpretations matched up with their individual understanding (Maxwell, 1992). I spoke with 48 students who responded to a

request for member checks to verify my interpretation of how their relationships emerged, were organized, and changed. Students selected their own pseudonyms.

Limitations

This is an exploratory study of the study group network that emerged around one course in one institution. As this study was focused on an introductory physics course, the challenges endemic to the physics field (e.g., lower enrollment of women, Black, Latinx, and Native American students; predominantly white cisgender men as instructors) shaped the research context and limited the resulting sample. It may be that the women and underrepresented students of color who enrolled in this course had more experience than white and AAPI men in cultivating networks of social and academic support resources, in order to reach the point where they could enroll in the course. The nature of the sample does not facilitate this kind of comparative analysis. Students' decision-making processes about whom to study with might look very different in courses or institutions with more compositional diversity.

Findings

Network Census

I begin with the network census results to provide insight into how the network emerged and changed over the course of the semester. The number of study group partnerships in the network that formed around the course decreased substantially as the semester progressed (see Table 2). As fewer students reported studying in increasingly smaller groups (or giving up on study groups), students who still sought out study partners found few opportunities to join new study groups. As a consequence, many

students who studied with partners at the start of the course were working independently by the third exam.

This is most likely a byproduct of a sparse network becoming sparser over time. The density measure provides an illustration of the trend towards fewer relationships. Density, in the context of a human social network, indicates the amount of connectivity in the network. Density refers to the percentage of observed connections out of all total possible connections in the network. Out of all potential connections among students, only 0.01% are present in the period before the first exam (n=338; Table 2). Further, in this network, students' tendencies to collaborate may have decreased over time, as the density measure decreased from 0.01% to 0.007%.

Social networks, as opposed to inorganic or animal networks, are traditionally sparse, so a low-density finding is not surprising (Robins, 2015). Sparse networks, like the one I observed in this study, make collaboration and resource-sharing difficult. Individuals tend to stay within their small cliques in sparse networks, and individuals seeking to form new relationships can find it challenging to do so.

Table 2. Network Census

	Before Exam 1	**Before Exam 3**
Connections	338	228
Density	0.01%	0.007%
Mutual Connections	28%	37%
Closed 3-person groups	16	17
Reciprocated Pairs	48	42
Unreciprocated Pairs	242	138

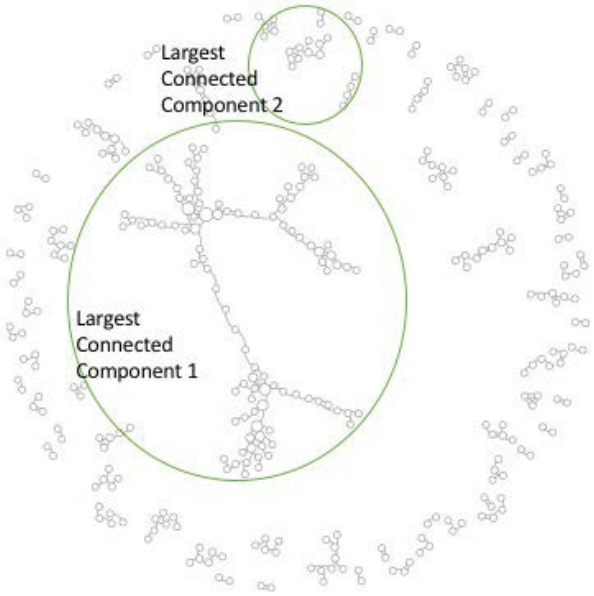
Students' participation in out-of-class study groups by lecture section was relatively consistent with the trend observed in the course as a whole. For example, in class A, the number of reported relationships decreased from 0.3% of all possible relationships to 0.1% between the two survey waves. In class B, the network density

decreased from 0.2% to 0.1%. The density of the classroom network in class C also decreased by about 0.017% over the same period.

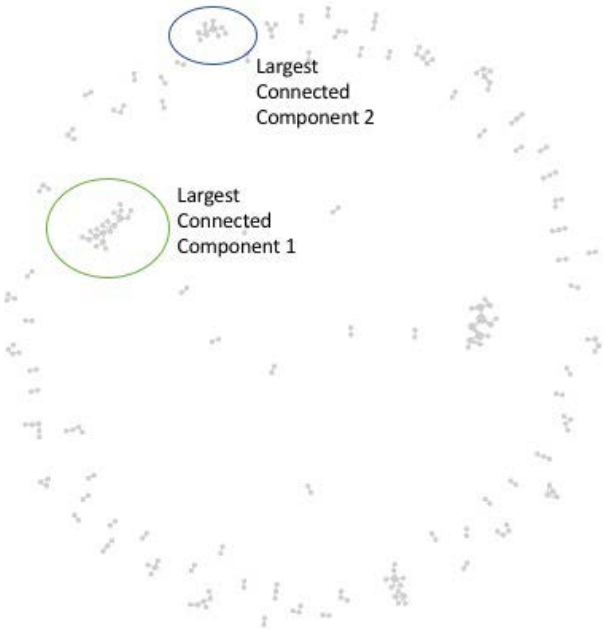
Analyses show that students reported collaborating with, at most, six other students at any point in the semester, but most students reported no collaborators. In figure 1, the network graphs illustrate students who reported or were reported as a study group partner. Within the network are a number of sub-groups (called 'connected components'), which change over time as students come and go from out-of-class study groups. The two largest connected components are identified in both figures. The largest connected component breaks up in the period before the third exam (i.e., the second survey administration), leaving a structure where study group relationships are organized in smaller cliques of peers. The decreasing number of reported relationships may signal the dissolution of a social structure that facilitates the kinds of weak ties that provide students with the benefits of a diverse network (McCabe, 2016). Instead, students are potentially left with fewer (and hopefully more tightly knit) cliques and subgroups.

