Collaborative Work Networks among Distributed Learners
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Abstract
This paper examines collaborative work networks and media use among a class of distributed university distance learners. Social network data on interactions via each of the available media were gathered at three times during the term. Class members made most use of Webboard, IRC, Email and face-to-face meetings. Results showed that media filled different niches in the collaborative work patterns of this distributed group and suggest that while some media were almost exclusively providing support for project work (e.g., Email), others came to provide the type of class-wide interaction that supports the exposure to ideas and experiences of others that is a requirement for collaborative learning (e.g., IRC, face-to-face).

1. Introduction
Computer support for learning, like computer support for work, has evolved from supporting individuals at their computers, completing tasks on their own, to supporting collaborative learning among sets of learners with each member contributing to the group goal. The adoption of collaborative learning strategies in education and advances in computer technology have combined to create the field of Computer Supported Collaborative Learning (CSCL) (see [35, 44, 48]). Both CSCL, and Computer Supported Cooperative Work (CSCW) share a common interest in the cooperative and collaborative work and learning processes that allow individuals to work together in groups, teams, or classes, and in how these processes can be supported and mediated through computer technology. CSCL environments are also the training ground for tomorrow’s computer-supported cooperative workers, and as such they provide not just subject-specific learning, but also the group collaborative skills necessary for the CSCW environment [20]. Thus, a collaborative learning environment shares much in common with a collaborative work environment, and vice versa, and research from each environment can have application and relevance to the other [12].

This paper brings together research in CSCL, CSCW, and computer-mediated communication (CMC), in the examination of collaborative work networks among a class of distance learners. The research takes a social network approach to collaboration and information exchange among these learners, examining the development of collaborative work networks over the term, and the way in which the class makes use of the available media to accomplish their collaborative work. By using a social network approach, it is possible to describe interaction patterns among all members of the class and to assess empirically the degree of collaboration among all class members.

1.1. Collaborative groups
Like any other group support system, the CSCL environment must provide the means to support group functions relating to task completion, goal attainment, interpersonal interaction, and group maintenance [12, 28, 44, 51]. CSCL and CSCW groups apply themselves to tasks within a limited timeframe during which they develop as a group [44, 52, 53]. Most notable in educational settings is adherence to the semester system, which enforces a temporal beginning and ending of tasks associated with course work. Within their timeframe constraints, groups begin their association, develop, experience crises, attend to deadlines, execute their tasks, and conclude their association [9, 10, 31, 52, 53]. Although groups go through stages when one type of support may be more necessary than others, groups may also show intermittent need for each kind of support [31, 51, 52, 53]. Therefore the mechanisms for each type of support must be ready and available throughout a group’s lifecycle.

When contemporary, technology-mediated groups begin to work together, they also begin an association with their technologies, and have the added task of developing group norms regarding technology use as well as interpersonal and task interactions. Members of such groups get to know each other and their technologies over time, learning how to interact with each other and how to use their technologies for group interaction and work production [10, 35, 59].

The importance of the computer in these collaborative and cooperative environments is not its use as a tool or task coordinator, but rather “as a medium through which individuals and groups can collaborate with others” [2, p. 271]. Collaboration requires facilities
for planned and ad hoc communication, resource sharing, and group process support [44]. It is not just “collaboration ‘around’ computers” with the computer providing a means to coordinate tasks or to simulate problem-solving situations, but rather “collaboration ‘through’ computers” [16, p. 168] where group members use the computer to structure and define their collaborative endeavors.

Communication, interaction, and exchange of resources are the building blocks of the social networks that sustain and define work groups, learning groups, and communities. Interacting through computers, learners, workers and community members develop computer supported social networks [29, 40, 71], successfully maintaining strong, close, multi-relational ties via CMC, as well as taking advantage of the diversity of experience available from the wider range of contacts afforded by CMC [13, 23, 45, 47]. Ties between pairs build into the social networks that are the underlying structures of groups and communities. For online groups, communication ‘through’ computers is the only way to create such ties and to form such communities. There is now a growing literature that agrees that virtual communities can and do exist online, and are sustainable in this way [4, 5, 17, 43, 46, 55, 60].

Both group support and community support are important for learning environments. Virtual communities are seen as a “powerful means of enhancing distributed learning” [20]. Learning, recognized now as both a social and intellectual task, can profit from the mix of interaction that occurs in a virtual community. The extension of interactions to times “outside class” afforded by the existence of a virtual learning community allows for more sustained interaction and the creation of closer interpersonal bonds [35]. These learning communities are also special because they provide transition communities: safe places where ideas can be tried as students learn to become members of their knowledge communities [7].

These virtual communities tend to be sustained via media that do not define the way in which interactions should take place. “Permissive” [28] and “interpretively flexible” [58] communication systems allow groups free reign in defining their collaboration. Communication systems that support CSCL in this way include asynchronous text-based electronic mail, bulletin boards, and webboards; synchronous audio- and video-conferencing and telephones; and synchronous text-based chat rooms (e.g., Internet Relay Chat (IRC), Multi-User Dungeons (MUDs and MOOs); for a description of IRC, see [72]; for a description of MUDs, see [17]).

