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Heard it through the Grapevine - Social Network Analysis of a Hydrology Class

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Abstract: Social network analysis (SNA) was investigated as an efficient way to understand the dynamics behind collaborative endeavors and group formation in project based courses. The SNA was applied to a junior level undergraduate engineering hydrology class with two sections taught by two professors with varying levels of structure. It was found that students tended to use formal sources of information (i.e., professor, teaching assistant, textbook, or class notes); however, the use depended on the amount of structure in the class. More independent students did not collaborate in assigned groups, preferring to self-select study groups. Furthermore, the less structured class created a split atmosphere of "connected" students who had many interactions as well as "disconnected" students on the other end of the spectrum. The more structured class created fewer but more even distribution of interactions between students. The SNA study corroborated that collaborations correlate positively with class grade. In fact, those students with fewer interactions with their classmates performed poorly in the class.

Keywords: *social network analysis, group based project, engineering hydrology course, teamwork, peer learning*

Water resources engineering is inherently a collaborative endeavor and each project poses unique multi-faceted challenges that need to be overcome for successful design. As such, water resources engineers and hydrologists regularly work in (often interdisciplinary) teams. The ability to work in teams is therefore an important skill necessary for successful water resources engineering practice and must be cultivated in students as quickly and frequently as possible. The first year introductory "cornerstone" design and senior year "capstone" design have been the typical academic responses to the industry criticism of not training engineering students in soft-skills such as teamwork and communication (Mills and Treaqust 2003; Dunlap 2005; McGann and Cahill 2005; Russell et al. 2005; Shuman et al. 2005; Janicki et al. 2006; Shelby et al. 2013; Liu and Dou 2015). A variety of different team-based activities such as allowing students to collaboratively complete assignments, work together on short class projects, and even take group exams have been adopted by faculty in various engineering courses (Felder et al. 1998; Johnson 1999; Mills and Treaqust 2003; Tonso 2006; Freeman et al. 2014; Huang and Pierce 2015). These approaches not only instill and impart teamwork and collaboration skills, but have the added advantage of facilitating "peer learning," the value of which is increasingly being recognized in academic circles (Boud et al. 2014).

While the benefits of collaborative learning are readily recognized, concerns exist as to whether all students are contributing equally within their teams. Some team-members may choose to be "free-riders" which causes undue burden on the other participating members of the team. On the other hand, certain groups (or teams) may contain a strong individualistic member who may dominate and not listen or allow other team-members to contribute. Teams may also form cliques (or sub-groups) and selectively exclude certain members. This issue may arise due to perceived educational competencies as well as differences in learning and operational styles between students of different genders, races, or nationalities. These dysfunctionalities not only take away from the benefits of team-based

learning paradigms, but also increase the student's dissatisfaction with the subject matter, lower self-esteem, increase self-doubt regarding the subject matter, and eventually may contribute to retention issues (Oakley et al. 2004; Knight et al. 2007; Oakley et al. 2007; Stump et al. 2011). Tackling these issues is somewhat easier in capstone (or cornerstone) design courses as teamwork is an integral part of the outcomes and deliverables of the course. On the other hand, dysfunctional team issues may largely go unnoticed in hybrid classes which include both individualistic content-based assessment, and team-oriented problem-based learning pedagogy. Often times, the team project is a small part of the overall student's grade and as such students may be less inclined to discuss team dysfunctionalities. Furthermore, team projects are usually assigned late in the semester as a way to tie-up individual concepts presented throughout the semester; therefore, the students most affected by team dysfunctionalities may give up hope and think it is too late to discuss matters.

In the traditional mode of undergraduate instruction, students formally obtain their information from the instructor and reinforce it by reading the textbook and other supplemental material (usually provided by the instructor) as well as carrying out prescribed assignments. Most classes also have graduate teaching assistants (TA) who help students with their queries informally during their office hours or semi-formally through supplemental instruction. In addition, students form study groups and share information informally. As TAs tend to be closer in age to students, and are in a somewhat similar situation (i.e., juggling their time between classes and other student-type activities) some students feel a higher level of comfort obtaining information from TAs rather than the instructor. This level of comfort may be further enhanced if the instructor has other administrative responsibilities and is perceived to be busy by students. In a similar vein, some students find it more comfortable to obtain information from a peer (who may have a better grasp of the subject matter) or one who has already met with the instructor or TA (despite the second-hand nature of the information) rather than go themselves. The proliferation of web-based materials, the advent of social media, and the availability of online resources have increased the informal channels through which students can receive information. Information presented with high graphical content (e.g., animations and YouTube videos) may be appealing to some students instead of the static presentations found in a textbook. Students may also find greater comfort and convenience in obtaining information from digital sources as they are available 24/7 and provide anonymity to the student which shields them from feeling inadequate in front of their instructors and peers.

Understanding the information flow in a classroom is important on several fronts: 1) it provides an understanding of how the textbook and assigned readings are being perceived and used by the students; 2) it helps evaluate the role of the TA and make appropriate adjustments mid-course; 3) it aids in the identification of online materials that students have found helpful but are otherwise unknown to the instructor; 4) it helps identify those students who have formed study-groups and those that appear to be working individually; and 5) it enables the instructor to understand the differences in working with students belonging to under-represented minorities versus those belonging to the majority population to find better ways to reach out to the class as a whole.