Figure 1. Course Network over the semester: Largest connected component before and after first exam; sized by betweenness centrality

Before Exam 1

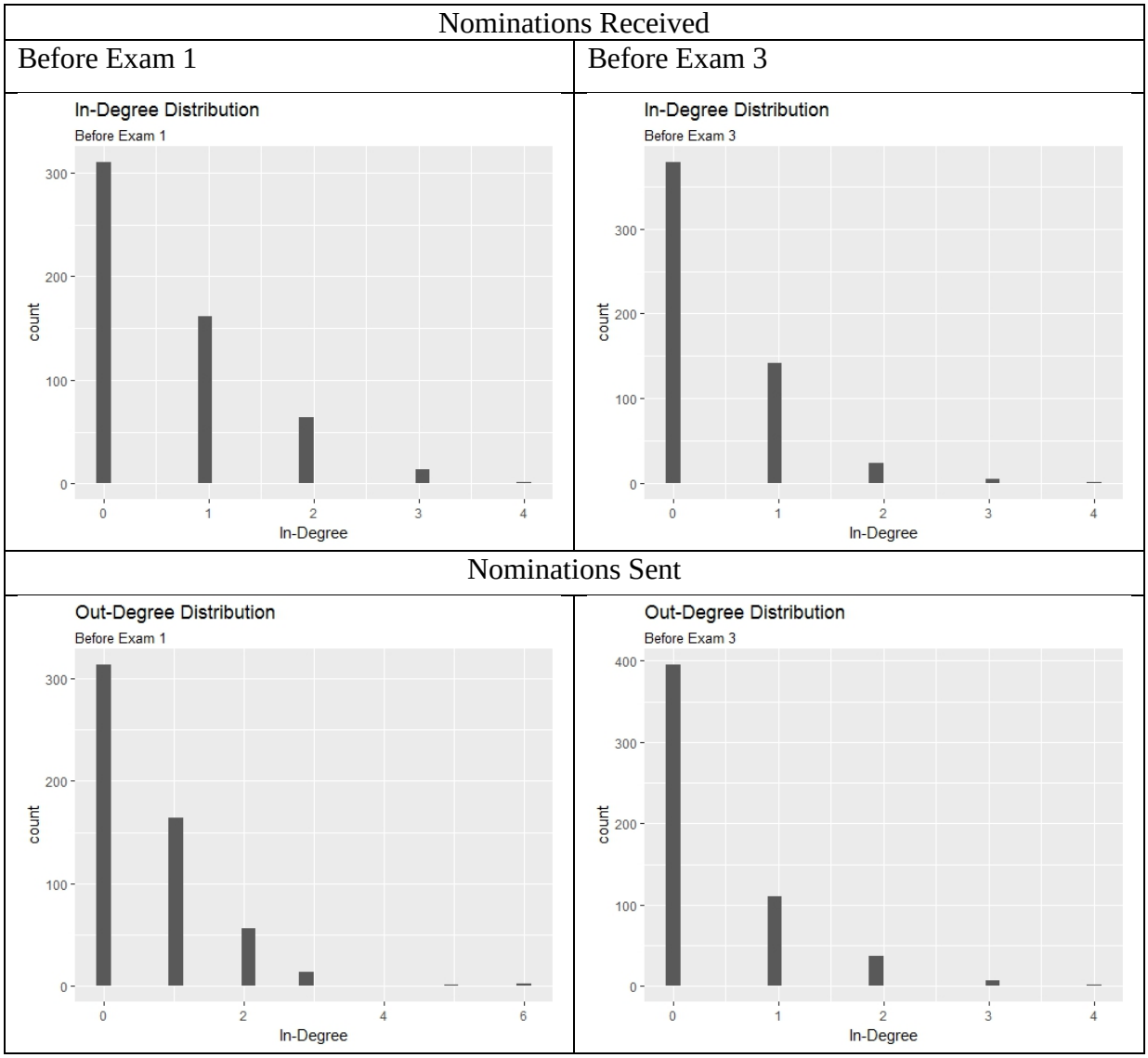


Before Exam 3



Between the two time periods, the number of reported relationships decreases substantially (from 338 connections to 228 connections). Within the network, many of the disappearing connections appear to be from relationships where one student nominates a peer who in turn does not reciprocate the nomination (from 242 to 138). Unreciprocated relationships were unlikely to be maintained between the two data collection periods, decreasing by 42%. Reciprocated relationships (where peers both nominate each other) also decreased by about 35%. Over time, fewer students reported 1, 2, and 3+ collaborators, and fewer students were named as study partners (see figure 2). This is most apparent among the total number of reported relationships (total degree distribution), where the number of students who identified no study partners and who were not identified as study partners increased from 207 to 300.

Figure 2. Received Nominations (In-degree)/ Sent Nominations (Out-degree) Distribution



Connecting and Disconnecting

It is worth noting that within most study groups there were few examples of 'pure' homophily where students socially segregated exclusively by race and/or gender at the first survey administration. Instead, the network appeared to reflect the preferences of the majority, where mostly white men were connected to mostly (but not exclusively) white men. By the second survey, where most study groups were composed of two or

three students, segregating on the basis of gender homophily was very common among men. In the groups where white women and Asian, Asian-American, and Pacific Islander women (AAPI) were included, they tended to be placed into a bridging role—serving as a connection point among different study groups.

Bridging roles are often denoted by high betweenness centrality scores (Robins, 2015). A betweenness centrality measure indicates the number of times an individual bridges the shortest path between two other individuals in the network (Wasserman & Faust, 1996). Women had, on average, much higher levels of initial betweenness centrality than men (Women's initial betweenness centrality= 3.57 to Men's 1.66).