When using these applications, it is the learners’ input that shapes the interaction, rather than a structured definition of the learning task.¹ Learner input contributes to the success of collaborative learning over former transmission models. Active construction of knowledge, problem articulation, and peer-to-peer communication are integral components in the success of collaborative learning [19, 35]. The free-flow of input from many participants is also important: the more input offered, from more others, the wider the exposure to different problem-solving approaches, different viewpoints, and different spheres of knowledge and information, each of which enhances an individual’s learning, adaptiveness, and ability to recognize opportunities [11, 8, 19, 33, 37].

Informal interaction is important for forming friendships and for maintaining support among group members. Bonds of friendship interact with work duties in ways which enhance the flow of information among closely tied individuals and promote the work process [24, 39, 51]. Harnessing these informal processes is also important in collaborative learning. Bruffee suggests that collaborative learning has “worked” when it has mobilized “to educational ends the informal cooperation typical of student life” [7, p.5].

Since distributed teams lack opportunities for traditional face-to-face forms of informal contact, understanding and providing support for informal communication has been an important part of the CSCW agenda (e.g., [21, 25]; see also [1]). Similarly, it is also important for CSCL. As Kaye states,

“It is very important to build into any system tools and resources for informal communication, socialisation, and group bonding. In the campus or office environment, informal and chance discussions in the corridor, the canteen, around the coffee machine, in the library, provide the ‘social glue’ for interpersonal collaboration. Effective virtual environments for group learning need to provide similar opportunities for serendipitous encounters.” [44, p.203]

Overall, it is clear that group interaction is important for both CSCL and CSCW. Although the outcome of interest differs—learning in the educational environment, production in the work environment—the group processes that bring about these outcomes are similar in both cases. Moreover, the work environment is

¹ Such systems come with the caveat that “unstructured” may also be “unproductive.” Reinstituting social rules to structure online discussion is a concern of CSCL researchers and distance educators. Kaye [44] notes in particular the need for “new skills for the management of social control” (p.206); and Murphy & Collis [56] reported the need to add structure to discussions via IRC so that speakers did not ‘trip’ over each other, discussion proceeded at an appropriate pace and the class objectives were met.
not devoid of learning, and the learning environment is not devoid of production. Individuals at work learn how to work with others and with local tools; as apprentices, they learn the skills and knowledge necessary to perform their work and to become members of their “communities of practice” [50]. Individuals in educational environments complete assignments, produce research papers and projects, and give presentations, often as a result of group effort.

Studying group interactions and the way in which they affect learning and the learning environment, and studying the role of technologies are important for both CSCW and CSCL researchers [12, 20, 44]. When members of groups interact, the connections they form create social networks that constrain or facilitate the flow of information and resources. The conditions that promote successful collaborative learning and collaborative work, namely the need for contributions to group discussion, circulation of information among members of a bounded group, and cooperative interchange among group members, are social network issues. Thus, a social network perspective provides an important way of viewing these processes, and of viewing computer use in support of these processes.

1.2. Collaborative learning and social networks

The social network approach holds that behavior is affected more by the kinds of ties and networks in which people are involved than by the norms and attributes that individuals possess. The social, informational, or material resources a pair exchanges characterizes their tie. In social network analysis, these resource exchanges are termed relations. The patterns of relations and ties build into social networks that reveal the flow of resources among members of a group, and the way in which group members are interconnected (for more details on social network analysis, see [37, 57, 63, 67, 68]). Social network approaches to computer-supported groups explore the nature and range of online ties and relations [29, 41, 39, 61, 68, 69].

Using a social network approach to CSCL we can ask: How well does information circulate to all members of the group, team or class? Is the true size of the group a class member interacts with the same size as the class, or do class members restrict their information exchanges to a smaller sub-set of the class, thereby limiting their exposure to ideas and information? For computer-supported and distributed groups, we can also ask whether particular media are better for supporting the production of work, for generating discussion, for reaching all members of a class, or for allowing sub-groups to complete projects.

1.3. Research questions

A fundamental question of the research presented here is one similar to that posed by Bannon regarding CSCL studies: “Who or what is collaborating with whom, and under what conditions?” [2, p. 270]. Here, Bannon’s question is modified to ask:

- Who is collaborating with whom, and what media support this collaboration?

This question is not answered a priori, but rather from an examination of the interaction patterns of the group.

There are two issues related to the first part of the question, who is collaborating with whom: how (and whether) information circulates among all group members, and who is actually collaborating with whom among the class members. If a key to successful collaborative learning is that group members interact and share experiences with each other, then the first issue to examine is how much the total group is participating in interactions. How well does information flow among group members? How much does the group share its information? For collaborative classes, this makes the difference between an intended collaborative learning situation and a true collaborative learning situation. Thus, we can empirically evaluate the extent of collaborative activity. Second, if information is not evenly distributed among group members, how is it distributed? How large (or small) are the collaborating sets, i.e., what is the actual size of the collaborative group rather than the size of the class.

The second half of the question addresses the content of the communication that supports collaboration, and the media that support this communication. Arguments about using rich media for equivocal communications and lean media for more instrumental communication (e.g., [18]) have largely given way to emergent group definitions of media use [14, 27, 59]. This means that what medium will be used for what communications cannot be predicted a priori. Again, an empirical assessment of media use is needed.
Since group norms may emerge over time, communication and media use need to be examined over the term to see whether and how collaborations develop and how they are managed. Therefore, a second question in this research examines how collaborative networks develop and change over time.