Social network analysis (SNA) is an information-theoretic approach that seeks to characterize and quantify the structure of social interactions among a set of actors (individuals within a system). SNA uses concepts derived from network and graph theories to map interactions within the network (Otte and Rousseau 2002; Freeman 2005). SNA has not only found widespread acceptance in various social sciences and natural resources disciplines, but has also been used to understand computer and telecommunication networks (Pinheiro 2011). Martinez et al. (2003) made use of social network analysis to study social interactions in a project-based computer architecture class. de Laat et al. (2007) used SNA in conjunction with content analysis (CA) and critical event recall (CER) to understand how students learned in a computer-assisted network learning environment. Amory (2007) presented a game object model (GOM) for transformative learning and acknowledged the important role of social networks in promoting

gender-inclusive, non-confrontational outcomes and building democracy and social capital through computer-mediated communication tools. More recently, Vaquero and Cebrian (2013) reported that students' performances are linked to social structures and interactions. Lee and Bonk (2016) evaluated the role of blogs in improving peer connectivity among students and use social network analysis to quantify improvements in classroom interactions that are critical to building learning communities. However, the use of SNA as a mid-course assessment tool has not been reported in the literature and as such forms the focus of this study.

The present study is an innovative application of social network analysis in a project-based introductory junior-level engineering hydrology course. The study demonstrates how social network analysis of data generated from a simple, less than 10 minute survey that asks students to list the names of students and other sources (TA, textbook, instructor, etc.) they use to solve homework problems, study for exams, and work on the project during the semester can yield valuable insights related to information flow in the class. The results of the study lead to a fundamental understanding of where the students are getting their information and help identify key resources and personnel upon which students most rely. The analysis also provides other insights critical to reaching out to students in the class and thus promotes effective, information-oriented teaching practices.

Structural Characteristics of Networks - Social Network Analysis

The mathematical theory of SNA provides a formal framework to assess the interactions taking place in a social system. The basic vocabulary and key concepts pertinent to understanding social networks, particularly in the context of this study, are summarized here. The interested readers are referred to several excellent textbooks such as Knocke and Yang (2008) and Borgatti et al. (2013) for more detail. SNA begins with the definition of a social system of interest. Just as with physical systems, a social system is conceptualized to have well-defined boundaries. The social system is comprised of a set of individuals (referred to as **actors** in SNA parlance). There is a certain degree of interaction between the actors within a network. Characterizing the nature and extent of these interactions is the primary focus of SNA.

Networks within a social system can be defined at several levels. The **ego network** maps the interactions of an individual actor within the social system. The focal actor is referred to as the **ego** and those connected to this actor are referred to as **alters**. An ego network can be constructed for every actor within the social system. In contrast, a **complete network** simultaneously maps the interactions between a set of actors within a social system. A **directional graph** or a **digraph** is a graphical representation of the social network. The actors of the network form the **nodes** of the digraph and directed lines called **arcs** connect the nodes. The arcs have a direction and connect senders to receivers. **Senders** are actors who nominate and **receivers** are the nominees. A **reciprocal** or a **mutual tie** exists between two actors when they both nominate each other. Unlike a digraph, a **graph** has no directional arcs and simply connects the actors with arrowless lines called **edges**. In a classroom setting, links to formal information sources (i.e., instructor, textbook, and TA) are the senders of information while students are mostly receivers. In groups with high collaboration and teamwork, there are a large number of mutual ties.

Ego networks are useful to compare various actors within a social system. For example, some egos (actors) have larger networks than others which may have an effect on external measure (e.g., performance in the class). In addition to the size, it is also important to understand: 1) how the alters of an ego share ties with others (referred to as **ego network density**); 2) the attributes of egos and alters (e.g., gender, race, grade point average (GPA)); and 3) the tie-strengths across the ego networks (i.e., is there a shared learning or one-directional teaching type behavior). **Centrality** is an actor-level measure that reflects the ideas of relative importance of an individual within a larger (complete) network. Actors who have more ties compared to others in the network are considered to be more **central** to the network. Several measures of centrality have been proposed in the literature and are summarized in Table 1. Many of these centrality measures can only be measured on graphs

(and not digraphs) and do not account for mutual ties. In a classroom context, formal information sources (instructor, textbook, and TA) should have high centrality scores relative to individual students. Centrality measures are also useful to identify connected students who are sought after by other classmates for information. In a similar vein, actors having low centrality scores are not well connected within the network and could be used to identify students who are not fully integrated within their groups and/or information sources that are not perceived as effective by the students.