For different groups of students to be connected, and for information to flow freely among study groups, pathways must pass through individuals who serve as bridges. Students in bridging roles, in this study most often white and AAPI women before the first exam, need not have many connections (see Table 3). They simply need to serve as the connector among individuals who would otherwise not be connected (Wasserman & Faust, 1996). It appears that AAPI and white women lie at the periphery of a number of study groups at the first survey administration. Some of this is attributable to a small group of AAPI and white women in the network who had very high betweenness centrality scores (as suggested by the standard deviation of each score). While both groups had higher average scores than AAPI and white men, on average, the high standard deviation for both scores suggests that some AAPI and white women played a very central role in the network. It should be noted that women underrepresented by ethnicity also had higher average betweenness centrality scores than the comparable group of men with a similar trend.

As students make choices about whom to study with, the centrality of AAPI and white women in the network also decreases. In general, as the number of connections in the network decreased, the number of individuals serving as bridges also decreased. By the administration of the second survey, the betweenness centrality scores among socio-demographic categories were closer to being in line with each other. This is most likely a result of the decreasing number of connections in the network. AAPI and white women were positioned on fewer paths because fewer paths existed. How and why students choose to end relationships with a study partner is a question I address in the next section.

Table 3. Average Connections (In-Degree) and Betweenness Centrality by Classroom Representation

		Mean Connections (In-Degree)		Mean Betweenness Centrality	
Gender	Race	Time 1	Time 2	Time 1	Time 2
Network		0.62	0.40	2.35	0.77
	Asian (n=105)	0.62 (0.80)	0.42 (0.73)	0.95 (2.63)	0.46 (1.78)
	Underrepresented (n=59)	0.63 (0.96)	0.36 (0.71)	0.41 (1.25)	0.03 (0.18)
Men	White (n=227)	0.53 (0.74)	0.36 (0.62)	0.57 (2.25)	0.11 (0.80)
	Asian (n=45)	0.82 (0.91)	0.62 (0.96)	2.33 (7.26)	0.18 (0.62)
	Underrepresented (n=21)	0.71 (1.01)	0.19 (0.40)	0.71 (1.49)	0.38 (1.20)
Women	White (n=93)	0.69 (0.81)	0.47 (0.67)	1.97 (7.01)	0.28 (1.00)

Interview Findings

I now turn to the results of the qualitative interviews to provide insight into students' perception of their out-of-class study group relationships. I begin with the

students who had higher average betweenness centrality because these students played an important role in connecting peers in the network. During interviews, students who had higher than average betweenness centrality described how their relationships changed over the course of the semester. Two sentiments were common. First, students expressed ambivalence about the relationships that ended. Cassie, a white first-year woman in the college of engineering, said,

> I had—like there were too many of us to coordinate so when she said she was not going to work with us anymore……I mean basically I felt relief. And it didn't feel like—I would say she was any better at [the course] than we were so, I didn't feel frustrated.

Nearly all of the students who expressed ambivalence about relationships ending described study group relationships that were almost exclusively academic. These relationships were more often temporary than relationships that spanned social and academic activities.

In contrast, the second group of 'bridgers' described intervening events that usually precipitated someone leaving a study group. Students often organized their study group time around other activities they shared in common, like campus student groups or first-year living/learning communities. When a student stopped participating in a shared activity, they effectively 'quit' the study group. Aldo, a white first-year man in engineering, described this happening multiple times over a semester with classmates who were also on a robotics design team.

> It was like, boom, boom, boom, one after the other. They all dropped like flies after the first midterm. I don't even think it was physics. They didn't

> do amazing in their other class, and they were like "I have to quit [the robotics team]. I need to spend more time studying."

When these study partnerships ended, the students left behind expressed frustration as study group participation was connected to other social obligations.

Leaving their existing group after the first exam also created complications for those who departed. Rick, a white first-year man in engineering, said that after he left a study group that conflicted with his off-campus job he was unable to find other students to study with. This was a common response among leavers. If you left a group early on, and many students did, it was hard to find other students to work with, especially as the course progressed.

Students had different reasons for leaving their study groups, and accordingly their reactions to leaving a group varied. Often, students expressed concern for the relationships to which they no longer had access. In three cases, students described leaving the group as a necessary corrective for their mental health, as they perceived the situation to be toxic. In each of these cases, men described personality conflicts with other men in the group around how work should be completed by the group.

Although students were making changes to their course networks over time, there is no broad mechanism that explains how and when students sorted into new collaborations. In general, however, students were simply not collaborating with their peers in the way that I initially expected to observe, given prior research. I expected that in-class interactions during class time would extend to interactions outside of the classroom. Rather than in-class interactions driving out-of-class relationship formation,

out-of-class relationships appear to have driven in-class selection. Accordingly, a variety of other campus social forces brought students together.