- Who is collaborating with whom over the life time of the group, and what media support this collaboration?

2. The Study

To address these questions, social network data on communication among 14 student members of a university graduate distance learning class were gathered in Fall, 1997. Members of the class were interviewed by phone at three times during the fifteen week term and asked to report on their interactions with every other member of the class. Nine of the students lived in the same state as the university giving the course, but were not local to the university, and five came from other states; three of the students were male. All but two of the 14 completed the class. The two who did drop the class did so late in the term (during the last month); they were interviewed for their last month’s interaction and their names were kept on the roster so that other members of the class could indicate their interactions with them. Their data are included in the data presented here; however, to preserve anonymity they are not specifically identified.

Students were asked how often in the last month (daily, weekly, monthly) they had collaborated on class work with each other member of the class. They reported their frequency of communication with each other member of the class via each of the available means of communication: Webboard, Internet Relay Chat (IRC), electronic mail (Email), the phone, face-to-face scheduled or unscheduled meetings, or other media they indicated they used. Data on this collaborative work relation allows construction of the networks of who collaborates with whom, and via which media.

Data on four other social network relations were also collected at the same time. Students were also asked how often they had (i) given, or (ii) received, information or advice about class work, (iii) socialized, or (iv) exchanged emotional support with each member of the class. Although this paper focuses on the collaborative work relation only, an earlier examination of the results suggests that this network overlaps with the information/advice and socializing networks (see [38]). Positions in the network showed a higher association across the collaborative work, information/advice, and socializing networks than with the emotional support network, suggesting a difference in who is more prominent in the work versus emotional support networks. (Further examination of the work versus emotional aspects of group behavior will be the subject of future work.)

Thus, this paper focuses on the collaborative work relation only, but with an awareness that this collaborative work is directed toward a learning activity, i.e., class work, and that this relation is also associated with the exchange of information or advice about class work, and with socializing.

2.1. Class contact

The class met each week via a required “live” online session. The instructor lectured from the faculty laboratory using RealAudio and PowerPoint slides presented over the Internet. Students used an Internet Relay Chat (IRC) facility to submit questions during the live session which were answered via the RealAudio link. During the week students responded to discussion questions posted on a webboard by the instructor. Students were required to respond during the week and most did so regularly.

Students signed up for group projects according to common interest in one of four topics, with three to five members in each group. For each topic, the instructor established a webboard conference for the group members to use for communication. Three groups met regularly in their conferences. Groups gave presentations at two times during the term. The first presentation was a practice run on using the technology. Students nominated a spokesperson whose phone line was patched to the RealAudio link so all class members could hear the talk. Another student managed the presentation of the slides on the Internet. A similar presentation was also given for the final project. Students completed five individual assignments and the group final project. With few exceptions, all these were “handed in” over the Internet.

Students had continuous access to Email, the class Webboard conference, IRC facilities, and the telephone. One set of students made use of NetMeeting, (Microsoft’s network meeting software); and another group made use of a repository facility (SiteShare) for sharing documents. Although asked about face-to-face interaction during each of the three time periods, students reported meeting face-to-face only during the second time period (Time 2). This is the time period during which students came to campus for a scheduled two day session. Therefore, it is likely that all the face-to-face interaction that was reported occurred during, and because of, the on-campus
meeting. Students may have met each other previously: all students attend an on-campus two week session when they begin the distance program, and students may have been in courses together before this class. However, if students had joined the program at different times they would not have met face-to-face before the class began.

2.2. Data

Data were collected from 13 of the 14 students in the class (93%). One student could not be contacted. Of the 13 who responded, 12 reported on their interactions at each of the three time periods and one responded at two time periods (90%).

Adjustments were made for the one missing time period and the one missing student. Reasonable estimates of a student’s interactions with others at these time periods are the responses given by the others [65]. For these individuals, data were taken as the responses others gave for interaction with them during this time period, e.g., if student A said they communicated with B, the missing student, four times in the last month, the data for B’s interaction with A was taken to be four.

The data are reported estimates of frequency of communication about collaborative work, via each of the media, at three time periods. Students reported frequency estimates of daily, daily to weekly, weekly, weekly to monthly, and monthly. These responses were converted to numerical estimates of frequency of communication per month: daily communication was scored as 20, daily to weekly as 12, weekly as 4, weekly to monthly as 2.5, and monthly as 1. Total frequency of interaction for a relation for each time period is calculated as the sum of the frequencies of interaction via each medium; and totals across the term as the sum of the frequencies of interaction at each time period.

Such self-report frequency data are not expected to be objectively accurate, but are expected to allow comparison across relations and across media. Previous studies have found that data on whether or not participants performed a task were reliable, the rank of the activity relative to other activities was fairly reliable, but estimates of specific amounts of time spent on activities were not accurate [36, 62]. Thus, such data should be taken to indicate a relative rather than an absolute measure.