Subgroups of networks can be viewed as cohesive subsections of a network and as such could represent a study group or a design team within the class. Alternatively, subgroups can also be conceived as subsets of actors (e.g., instructors of different sections, TAs) that share a similar role. Positional analysis is a class of SNA that seeks to evaluate networks associated with actors who are in a similar position (e.g., TAs) within the social system of interest. **Cohesion** is an important concept associated with the network as a whole. A perfect cohesion implies that all actors of the social system are connected through some kind of social tie. **Density** is a measure of cohesiveness and measures the proportion of all possible ties that are realized within the system. If the density is high there are considerable interactions among different members. Density in itself is, however, an incomplete measure of the network. Clearly, density will be expectedly low when there are a large number of actors. A large value of density could arise because a single actor has a large number of ties. In a classroom system, there could be a popular instructor, TA, or student from whom many students may be obtaining information. These actors will increase the density measure, but do not necessarily contribute to the overall cohesiveness of the class. **Degree centralization score** (or centralization score) looks at the extent to which one actor in a network is holding all the ties and can vary between zero and one. For example, if the centralization score is unity then there is a single actor who is connected to all other actors. At the other extreme, a score of zero indicates a perfectly diffused network where all the actors have the same number of ties. A simultaneous evaluation of density and centrality provides vital clues towards network cohesion. A network with a high density and centralization score is less cohesive than a network with the same density score but a lower centralization score (Prell 2011). A network with a high density and centralization score where the central actor is a formal information source (i.e., instructor, textbook) is preferred in classroom settings. In a similar manner, less dense and more diffuse networks are preferred when evaluating teamwork and collaboration efforts among students. As can be seen, SNA provides a useful set of tools to evaluate the effectiveness of classroom and group work.

Table 1. Various centrality measures used in Social Network Analysis.

Centrality Metric	What does it Measure?
In-Degree	How many people come to this person for information?
Out-Degree	How many people does this person go to for information?
Betweenness	How likely (or how many times) is this person between two other people in network?
Closeness	How fast can this person get information to others in network?
Eigenvector	How well is this person connected to other well connected persons in network?

Illustrative Study

CE 3354: Engineering Hydrology is an early junior level class that is required for the four year Bachelors of Science in Civil Engineering (BSCE) and a five-year integrated Masters of Environmental Engineering (MSEE) degree offered at Texas Tech University. The course is the first water-related design course in the curriculum and covers traditional concepts related to watersheds, water budgets, hydrologic processes (rainfall,

initial abstractions, infiltration, evapotranspiration, and runoff), river and reservoir routing, and basic concepts of groundwater hydrology. The course also provides the first design experience within the curriculum and requires students to work on a team project which accounts for 30% of the overall grade. The design project is assigned roughly a month after class begins and is due at the end of the semester. Students are semi-randomly divided into teams of four or five members. The project provides an opportunity for the students to apply certain concepts learned in the class (e.g., watershed delineation, flood routing) in a "real-world" like setting. The project also expands the coverage of certain concepts, such as the time-distribution of design storms, which are only cursorily covered in the lecture. The students make use of the industry-standard HEC-HMS software (USACE, 2015) for the project. The projects generally require the students to evaluate and pick the best (from a hydrologic standpoint) land-development (urbanization) option among several potential alternatives and/or require students to evaluate the adequacy of detention structures to minimize flooding hazards downstream. The students are required to work in groups, keep track of their effort using time-sheets (that are signed by all team members), and write technical memos during the course of the semester. The class is designated as a writing-intensive course and students are provided feedback on the technical memos without penalty to improve their writing skills. These memos are then aggregated with appropriate additions and submitted as a final report which is graded. Each team submits one final report which is awarded an average grade. This average, in conjunction with the reported time and effort, is used to assign project grades to individual group members.

Project teams are identified early in the semester to ensure that students become aware of the working habits of their team members. A short team-building exercise is conducted in class to help students brainstorm and learn how other members on the team think. To further develop teamwork and collaboration skills, students also work collaboratively on several homework assignments. Students are required to make individual submissions and must explicitly acknowledge the help and assistance obtained from other classmates and other sources. Students are also encouraged to sit together as a team during class hours and work together on in-class assignments. This project-based seating is, however, not strictly enforced in the class. Semi-random assignment of team-members based on overall GPA and grade in Fluid Mechanics is used to increase diversity of teams and spread out students of different academic preparation, backgrounds, gender, and race. However, collaborations outside the project team are not discouraged for other class activities. Students can form their own study groups to study for exams and solve homework assignments.

A short-survey was conducted roughly two months into the Fall 2013 semester. Two sections of the class were taught separately by the authors of this paper and each section had a separate TA. While the instructors followed the same textbook and roughly followed the same sequence of topics, the homework assignments and in-class lectures were not synchronized by the instructors. Furthermore, the instructors were free to employ their own pedagogic style. Professor 1 mostly provided hints to solve problems or provided an overview of necessary steps, whereas Professor 2 walked students through the various steps involved. At the time the survey was administered, the project teams had been identified and had performed a few tasks (e.g., watershed delineation and synthetic hyetograph generation) for their final project in both sections. Also, students in both sections had completed several homework assignments where they had the option to work collaboratively, and had taken a test for the class.

The survey was short and administered at the beginning of the class, without any prior notice to the students, and consisted of the following question:

> *List the names of students as well as other resources (TA, Professor, Textbook, Notes) that you get information from to solve homework problems, study for exams, work on the project for CE 3354 Engineering Hydrology. (Please be as complete as possible).*

Students were given an opportunity to provide additional comments. Student names were coded to preserve their anonymity. The gender, ethnicity, and overall GPA of each student were ascertained and summarized for additional analysis. Most students in the class were either in the four-year BSCE or five-year integrated MSEE program,

except for one Engineering Technology student who was taking this class as a technical elective. Figure 1(A) shows the incoming GPA for each section and there was no statistical difference between the two sections. While both sections had similar class sizes (25 and 24 students in Sections 1 and 2, respectively), the gender and ethnicity of the students varied considerably in both classes; these characteristics are summarized in Table 2. In addition, a majority of the students belonged to the same cohort. Similarly, many students had taken earlier engineering classes together and belonged to the same student organizations. As such, many of these students had prior interactions and had established informal coalitions (e.g., study groups) before entering this course. However, the survey did not ask any questions to determine these prior interactions. The required data were compiled separately for each section in a spreadsheet and SNA was carried out using the R programming environment (RDC Team 2011).