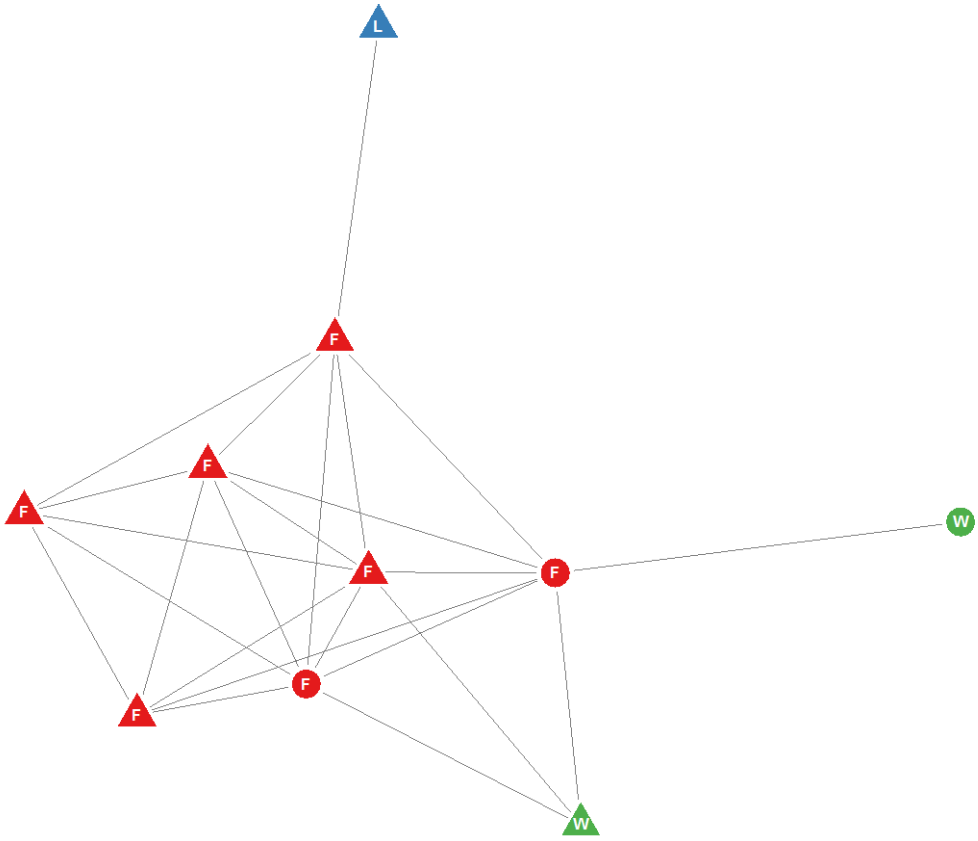
Shared Affinity Spaces and Times

Through interviews, it emerged that many students' networks came together in ways that reflected their participation across campus, instead of organizing around in-class connections. One common approach to group formation was to connect with individuals one already knew from prior experiences on campus. Students across the spectrum of their undergraduate career reported seeking out people that they already knew to at least collaborate with initially. This tendency was common across identity groups, but the kinds of prior relationships that were salient differed between groups. In the following section, I describe how two different forms of social forces informed very distinctive types of out-of-class study group formation.

The push and pull of shared interests. First, students brought their prior connections into the course through out-of-class affinity groups they participated in. Three students described connecting through the Filipino student association before the first exam. All three women (and the rest of their group) continued to work together throughout the semester. This group included seven students who were members of the organization and three more students who were connected through residence halls, as lab partners, and through high school. The core group of Filipino students spent time together studying, socializing, and participating in social activities through the Filipino student organization (see figure 3). In contrast to other study groups in the network, this group was durable. Despite its relatively large size (10 students), this group did not splinter into smaller study pairs and triads. Instead, the students in this group made a concerted effort

to connect on a regular basis and planned their physics study time around other campus engagements.

Figure 3. Filipino Student Association Study Group



Key: Filipino/a, **L**atina, **W**hite; Circle=Women, Triangle=Men

Renee (1st Year, Engineering, Filipina), one of the students in the group, described the connection she felt as stronger than a study partnership.

> They are like my family here. We hang out, we eat, and then we do work. But when we do work we are serious about it. There is some natural accountability when you work with folks who want you to—we want each other to be successful in a way that like a regular study group might not care so much? We want each other to be successful, so it makes me work harder when we do work.

Some of the students who studied with the group were not connected through the Filipino student organization. Kerri described this as part of the process of merging social and academic worlds, also acknowledging the familial role that the group played: “It’s like—

sometimes you have a cousin with a rude girlfriend. You know they are going to come around." Kerri's roommate, who also was enrolled in the course, regularly joined the study group to study. However, despite Kerri's repeated invitations, she never attended Filipino Student Association programs or connected with the group socially. None of the other students in the group identified Kerri's roommate on their socio-metric surveys, although in interviews they acknowledged that she regularly attended the study group. Kerri suggested that her roommate might not have connected to any of her Filipino friends had she not been enrolled in the course.

Other students became more integrated into the group over time. Kerri noted that Joe, another Filipino student association member, and his lab partner Peter, who was white, would regularly coordinate the group over a social messaging mobile application. Although this was initiated by Joe, Peter took on the lead role over time. Peter also attended Filipino student association events and forwarded other social events on campus to the group. Kerri described Peter as ad hoc "social chair."

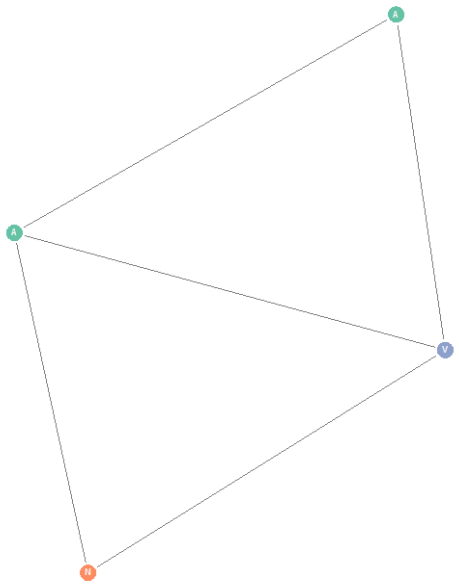
A similar group of students connected through a Southeast Asian student dance group (see figure 4). Cam, who described herself as Southeast Asian/Vietnamese, attended auditions and noticed another student reading the course textbook.

> I said to her, 'Are you in my class?' She was in the course, but not my lecture. We started complaining about the homework, and then like three more girls were like "Are you in my class?" too.