3. Who is collaborating with whom?

To examine who is collaborating with whom, we turn to an examination of the collaborative work relation and the way in which the maintenance of this relation builds into social networks over the term as a whole, and at each of the three time periods. If, as suggested by CSCL researchers, a key to successful collaborative learning is that class members interact and share experiences with each other, then one issue to examine is the distribution of collaborative work relations among all class members.

Although we know that project team members are likely to collaborate more with each other than with other students, we do not know how the presence of project teams affects collaboration across the class as a whole, and across the term. Class members may still be motivated to work with others, even if not involved in the same projects. Some may wish to share their expertise, while others may seek it out; some may want to work on clarifying concepts from class; project team members may seek help outside their team in order seek information that is unavailable among the team members.

We also don’t know how teams manage their collaborations via the available media. Thus, a second issue is how different media were used by teams, and by the group as a whole, to maintain their collaborative work relations.

The examination of the collaborative work networks begins with a view of the network over the term, and then examine changes over time. Then the media networks for collaborative work are examined.

3.1. Collaboration over the term

Social network data reveal the connections between and among all members of the network. These connections can be portrayed numerically, as numbers in a matrix, and in graphical form as whole network sociograms. Actors are shown as points in these graphs, and relations maintained by pairs of actors are shown as lines between the points. The lines show the paths along which relational information or resources flow, and who exchanges these resources with whom.

Figure 1 gives a view of the whole network for collaborative work over the term. The graph is produced using the KRACKPLOT social network graphing package [49]. Positioning of the points in the graph is accomplished using a simulated annealing algorithm. The figure shows only those connections which were maintained at a frequency of more than once a week, i.e., showing only those connections which were maintained more often than the frequency of the live weekly session. (To produce the whole network diagrams, the data are dichotomized at communication 12 times over the term, i.e., once per week across the three one-month time periods. The resulting data used for the diagram is a set of one’s and zero’s: one where frequency of communication is greater than 12, zero otherwise.)
The project team structure is immediately evident in this picture: Team 1 members R6, R7, R11, and R14 are evident as a group at the top of the network picture; Team 2 members R2, R4, and R10 are evident at the bottom of the network picture; Team 3, R3, R5, R9 and R12 are at the left; and Team 4, R8, R13 and R15 are at the right. (The orientation of the graph, e.g., top versus bottom, does not carry any information about relations or interconnections; the graph would have the same meaning if this group appeared in other locations on the graph.)

Team structures are even more pronounced when higher frequencies of communication are examined. At communication rates of more than four times a week, members of Teams 3 and 4 form cliques, i.e., maximally complete subgraphs in which each member of the clique is connected to each other member. No other cliques of size three or greater are present at this frequency of communication. At communication greater than three times a week, each of the project teams emerges as a clique and all but one member of the class is identified within one of these cliques (i.e. one team shows complete interconnections only among three of its four members), and no other cliques are present. Thus, it can be seen that the project team structure has a marked effect on focusing who class members communicate with on a frequent basis.

It is also evident from the network diagram that project teams were not isolated from each other. However, connections between teams were maintained at a lower frequency of communication than connections among team members. At communication rates of at least twice a week, three cliques emerge composed of class members who do not belong to the same project team: R3, R5, and R10; R4, R5 and R10; and R5, R13 and R15 (see Figure 2).

Inter-team connections are important for conveying information that may be available in one team to members of another team. In collaborative learning and information sharing situations this means that information known in one group has the opportunity and the path along which to travel to other groups. Even when infrequently maintained, these ties afford the opportunity for information to flow around the network [8, 33, 34, 37]. However, frequency of interaction matters more to time limited groups than to other networks. For example, communication only once a month during a 15 week term, means pairs communicate fewer than 4 times in total. Moreover, the timeliness of the information is likely to suffer, since more time elapses between exchanges, e.g., information might not arrive in time to meet a deadline.

Figure 2 shows how information flows between teams in this class at frequencies of at least twice a month. Team 2 (R2, R4, R10) and Team 3 (R3, R5, R9, R12) are connected by communication (i) between Team 2 members R10 and R4 and Team 3 member R5;

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2 Direction of connection is ignored in this clique identification; UCINET IV, a social network analysis package was used for the analyses [6].
and (ii) between Team 2 member R10 and Team 3 member R3.

R5 emerges as a central figure, or star, in the collaborative work network, and as a bridge between teams. R5 is positioned to act as a conduit for information to and from Team 3 (R5’s own team) and both Team 2 (R2, R4, R10) and Team 4 (R8, R13, R15). The following section explores further the actor’s positions and centrality in the network.

3.2. Centrality in Collaborative Work

One way to examine the distribution of collaboration is to examine whether some individuals are more prominent or central than others in the collaborative work network. When information and resources reach all actors equally, no single actor or set of actors assumes a central position in the network. However, if information or resources flow through certain actors before reaching others, these actors are more prominent in the network and are positioned to control and influence the flow of the resource.