Table 2. Gender and ethnic characteristics of students in CE 3354 Hydrology Class.

Gender/Race	Section 1	Section 2
Male	19	20
Female	6	4
Hispanic	9	1
White	15	19
Black	0	2
Other	1	2

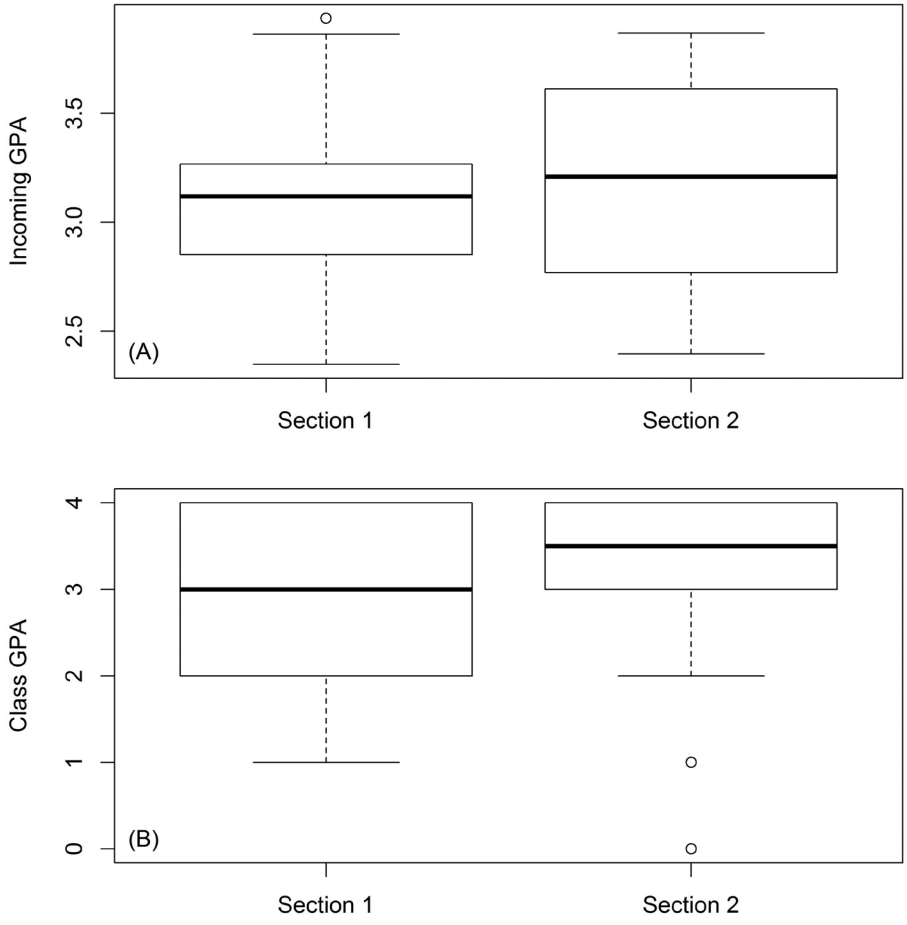

Figure 1. (A) Distribution of cumulative GPAs of students entering CE 3354: Engineering Hydrology. **(B)** Distribution of student grades in CE 3354: Engineering Hydrology.

Results and Discussion

How Are Students Seeking Information from Formal Information Sources?

The ego networks for professors and TAs are shown in Figure 2. Approximately 10 students in each class went to their respective professors for information outside the class. In addition, five students from Section 1 sought help from the professor of Section 2 (Professor 2). It is evident there were greater (two-way) interactions among students who visited Professor 1 outside the classroom than those who visited Professor 2. This situation can be attributed to the pedagogic styles of instructors. The teaching style of Professor 1 required students to compare notes and solutions more frequently than Professor 2. These differences in pedagogy may also explain why very few students in Section 2 went to their TA (TA 2), while the TA for Section 1 (TA 1) was sought after by many students.

Are Students Reading Their Textbook and Referring to Their Notes?

The ego networks for the textbook and class notes as sources of information are depicted in Figure 3. The in-degree centrality for the textbook was 14 and 16 in Sections 1 and 2, respectively. The reliance on the textbook was higher than on professors and can perhaps be attributed to the fact that the course required students to pull out design information (e.g., curve numbers, Manning's coefficients) from the textbook to solve homework