Cam's study group consisted of four women who auditioned and were accepted into the campus' Southeast Asian Dance group. The group travelled to other campuses for competitions and required upwards of 10 hours a week in out-of-class rehearsals. Their

study group would meet before rehearsals to complete homework assignments and prepare for in-class exams. Cam and another student were in the same lecture section, and they regularly sat together to work on i-clicker questions during lecture.

Figure 4. Southeast Asian Dance Troup Study Group



Key: Asian American, **N**epali, **V**ietnamese

Participation in campus cultural and social organizations was one of the ways that students connected their academic obligations to resources in their social worlds. Cam described the benefits that came from working with her study group:

> I am not an extrovert. I have a hard time meeting people. So class was like the natural way in for me to make a friend with people in the (dance) group.

Connecting through an out-of-class experience also helped Cam find peers who had more extensive coursework in physics.

> I think if I had not met them through the group, [the other women in my group] might not have worked with me. They all had physics and calculus

> in high school, and this was my first physics class. They helped me a lot in the course.

While students may have connected through affinity groups, these groups also created the potential for diverse sorting along other aspects of academic experience and social identities. Similar to Renee and Kerri's study group and dissimilar from the network as a whole, Cam's study group was tightly knit and maintained connections throughout the semester.

This kind of tightly knit group was particularly common for women in the study, as they experienced (and perhaps sought) substantial overlap between their social and academic worlds. Cam, Renee, Kerri, and the majority of the women I interviewed noted that they had a harder time finding women who shared their academic interests. Carla, a white first-year student, noted, "I live in [the biggest residence hall on campus] and I live on an all-girls floor and there are only three engineers on the floor." Women had to purposefully seek out individuals who were both connected to their academic lives and shared their social interests because they did not perceive that there was enough time in a week to engage in each independently. For example, Cam described attending dance performances around the state with her friends and studying together during long van rides. Her friends were able to answer questions and help her work through challenging problems. Cam did not need to make a choice between preparing for class and pursuing outside interests, as she was able to combine the two.

The convenience of shared space and time. The men I interviewed, in contrast, tended to participate in groups that were less tightly connected. These groups were ad hoc and appeared to capitalize on the opportunities presented by sharing space and time on

campus. All of the white men I spoke with described study groups that came together on residence hall floors, usually to prepare for a major assessment. Jeff, a white first-year chemical engineering major, said, “a lot of people in my dorm too, I just see them studying. And I’d be like, ‘Oh, is that Physics [100]?” Roommates and neighbors who shared a floor would convene in their shared study room (or lounge) and work through the practice problems provided by the instructor. These groups would start as early as the weekend before an exam although most of the men who participated in convenient ad hoc groups reported convening the night before an exam.

These groups most often did not involve much overlap between social and academic worlds. Roger, a white first-year man in engineering, offered a characteristic response to a question about overlap among friends and study partners:

> Very little. Like, I have friends from high school who are [at the University]. They are not engineers. They work much less than I do….the guys on my floor are in all of my classes, so we just get together right before exams to study.

Less than a quarter of the white men I spoke reported overlap between their social and academic worlds. The few who did suggested that their friendships largely emerged through classroom connections, in part because of the amount of time required to be successful in their courses. Josiah, a white first-year engineer, made connections primarily through his courses. “It is kind of like, ‘Oh, I met you; you’re in Calc-3 and Physics-[100].’ And then you start hanging out with them and then it becomes social.” As these students were spending substantial time together in the classroom and in their

residence hall, they fell into a natural connection. However, these connections differ in their strength and utility from those described by students like Renee, Kerrie, and Cam.

Instead, the connections fostered by convenience tended to be limited in their utility. Jay, a white first-year man in Engineering, described studying with two other students on his floor:

> We would get together during like crunch time. And I would see them—maybe we would hang out on the weekend if we were just around. But it was mostly about studying for class. I had no time to do anything but study for class.

In contrast to the women I described above, the men in this study had a harder time connecting their social and academic worlds in order to facilitate the kind of benefits that Cam (and other women in the study) reported.

The connections fostered by convenience tended to wither away if students did not continue to share class time. Mark, a first-year who switched from engineering to physical sciences, said he rarely spent time with his study partners during the semester outside of the study group. He also did not continue to work with his study partners after the course ended, a sentiment echoed by nearly all of the men who organized their groups around convenience as opposed to the men who connected around affinity groups.

As suggested by Cam, Renee, and Kerri's experiences, shared affinity groups produce shared space and time. Attending dance rehearsals and competitions resulted in socio-academic integration because Cam spent time in shared social and academic spaces with her study partners. Students in the study described how affinity group participation could structure and shape their social lives in a way that produced deeper socio-academic

integrative relationships. For example, a substantial number of students in the course were also in the marching band (65/450 survey respondents; 14%). These students spent more of their time together before the semester began (for many, before they officially became undergraduate students). This resulted in little social sorting among students in their classes who were not in the band because students had pre-existing ties and because so much of their out-of-class time during the semester was already accounted for. As Kyle, a white man in engineering in his first year who played in the marching band, noted, “I walk into the room and I see people I know. It is automatic. I don’t have a choice really. I might offend people if I tried to work with someone else.” Still, the band did not result in one large study group of 65+ students. Instead, within the band, study relationships were shaped by other exogenous factors like being in the same lecture, living in the same residence halls, and being co-enrolled in other shared courses.

A similar push and pull occurred among students who lived in the women in science, technology, engineering, and math (WSTEM) learning community. Nearly all of the first-year students in this small group took physics simultaneously. As part of learning community activities, the women studied together, and nearly all also participated in a student-led sustainability initiative. These women had high levels of academic integration as they were advised to co-enroll in the same set of courses. Yet, the tightly knit network resulted in a feeling of social isolation from the rest of the campus. As Brit, a first-year white woman planning on majoring in biological sciences, said, “It can feel suffocating. Like, I love you, you are like my sister, but get away from me, sometimes.”