A measure of an individual’s position in a network is their individual centrality. This measure indicates how well positioned an individual is to both receive and disseminate information to all other members of the network. Actors who are central in a network are on communication paths that keep them in contact with others in the network. The most central or prominent are known as stars. They are well positioned to give and receive information from and to many others and thus to be aware of activities across the network as a whole. Moreover, they are likely to receive this information sooner than those on the periphery. Where exposure to information is important, as is suggested for collaborative learning, centrally located actors are the ones best positioned to receive the benefits of such collaboration. At the other end of the scale are non-central, or isolated individuals. The isolate does not maintain connections with others, and thus does not receive communications from others in the network. Relatively isolated individuals who maintain few links with others may still receive information, but, depending on who they rely on for that connection, they may receive the information later than others. Isolates can be expected to benefit least from collaborative activities.

Centrality can be measured in a number of ways (for a full discussion of centrality, see [26, 67]). The simplest is to count the number of others with whom an actor maintains a particular relation. The actor with the most connections, i.e., the highest degree, is most central for that type of exchange. Another measure is closeness, which calculates the distance from each person in the network to each other person based on the connections among all members of the network. Central actors are closer to all others than are other actors. This closeness means they are more likely to hear information that is available in the network. A third measure is betweenness which examines the extent to which an actor is situated between others in the network, i.e., the extent to which information must pass through them to get to others, and thus the extent to which they will be exposed to information circulating in the network.

These measures assume communication flow along the shortest path between individual actors. However, Stevenson and Zelen [64] argue that information does not have to take the shortest route and suggest a measure of centrality based on an examination of all paths that information can take to reach an actor. Their information measure calculates centrality based on all possible paths, and takes into consideration the weight of the relation, e.g., the frequency of communication. Since it is not known at this point which type of connections between individuals (e.g., direct or indirect; frequent or infrequent) contribute to the benefits of collaborative learning, Stevenson and Zelen’s information measure, which includes all connections, appears to be the best starting place. Moreover, this is the only measure that takes into consideration the frequency of interaction. Thus, information centrality is used for actor centrality. The mean of the information centralities gives an estimate of central tendency for the network as a whole (although it is not a true measure of network centralization, see [67]).

Information indices are calculated for non-directional, symmetrical matrices. Since the data from this study were frequency estimates from two perspectives (e.g., actor A’s estimate of frequency of collaborative work with B, and B’s estimate of collaborative work with A), the data is first symmetrized based on the average of the estimates by each member of the pair. For example, if actor A reports communication with B once a week, and actor B reports communication with A three times a week, then communication for both A to B, and B to A, is taken to be twice a week.

3.3. Actor centrality and network structure over time

We have already noted that class member R5 occupies the most central position in the network. This is shown again in R5’s information centrality; this class member shows the highest centrality score in the class (see Table 1). Also central in the network over the term are all the members of Team 3 to which R5 belongs (R3, R5, R9 and R12), and R10, who, along with R4, connects Team...
Table 1: Information centrality for collaborative work

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<td>59.4</td>
<td>9</td>
<td>38.7</td>
<td>5</td>
<td>139.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean: 31.4  SD: 2.6

**bold:** >1 standard deviation from the mean;  
**bold italic:** >.5 standard deviations from the mean

It is interesting to note that the inclusion of on-campus interaction does not change who is central, but rather accentuates the prominence and isolation of individuals. For example R10 is among the more prominent at Time 1 and Time 3, but R3, R5 and R9 emerge more strongly at Time 2. Note, however, that this accentuation is *not* only due to face-to-face interaction.

One of the three most central individuals, one did not actually attend the on-campus event and therefore could not exercise a face-to-face influence (for anonymity, the individual is not identified more specifically), yet they maintained a prominent position in the network. Thus, there are more than just CMC versus face-to-face effects in operation. Some members of the network maintain their extreme position regardless of the media and time period, while others gravitate toward a more neutral position.

Central class members appear to have retained their position over time, possibly because of individual attributes that contributed to their taking and keeping such positions across the term. However, others were less fixed in their network positions until later in the term. Time 2 appears to be critical for establishing positioning in the network. Rank correlations of positions in the centrality hierarchy for collaborative work are more highly correlated between Times 2 and 3 (r=0.67, p=.009) than between Times 1 and 2 (.34, p=.233), or Times 1 and 3 (0.49, p=.078). Thus, it appears that network positions tend to solidify during the mid-term period.

In practical terms the fixing of positions in Time 2 makes sense: individuals must join project teams and begin to produce classwork during Time 2. During Time 1, class members may learn how to work together and who to work with. Thus, network position during this period is less long-lasting. However, by Time 2, project teams have been formed and team members learn who can do what kinds of work or provide which kinds of information. Thus, the network stabilizes during Time 2 and remains essentially that way for the remainder of the term. This centrality measure may be capturing the group development process, with members of the group exhibiting an amorphous start-up phase that ends at the half-way point when the group modifies itself toward the attainment of the goal of project completion (see [9, 15, 31, 32, 53, 54]). Again, the face-to-face interaction during Time 2 may also serve to solidify network interactions. However it is not possible to tell from this data whether the solidification is a matter of time, or whether it is due to the face-to-face “intervention.”

When individuals do show a change in network position over time, most show a migration toward their group’s position in the network. For example R6, who is relatively central during Time 1, becomes relatively isolated during Time 2 and 3 and shows a centrality score similar to others in the team (Team 1: R6, R7, R11, R14). R12 and R13 each move up in terms of centrality...
across the term, to a level similar to others of their teams: by Time 3, R12 is occupying one of the more central positions, along with team members R3, R5, and R9; and R13, moves from a low centrality position in Time 1 to a mid-level position in Time 2 and 3, similar to team members R8 and R15.