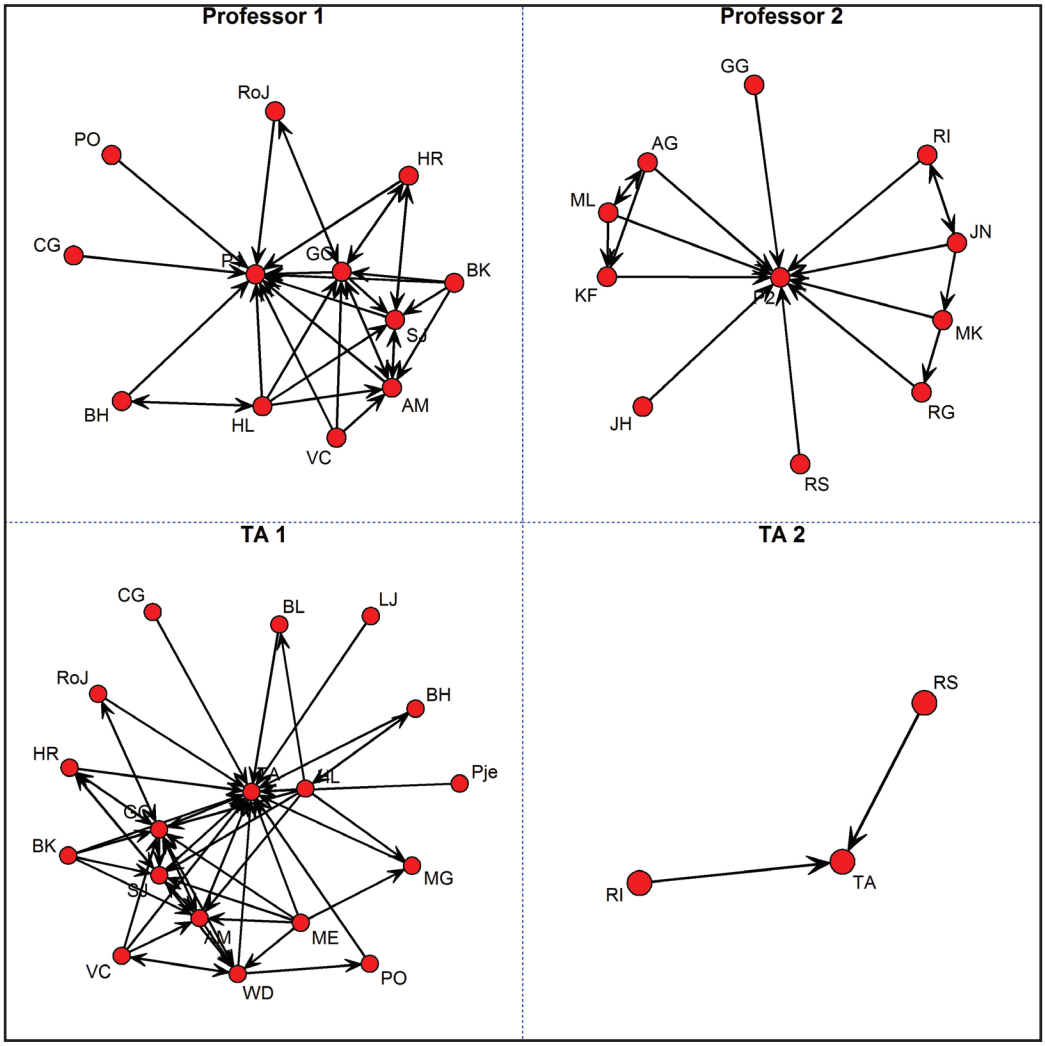

Figure 2. Ego network of professors and graduate teaching assistants.

problems. This result also indicates that nearly 44% of students in Section 1 and 33% in Section 2 did not refer to their textbook and possibly relied on other sources. Furthermore, 16% of students in Section 1 and 12.5% of students in Section 2 who did not rely on the textbook, sought help from the instructors; therefore, a significant number of students (over 20%) relied solely on class notes and/or did not indulge in additional reading outside of the classroom. The ties between students who indicated using the textbook for information are low. This result indicates that students are probably reading their textbook on their own rather than in group study sessions.

Professor 1 mostly used a non-structured lecture style (i.e., devoid of PowerPoint or other electronic technologies) and provided printed problem statements on blank sheets that students used to take notes during class. On the other hand, Professor 2 mostly used the Document Cam in class and provided these structured in-class lecture notes online (via Blackboard) after the completion of the lecture. Nearly 2/3rd of the class in Section 2 indicated they relied on these structured in-class notes, while only 36% of the students relied on in-class notes (that they took on their own during the class) in Section 1. Again, the lack of structured notes increased collaborations between students in Section 1 as they had to compare notes to ensure they had all the necessary information captured from the lecture. While the lack of structured notes allowed for greater collaboration, it is important to note that nearly 66% of the class did not rely