Outside of the Network

About half of the students who completed the survey did not participate in peer study groups, which meant they were not connected in the larger network of academic-centered interaction that emerged through the course. Students who worked independently offered three primary reasons for their independence during interviews. First, one set of students asserted that they preferred to study independently. Many described peer study groups as a waste of time, especially when there were differing levels of academic preparation. Working on their own allowed students to progress at their own pace and seek out help resources when necessary. These students generally had little overlap between their social and academic worlds. There were no clear demographic trends among these students, as equal proportions of women and men reported working on their own, as did students from different racial/ethnic groups.

The second set of students suggested that the course—though a requirement—was not important to their academic goals. Their aim was to get a satisfactory grade and focus their time and energy elsewhere. These students described working with peers in other courses that were either more important or more intrinsically interesting. They described high levels of overlap among their social and academic worlds, but integrative socio-academic relationships were formed through courses that more closely aligned with their interests. Nearly all of these students were in engineering.

The final set of independent students reported that they worked independently because they had a hard time connecting with other students in the class. The majority of these students tended to hold minoritized racial and ethnic identities. Nearly all of these students identified as men. These students tended not to participate in out of class

activities through which they might connect with other students. They also described their residence hall floors as quiet and cloistered.

It is worth noting that many of the students who worked independently shared space and time with students who collaborated with peers. A handful of the students in the band acknowledged both on the survey and in interviews that they preferred to study alone. Similarly, during interviews, many of the students who described their social and academic worlds as largely separated also acknowledged that even if their friends had been enrolled in their classes their preference would have been to work independently. Within the larger macro-structure of the peer network that emerged around study behavior and the micro-interactions that created social obligations (like participating in affinity groups or living next door to a classmate), students were still able to make choices about whom they would connect with.

What is clear in this course, and what merits further investigation in other courses, are the ways that macro-structural properties, micro-interactions, and students' individual preferences come together to create opportunities for socio-academic integration. In this research, it appears that micro-interactions, social obligation, and macro-structures might influence women's and men's relationship formation in different ways. Systematic research is needed to understand how these findings might translate across contexts.

Discussion

Students in this study found themselves making choices about whom to collaborate with amidst a dynamic, evolving network. Opportunities to collaborate disappeared as the network contracted. Unfortunately, the contraction of the network also coincided with closing temporal windows like deadlines for signing up for supplemental

instruction. This meant that students who wanted to collaborate but were not able to form durable relationships or did not possess pre-existing relationships early in the semester were potentially left at a disadvantage.

Relationships that were durable tended to be based on factors external to the classroom, like sharing space and time or sharing interests. Students connected through other forms of engagement on campus to find partners. Sometimes these connections facilitated successful collaboration, as in the case of the Filipino Student Association, or were, perhaps, the cause of relationships dissolving as with the robotics team. As network density decreases substantially, it becomes more difficult to engage in the 'logic of collaboration' required to be successful in courses like physics (Nespor, 1994).

Socio-Academic Integrative Capacity and Network Internalities

Networks afford the most benefit when more individuals participate in the network (what is commonly termed network externalities; Tufekci, 2017). The tendency of likes to attract, of students to sort on the basis of homophily and shared affinity, means that individuals potentially have different opportunities to participate in the network. With different access to the benefits of the network, network participation (or isolation) has the potential to produce classroom inequality (or magnify existing forms).

Yet, homophily is not always a negative force. Through affinity and cultural group connections, students found durable study partnerships and relationships that lasted beyond the classroom context. These relationships provided multiple opportunities for socio-academic integration. As a result of that integration, students described relationships that were multifaceted, providing social, emotional, and informational support, in addition to the opportunity to prepare for class.

The network that emerges through the course, then, is inextricably connected to networks outside of the course. Increased campus connectivity enhances what Tinto (1997) called the academic opportunity structure of the classroom by connecting it to other academic and social opportunity structures on campus. When students are able to connect through socio-academic relationships, and when students experience socio-academic integration, they build upon and enhance the network externalities that are part and parcel of increasing network size and connectivity. Put simply, the more students network the more they have the potential to build social structures that facilitate opportunity.

It also appears that increased networking through socio-academic relationships can increase students' sense of belonging. Minoritized students who connected through shared affinity and cultural organizations described an easier time finding study partners and more durable relationships that transcended course space and time. Prior research suggests that women of color who seek out peers with shared identities and experiences may end up creating tightly knit networks with limited access to diverse information or social opportunities on campus (McCabe, 2016). In this study, the students who described connecting through affinity and cultural organizations reported stronger ties with their peers than students who connected through convenient meetings in shared time and space. Rather than being isolated within their affinity groups, more often these individuals were placed in a bridging role where they did the work of connecting students to each other.

While that bridging work is not without cost, it appears to produce network internalities (Tufekci, 2017). When students capitalize on the academic opportunity

structure within a course to make connections around socio-academic interactions, they appear to build stronger, more durable peer networks. Engaging in the process of social capital exchange builds up network capacity. Building a functional and durable social structure creates opportunities for engagement. Building a structure that rests upon and interacts with institutional structures like classrooms and courses allows students to pull diverse forms of socio-academic capital into their academic work and their social lives. At the same time, as students network, they build socio-academic integrative capacity. Whether students are able to capitalize on the increased capacity of their networks to move seamlessly between social and academic worlds is a question for future research.