The remaining two individuals whose positions change markedly over the term appear to have assumed a bridging role between their team and other teams. As noted above, over the term, R10 connects Team 2 to Team 3 at frequencies of more than twice a week. R11 increases contact with other teams dramatically in Time 3, from maintaining connections more than once a week with only one or two class members outside their team in Times 1 and 2, to maintaining connections with all others at this frequency during Time 3.

Isolation is not necessarily a poor strategy for getting work done. It may be a good tactic for reducing information overload and insulating oneself from too much interaction. However, the isolation may also affect commitment to the team and class goal. It may reduce access to information that may make it easier or more satisfying to complete the work projects and which contributes to collaborative learning. Isolation may also contribute to a feeling of alienation from the class and its goals. Results from this class suggest that the isolation was not productive: the few class members who dropped the course (late in the semester but before project completion) came from the low centrality set. It is possible that their intended withdrawal is presaged in their low centrality, i.e., that they had ceased to collaborate with others even before they actually withdrew from the class. Therefore it is not possible to say whether they had low centrality because they were thinking about dropping out, or whether they thought about dropping out because of the effects of their low centrality.

3.4. Media connections

The previous section showed that group structures for collaborative work are highly influenced by the project team structure. The next question to address is how these project teams make use of media for their collaboration.

The communication media used by the students were the webboard, IRC, Email, telephone, NetMeeting, and scheduled and unscheduled face-to-face meetings (Time 2 only). The media that connected most members of the class with most others were the Webboard and IRC, the two media that were used as part of the class structure, followed by Email (see Table 2). Each medium connects more pairs over the term than in any particular time period. This shows that different pairs used different media at different times during the term, perhaps in response to the task or group needs at the time, perhaps as they find the media that best support their team interactions.

### Table 2: Number of pairs collaborating on work at least once during the time period, by medium

<table>
<thead>
<tr>
<th>Medium</th>
<th>Time 1 n (%)</th>
<th>Time 2 n (%)</th>
<th>Time 3 n (%)</th>
<th>All Term n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Webboard</td>
<td>88 (97)</td>
<td>90 (99)</td>
<td>81 (89)</td>
<td>91 (100)</td>
</tr>
<tr>
<td>IRC</td>
<td>33 (36)</td>
<td>41 (45)</td>
<td>68 (75)</td>
<td>75 (82)</td>
</tr>
<tr>
<td>Email</td>
<td>33 (36)</td>
<td>23 (25)</td>
<td>21 (23)</td>
<td>41 (45)</td>
</tr>
<tr>
<td>Telephone</td>
<td>3 (3)</td>
<td>9 (10)</td>
<td>10 (11)</td>
<td>13 (14)</td>
</tr>
<tr>
<td>NetMeeting</td>
<td>3 (3)</td>
<td>3 (3)</td>
<td>2 (2)</td>
<td>3 (3)</td>
</tr>
<tr>
<td>Scheduled</td>
<td>—</td>
<td>25 (27)</td>
<td>—</td>
<td>25 (27)</td>
</tr>
<tr>
<td>Unsched.</td>
<td>—</td>
<td>10 (11)</td>
<td>—</td>
<td>10 (11)</td>
</tr>
</tbody>
</table>

Based on symmetrized data; maximum number of pairs is (14x13)/2=91; “All Term” pairs are the number of unique pairs who communicated over the term; no face-to-face interaction was reported for any time other than Time 2.

NetMeeting was used only by members of one team, at a frequency of approximately once a week during the term. Although it appears to have been useful for that group, since its use was restricted it is not discussed further here. The team that used NetMeeting is not identified in order to maintain the anonymity of the team members.

The telephone was used by few pairs, with an average frequency of twice a month by those who did use it. Again, since use was so low, telephone use is not examined in detail here.

#### 3.4.1. Webboard

Reports of webboard use varied little across the term, or across members of the class. Each respondent indicated that they used the webboard for collaborative work weekly to monthly (converted to 2.5 times in the month) at each time period. With few exceptions, they reported communicating with all other members of the class via the webboard at this frequency, making no distinction among the others in the class nor in the frequency of communication. Centrality scores for this medium show little differentiation, and few individuals show extreme positions. The cliques that form are large: at Time 1 there are three cliques who communicate at least once during the month, each with 12 members (out of 14 maximum); at Time 2 there are two cliques, each with 13 members, and at Time 3 there are five cliques, each with 10 members.

Thus, the webboard serves as a constant communication background, with other media used for more select communication interactions. It is also...
interesting to note that this medium was considered as a means for collaborative work among class members, indicating its success as a support for more generalized, class wide interaction. In social network terms, this medium shows a greater range of connection than other media. It supports generalized collaborative ties rather than specialized ties.

3.4.2. IRC
Over time, more class members report talking to more others via IRC. Connections in the last month of term were 20% higher than in earlier months. This increasing density is apparent in the network diagrams of IRC connections. Figures 3 and 4 show the networks at Time 1 and at Time 3.