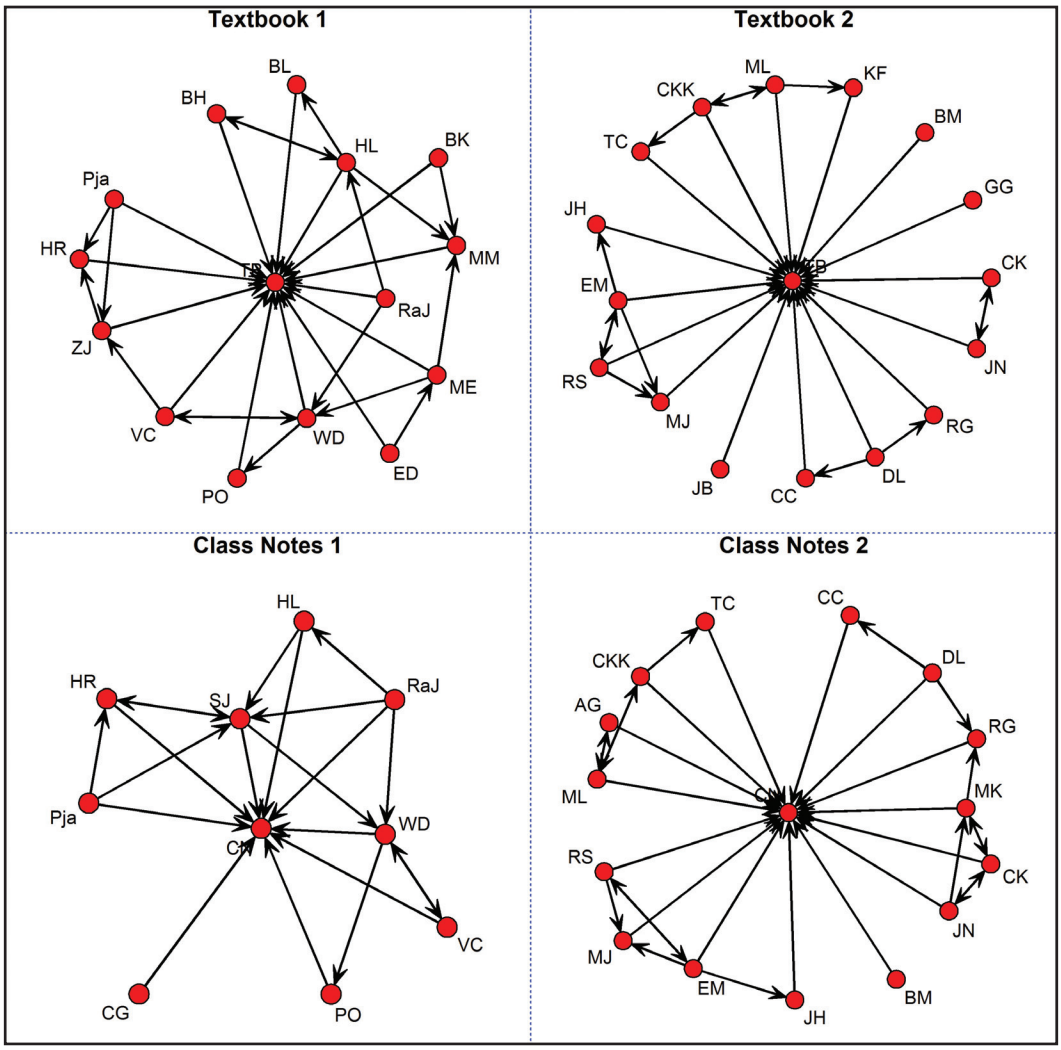

Figure 3. Ego network of textbook use and class notes use.

on class notes in Section 1 and had to depend on other sources of information.

Are We Creating Connected and Disconnected Students in Class?

Connected students are those sought by other students in the class for information. The degree of in-centrality can be used to identify such connected students and their ego-networks (Figure 4) and help identify students who rely on them. All these connected students made use of formal information resources and made regular appearances during office hours. The eigenvector centrality values (ranging from a high interaction value of 1 to a low interaction value of 0) presented in Figure 4 also indicate that these students were interacting among each other to a relatively higher degree. Interestingly, all the connected students identified were in Section 1 which was far less-structured than Section 2.

There were a total of nine students (six in Section 1 and three in Section 2) that had an in-degree centrality of zero. These students were not sought out by their classmates for information. On the other hand, five students (two in Section 1 and three in Section 2) had an out-degree of zero indicating that while these students were sought by some students for information, they did not rely on other students to get their information. These students largely worked independently and did not often collaborate with their classmates. A total of two students (both in Section 1) had both their in- and out-degree centralities as zero, indicating that they were