Network internalities may afford the kinds of opportunities and relationships that facilitate campus engagement. When researchers seek to understand how in- and out-of-class engagement improves outcomes, they should turn their attention to the opportunity structures created by students' dynamic social networks. The current approach to understanding disparities in engagement and outcomes suggests that some students (by benefit of their socio-demographics) have access to more opportunities on campus. This framing might overlook the important ways that students who are minoritized are able to construct dynamic diverse networks that create opportunities for socio-academic integration. In fact, it may be that minoritized and underrepresented students are best positioned to learn the skills of network building, which have translatable value for after college career and social life outcomes.

Implications for Instruction

This study provides some insight into how course networks in undergraduate lecture courses are formed and maintained around the preferences of students in the

majority over the duration of the semester. Although instructors cannot address the unequal enrollment in large undergraduate science lectures in the short term, they can create more equitable pathways to participation through instruction.

Instructors could capitalize on the affordances of shared space and time by creating instructional activities that allow for more intentional peer sorting. Students who engage in academic-centered interactions as part of multiplex social and academic relationships appear more likely to maintain their connections over the course of the semester. By creating opportunities for students to engage and foster these connections, instructors might be able to structure more equitable pathways to participation. Additionally, providing opportunities for students to make connections in the classroom among their social worlds and their academic environments could foster the kind of durable relationships that promote resource sharing. Encouraging students, during interactions, to share information about their individual interests could foster the kind of connections described by Cam, Rene, and Kerrie. Instructors should also consider when in the course they encourage peer sorting. In prior research, I observed (Brown, 2017) that instructors primarily encourage sorting early in the semester. But later in the term is when students whose groups have dissolved need the opportunity to connect with peers.

Directions for Future Research

This study highlights some potential structural properties of the emergent social system that influence how students come together to prepare for coursework. These results are limited to one course in one discipline at one institution. The way that disciplinary norms, institutional arrangements, and student enrollment might impact how social structures emerge around coursework merits further investigation. Similarly, the

role that network positioning and participation plays in academic performance should be given further attention.

Given the increasing empirical evidence that identifies a significant relationship between measures of network position and end-of-course outcomes (Brown, 2017; Biancani & McFarland, 2013), future research is needed that investigates the results I have highlighted here in relationship to students' academic performance and academic functioning. When students benefit from working collaboratively and when they benefit most as independent learners merits further consideration.

The moments of socio-academic integration that I highlight in this study may be fostered by the network internalities produced through interaction. The more students interact and the more they interact across social contexts, the more they potentially build networks that provide opportunities for socio-academic integration. In this study, it appears that women in STEM are more inclined to seek out peers ('to network') who share common interests; that is, to develop connections that facilitate socio-academic integration. Men in the study, especially white men, appear to capitalize on the convenience of shared space and time. It may be that white men on campus already have access to multiple opportunities for socio-academic integration, although the white men I interviewed indicated a tendency to segregate their social worlds.

There may be something about students' experience of underrepresentation in these spaces that encourages them to create socio-academic networks that provide multiple forms of support. Women who are underrepresented in STEM fields may have to work harder to find supportive connections, but that work may produce its own form of benefit (in terms of stronger, more durable connections). Further research about women

and students of colors' networking behaviors on campus is needed to fully unpack the mechanisms, benefits, and costs that come from socio-academic peer relationships.

References

Brown, M. (2017). Interaction and Mechanics: Understanding coursework engagement in large science lectures. (Unpublished doctoral dissertation). University of Michigan, Ann Arbor, MI

Aggarwal, P., & O'Brien, C. L. (2008). Social loafing on group projects: Structural antecedents and effect on student satisfaction. *Journal of Marketing Education*, *30*(3), 255-264.

Anaya, G., & Cole, D. G. (2001). Latina/o student achievement: Exploring the influence of student-faculty interactions on college grades. *Journal of College Student Development*, *42*(1), 3-14.

Baepler, P., & Walker, J. D. (2014). Active learning classrooms and educational alliances: Changing relationships to improve learning. *New Directions for Teaching and Learning*, *2014*(137), 27-40.

Biancani, S., & McFarland, D. A. (2013). Social networks research in higher education. In M. Paulsen (Ed.) *Higher education: Handbook of theory and research* (pp. 151-215). Dordrecht, Springer.

Brewe, E., Kramer, L., & Sawtelle, V. (2012). Investigating student communities with network analysis of interactions in a physics learning center. *Physical Review Special Topics - Physics Education Research*, *8*(1), 1-9, doi:10.1103/physrevstper.8.010101

Buchenroth-Martin, C., DiMartino, T., & Martin, A. P. (2017). Measuring student interactions using networks: Insights into the learning community of a large active learning course. *Journal of College Science Teaching*, *46*(3), 90-99.

Callahan, K. M. (2008). Academic-Centered peer interactions and retention in undergraduate mathematics programs. *Journal of College Student Retention: Research, Theory and Practice, 10*(3), 361-389. doi:10.2190/cs.10.3.f

Canche, M. S. G., D'Amico, M. M., Rios-Aguilar, C., & Salas, S. (2014). It's who you know: Leveraging social networks for college and careers. *The Community College Enterprise, 20*(1), 17-34.

Carolan, B. V. (2013). *Social network analysis and education: Theory, methods & applications*. Thousand Oaks, CA: Sage Publications.

Chambliss, D. F., & Takacs, C. G., (2014). *How college works.* Cambridge, MA: Harvard University Press.

Christakis, N. A., & Fowler, J. H. (2009). *Connected: The surprising power of our social networks and how they shape our lives*. New York, NY: Little, Brown Spark.

Dawson, S. (2010). Seeing the learning community: An exploration of the development of a resource for monitoring online student networking. *British Journal of Educational Technology*, *41*(5), 736-752.

Deil-Amen, R. (2011). Socio-academic integrative moments: Rethinking academic and social integration among two-year college students in career-related programs. *The Journal of Higher Education*, *82*(1), 54-91.