![Figure 3: IRC connections for collaborative work, Time 1 (communication more than once in the month)](image)

More, smaller cliques are maintained via IRC than via the Webboard, with the size of the cliques increasing over the term. At Time 1 there are eight cliques whose members communicate more than once a month (3-5 members: one with three, six with four, and one with five members). At Time 2 there are 11 cliques (3-5 members: one with three, five with four, and five with five members). By Time 3 there are five cliques, now made up of seven to nine members (one with seven, two with eight, and one with 9 members).

While some class members show a similar centrality in the IRC network across the term, others change positions over the term (Table 3). Team 3 members (R3, R5, R9, R12) who generally occupy the most central positions do not occupy them all term.

![Figure 4: IRC connections for collaborative work, Time 3 (communication more than once in the month)](image)

Table 3: Information centrality for collaborative work via IRC

<table>
<thead>
<tr>
<th>ID#</th>
<th>Ctr (Time 1)</th>
<th>ID#</th>
<th>Ctr (Time 2)</th>
<th>ID#</th>
<th>Ctr (Time 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R4</td>
<td>1.6</td>
<td>R7</td>
<td>2.0</td>
<td>R7</td>
<td>4.7</td>
</tr>
<tr>
<td>R2</td>
<td>2.4</td>
<td>R11</td>
<td>3.6</td>
<td>R6</td>
<td>6.5</td>
</tr>
<tr>
<td>R10</td>
<td>2.5</td>
<td>R6</td>
<td>3.7</td>
<td>R2</td>
<td>6.9</td>
</tr>
<tr>
<td>R14</td>
<td>2.5</td>
<td>R12</td>
<td>6.6</td>
<td>R3</td>
<td>7.1</td>
</tr>
<tr>
<td>R11</td>
<td>2.8</td>
<td>R2</td>
<td>7.1</td>
<td>R4</td>
<td>8.1</td>
</tr>
<tr>
<td>R8</td>
<td>2.9</td>
<td>R15</td>
<td>7.1</td>
<td>R13</td>
<td>8.3</td>
</tr>
<tr>
<td>R15</td>
<td>3.2</td>
<td>R14</td>
<td>7.2</td>
<td>R15</td>
<td>8.7</td>
</tr>
<tr>
<td>R7</td>
<td>3.4</td>
<td>R3</td>
<td>7.3</td>
<td>R8</td>
<td>8.9</td>
</tr>
<tr>
<td>R13</td>
<td>3.7</td>
<td>R13</td>
<td>7.3</td>
<td>R14</td>
<td>9.2</td>
</tr>
<tr>
<td>R12</td>
<td>4.0</td>
<td>R8</td>
<td>7.4</td>
<td>R10</td>
<td>9.5</td>
</tr>
<tr>
<td>R6</td>
<td>4.1</td>
<td>R10</td>
<td>7.5</td>
<td>R5</td>
<td>9.6</td>
</tr>
<tr>
<td>R9</td>
<td>4.1</td>
<td>R4</td>
<td>8.3</td>
<td>R9</td>
<td>9.6</td>
</tr>
<tr>
<td>R3</td>
<td>4.3</td>
<td>R9</td>
<td>8.6</td>
<td>R12</td>
<td>9.6</td>
</tr>
<tr>
<td>R5</td>
<td>4.4</td>
<td>R5</td>
<td>9.1</td>
<td>R11</td>
<td>9.7</td>
</tr>
</tbody>
</table>

Mean: 3.3 6.6 8.3
SD: 0.8 2.0 1.4

Bold: >1 standard deviation from the mean;
Bold italic: >.5 standard deviations from the mean

Thus, the IRC network is dynamic, evolving and changing over term, perhaps with the topic under discussion and the expertise individuals can bring to the class. The volatility in network positions suggests that different opinions are being heard and that the forum is
not dominated by one voice or one set of voices across term. Both this medium and its use in this class suggest it to have been a successful collaborative environment, particularly if contribution to the forum is a key to such success.

3.4.3. Email

While the IRC networks include more of the class as the term progresses, the Email networks change from generalized communication in Time 1 to project team focused communication in Times 2 and 3. Figures 5 and 6 show the Email networks at Time 1 and how the team focus is already evident by Time 2.

During Time 1, 12 cliques are present whose members communicate more than once in the month (eight with three, and four with four members). In Time 2 and 3, there are fewer cliques, and their size remains at three and four members. At Time 2 there are five cliques: Teams 2, 3 and 4 each form a clique, and Team 1 members form two cliques (R6, R7, R11 and R6, R11, R14). At Time 3 there are six cliques: Teams 2, 3, and 4, and 3 members of Team 1 each form a clique, and there are two cliques of size three which bridge Teams 2 and 3 (R2, R9 and R10; R3, R9 and R10).

Position in the Email network is associated with team membership: individuals show centralities similar to others in their team (see Table 4). Members of Team 3 are central in the Email network during all time periods. Members of Team 2 (R2, R4, R10) move as a group from a peripheral position in Time 1 to relatively central positions in Time 2 and 3, suggesting their adoption of this medium as their preferred mode of communication with each other and with others. Team 4 (R8, R13 and R15) also moves as a team; they are generally peripheral until Time 3 when they show moderate centrality. The last team (R6, R7, R11, and R14) starts off more central and moves to the periphery in their Email use.