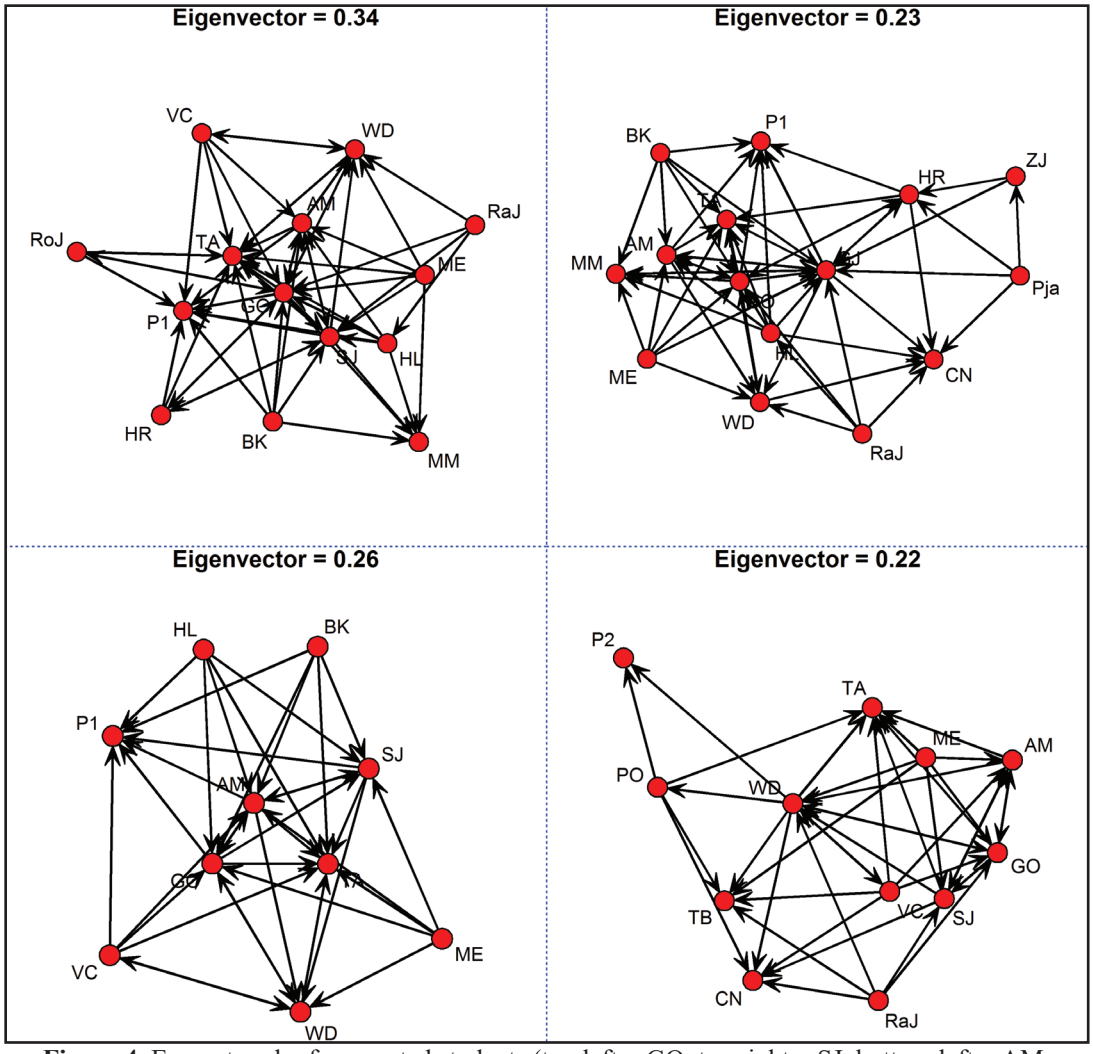

Figure 4. Ego network of connected students (top left = GO, top right = SJ, bottom left = AM, bottom right = WD) and their eigenvector centrality measures.

completely disconnected and did not interact with others in the class even on project tasks that required teamwork. These disconnected students were mostly present in the far less-structured Section 1.

Identification of disconnected students is essential to correct "freerider" problems in teams. Discussing students' situations and reasons for their inability to work with groups, and discussion with other team members with regards to their inclusiveness efforts, provide suitable interventions to improve team efforts. In a similar fashion, information content of connected students must be carefully evaluated throughout the semester to ensure that "misinformation" is not accidently propagated through the class. Scheduling regular meetings with these students can help get the pulse of the class and provide the right structure and guidance to ensure information presented in the class is being transferred effectively throughout. It is perhaps best to use TAs for this purpose to avoid any semblance of favoritism to students.

Are Students Working with Their Assigned Teams or Self-Selecting Study Groups?

For the class design project, both sections divided students into six groups of four students each (one group in Section 1 had five students). The assignment of teams was done early in the semester to improve teamwork and collaboration within the groups. The degree value for each team was computed by quantifying the number of times the students within a group identified other members of the group as someone they went to for information, summing up all such interactions, and dividing the result by the number of all possible interactions. For example, a team of four would have 12 potential interactions as each member can interact with three other teammates. If the total number of actual interactions was six, then the degree of the project team was 50%. The results presented in Table 3 indicate minimal interactions between teammates, suggesting that students primarily created study groups prior to the design team assignments and mostly worked with them unless required to work with other teammates. Extremely low group interactions were seen when disconnected students were paired with connected students. This result corroborates an earlier study by Vaquero and Cebrian (2013) who found evidence of "rich-club phenomenon" in unstructured classes. The "rich club phenomenon" states that certain students have a disproportionately high level of information when compared to others in the class and some students find it hard to fit in with these popular students, perhaps due to large differences in their academic preparation, and essentially become disconnected. The group degree of centrality measures could also be used to test the veracity of time-sheets submitted by students and also discuss the importance of teamwork with students and find ways to reduce dysfunctionality and increase collaboration.

How Does Collaboration Correlate with Class Grade?

The in-degree and out-degree centralities were plotted against the final GPA that students received in the class (Figure 5). In the less structured Section 1, the median in-degree centrality increases exponentially with GPA. Clearly, students with higher GPA are sought after by students who eventually received lower GPA in the class. This trend is not as evident in Section 2 which was more structured; and, as seen previously, students relied more on the instructor and the class notes provided to them. The median out-degree centrality also increases with eventual GPA in both sections. Furthermore, from Figure 1(B), it can be seen that while the individual GPA within each section varied, the less structured Section 1 showed less instances of students being left behind. In Section

Table 3. Degree measures for project teams (Number of Interactions/Possible Number of Interactions).