Deslauriers, L., Schelew, E., & Wieman, C. (2011). Improved learning in a large-enrollment physics class. *Science*, *332*(6031), 862-864.

Dijkstra, J. K., Lindenberg, S., & Veenstra, R. (2008). Beyond the class norm: Bullying behavior of popular adolescents and its relation to peer acceptance and rejection. *Journal of Abnormal Child Psychology*, *36*(8), 1289-1299.

Forsman, J., Linder, C., Moll, R., Fraser, D., & Andersson, S. (2014). A new approach to modelling student retention through an application of complexity thinking. *Studies in Higher Education*, *39*(1), 68-86.

Forsman, J., Moll, R., & Linder, C. (2012). Extending the theoretical framing for physics education research: An illustrative application of complexity science. *Physical Review Special Topics-Physics Education Research*, *10*(2), 1-13, 020122.

Freeman, S., Theobald, R., Crowe, A. J., & Wenderoth, M. P. (2017). Likes attract: Students self-sort in a classroom by gender, demography, and academic characteristics. *Active Learning in Higher Education*, *18*(2), 115-126.

Ge, X., & Land, S. M. (2003). Scaffolding students' problem-solving processes in an ill-structured task using question prompts and peer interactions. *Educational Technology Research and Development*, *51*(1), 21-38.

Goodreau, S. M., Kitts, J. A., & Morris, M. (2009). Birds of a feather, or friend of a friend? Using exponential random graph models to investigate adolescent social networks. *Demography*, *46*(1), 103-125.

Hall, D., & Buzwell, S. (2012). The problem of free-riding in group projects: Looking beyond social loafing as reason for non-contribution. *Active Learning in Higher Education*, *14*(1), 37-49.

Handcock, M. S., Hunter, D. R., Butts, C. T., Goodreau, S. M., & Morris, M. (2008). statnet: Software tools for the representation, visualization, analysis and simulation of network data. *Journal of Statistical Software*, *24*(1), 1548-1557.

Kuh, G. D., & Hu, S. (2001). The effects of student-faculty interaction in the 1990s. *The Review of Higher Education*, *24*(3), 309-332.

Li, M., & Campbell, J. (2008). Asian students' perceptions of group work and group assignments in a New Zealand tertiary institution. *Intercultural Education, 19*(3), 203-216.

Lin, N. (2002). *Social capital: A theory of social structure and action* (Vol. 19). Cambridge, UK: Cambridge University Press.

Mayhew, M. J., Pascarella, E. T., Bowman, N. A., Rockenbach, A. N., Seifert, T. A., Terenzini, P. T., & Wolniak, G. C. (2016). *How college affects students: 21st century evidence that higher education works* (Vol. 3). Hoboken, NJ: John Wiley & Sons.

Maxwell, J. (1992). Understanding and validity in qualitative research. *Harvard Educational Review*, *62*(3), 279-301.

McCabe, J. M. (2016). *Connecting in college: How friendship networks matter for academic and social success*. Chicago, IL: University of Chicago Press.

McPherson, M., Smith-Lovin, L., & Cook, J. M. (2001). Birds of a feather: Homophily in social networks. *Annual Review of Sociology*, *27*(1), 415-444.

Micari, M., & Drane, D. (2011). Intimidation in small learning groups: The roles of social-comparison concern, comfort, and individual characteristics in student academic outcomes. *Active Learning in Higher Education*, *12*(3), 175-187.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Thousand Oaks, CA: Sage.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative data analysis: A method sourcebook*. Thousand Oaks, CA: Sage.

Nespor, J. (1994). *Knowledge in motion: Space, time and curriculum in undergraduate physics and management.* Albany, NY: SUNY Press.

Newman, M. E. (2005). A measure of betweenness centrality based on random walks. *Social Networks*, *27*(1), 39-54.

Pascarella, E. T., & Terenzini, P. T. (1991). *How college affects students: Findings and insights from twenty years of research*. San Francisco, CA: Jossey-Bass.

Pascarella, E. T., & Terenzini, P. T. (2005). *How college affects students* (Vol. 2). San Francisco, CA: Jossey-Bass.

Robins, G. (2015). *Doing social network research: Network-based research design for social scientists*. Thousand Oaks, CA: Sage.

Rizzuto, T. E., LeDoux, J., & Hatala, J. P. (2009). It's not just what you know, it's who you know: Testing a model of the relative importance of social networks to academic performance. *Social Psychology of Education, 12*(2), 175-189.

Saldaña, J. (2015). *The coding manual for qualitative researchers*. Thousand Oaks, CA: Sage.

Seymour, E., & Hewitt, N. M. (1997). *Talking about leaving: Why undergraduates leave the sciences.* Boulder, CO: Westview.

Summers, J. J. (2006). Effects of collaborative learning in math on sixth graders' individual goal orientations from a socioconstructivist perspective. *The Elementary School Journal*, *106*(3), 273-290.

Tinto, V. (1993). Building community. *Liberal Education*, *79*(4), 16-21.

Tinto, V. (1997). Classrooms as communities: Exploring the educational character of student persistence. *The Journal of Higher Education*, *68*(6), 599-623.

Tinto, V. (2003). Learning better together: The impact of learning communities on student success. *Higher Education Monograph Series*, *1*(8), 1-8.

Tufekci, Z. (2017). *Twitter and tear gas: The power and fragility of networked protest*. New Haven, CT: Yale University Press.

Wasserman, S., & Faust, K. (1996). *Social network analysis: Methods and applications* (Vol. 8). Cambridge, UK: Cambridge University Press.

Webb, N. M., & Farivar, S. (1999). Developing productive group interaction in middle school mathematics. In A. M. O'Donnell & A. King (Eds.), *Cognitive perspectives on peer learning* (117-149). New York: Routledge.