Group	Section 1	Section 2
1	4/12	3/12
2	6/20	5/12
3	1/12	3/12
4	3/12	9/12
5	7/12	1/12
6	1/12	5/12

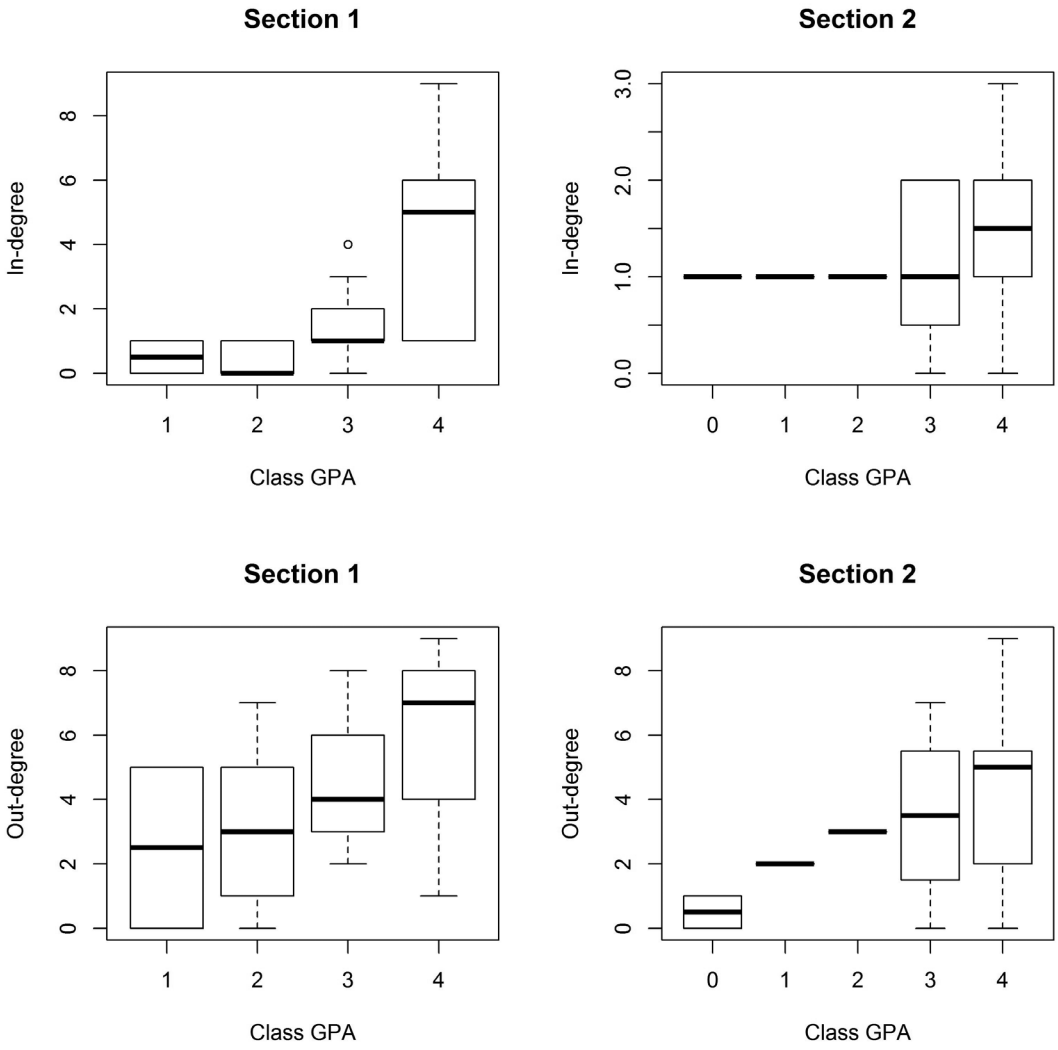

Figure 5. Variation of in-degree and out-degree by class grade.

2, while the average class GPA was higher, there were outliers of students at the lower grade level. These results suggest that collaborative learning correlates well with better class grades and corroborates earlier empirical findings that indicate collaboration among students improves learning the objectives of the course (Prince 2004).

Summary and Conclusions

This study presented the use of SNA in a project-based introductory junior-level engineering hydrology course to understand where students were getting their information and to identify students who were disconnected. Furthermore, insights into the efficacy of different teaching methods (structured vs less structured) and how they impacted student learning were discussed in the results of this study. Students were equally likely to seek information from the professor regardless of teaching style; however, assistance from the graduate TAs was sought to augment professor instruction in less structured classes. Conversely, the independence promulgated by the less structured class resulted in more mature and self-selected collaborations, but created extremities in classroom interactions (i.e., connected students and disconnected students). Not all students relied on the textbook for information, even though the homework assignments required students to pull

design information directly from the textbook. The design team assignments helped students who relied solely on their professor more so than students who were well connected in the classroom. Regardless of teaching method, students with greater collaborations resulted in higher individual final class grades.

SNA in the classroom has proven to be a useful tool for understanding the needs of the students and for recognizing which students may be falling behind their classmates. It aids in identifying specific weaknesses in information distribution and dissemination. Secondarily, SNA can be used to adjust teaching styles to fit the learning style of the class as a whole. Furthermore, implementing SNA along the entire undergraduate curriculum can aid in evaluating when students reach a level of independence that brings about more meaningful collaborations.

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