Table 4: Information centrality for collaborative work via Email

<table>
<thead>
<tr>
<th>ID#</th>
<th>Ctr</th>
<th>ID#</th>
<th>Ctr</th>
<th>ID#</th>
<th>Ctr</th>
</tr>
</thead>
<tbody>
<tr>
<td>R4</td>
<td>2.6</td>
<td>R13</td>
<td>2.4</td>
<td>R7</td>
<td>0.1</td>
</tr>
<tr>
<td>R2</td>
<td>2.9</td>
<td>R15</td>
<td>2.6</td>
<td>R14</td>
<td>0.3</td>
</tr>
<tr>
<td>R10</td>
<td>3.0</td>
<td>R8</td>
<td>2.7</td>
<td>R6</td>
<td>0.4</td>
</tr>
<tr>
<td>R8</td>
<td>3.0</td>
<td>R14</td>
<td>2.9</td>
<td>R11</td>
<td>0.4</td>
</tr>
<tr>
<td>R15</td>
<td>3.2</td>
<td>R7</td>
<td>3.2</td>
<td>R15</td>
<td>0.5</td>
</tr>
<tr>
<td>R13</td>
<td>3.3</td>
<td>R6</td>
<td>3.3</td>
<td>R8</td>
<td>0.6</td>
</tr>
<tr>
<td>R14</td>
<td>3.5</td>
<td>R4</td>
<td>3.3</td>
<td>R13</td>
<td>0.6</td>
</tr>
<tr>
<td>R11</td>
<td>3.6</td>
<td>R10</td>
<td>3.7</td>
<td>R2</td>
<td>0.6</td>
</tr>
<tr>
<td>R7</td>
<td>3.7</td>
<td>R2</td>
<td>3.8</td>
<td>R4</td>
<td>0.7</td>
</tr>
<tr>
<td>R6</td>
<td>3.8</td>
<td>R12</td>
<td>3.8</td>
<td>R3</td>
<td>0.7</td>
</tr>
<tr>
<td>R12</td>
<td>4.2</td>
<td>R11</td>
<td>3.8</td>
<td>R5</td>
<td>0.7</td>
</tr>
<tr>
<td>R5</td>
<td>4.5</td>
<td>R3</td>
<td>4.0</td>
<td>R9</td>
<td>0.7</td>
</tr>
<tr>
<td>R9</td>
<td>4.5</td>
<td>R5</td>
<td>4.0</td>
<td>R10</td>
<td>0.7</td>
</tr>
<tr>
<td>R3</td>
<td>4.6</td>
<td>R9</td>
<td>4.4</td>
<td>R12</td>
<td>0.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3.6</td>
<td>3.4</td>
</tr>
<tr>
<td>SD</td>
<td>0.6</td>
<td>0.6</td>
</tr>
</tbody>
</table>

**bold**: >1 standard deviation from the mean; **bold italic**: >.5 standard deviations from the mean

Thus, in contrast to the IRC network, the Email networks serve to support specialized ties among project teams members. While IRC appears to serve as a rotating forum of input, Email networks are more stable and move rapidly to team-based interaction.
3.4.4. Face-to-face interaction

Face-to-face interaction was limited to Time 2 only. Since no reports of face-to-face interactions were given in Time 1 or Time 3, it is assumed that all this contact occurred during the on-campus weekend. During that time, students were scheduled in class for a large proportion of the time, leaving little opportunity for spontaneous meetings, and few unscheduled meetings between pairs were reported (10 of 91 possible reports).

Although asked specifically about non-class scheduled interactions, it is still not surprising to find that the bulk of the interaction took place in scheduled rather than unscheduled meetings. The limited on-campus time does not adequately allow for spontaneous interaction, i.e., it is not practical to wait until you run into someone in order to clarify points or to ask a question. Under these circumstances, the unscheduled face-to-face meeting does not play the same role as it does for a co-located group. With these time constraints on face-to-face meetings, informal communication must be maintained electronically over the course. It cannot be ‘packed into’ a single weekend. Thus, we cannot look to these unscheduled face-to-face meetings as providing support for “informal” communication for this group.

Scheduled face-to-face meetings (again, occurring only while on-campus), connect a moderate proportion of the group (approximately the same amount of interconnection as for Email in Time 1; see Table 2). Seven cliques emerge who met in scheduled meetings (three with three, four with four members), but these were not exclusively team-based. Only one team emerges as a clique in these meetings; the six other cliques are a mix of members from different teams. The meetings that took place, and the collaborative work they were engaged in during this weekend, does not appear to have been project work based. Neither do teams seem to have taken the opportunity to work on team projects during this time. Instead, it is likely they engaged in work associated with on-campus exercises.

The formation of different groups during this time suggests that positive conditions for collaborative learning exist during these meetings. Class members are actively involved with other members of the class, and have the occasion to receive and share input from others in the class and from other teams. It also shows that, for this class, the face-to-face “medium” was not an important means of accomplishing the group project work. They did not appear to be desperate to get together face-to-face for this work, suggesting they were satisfied with the media they were using for group project work.

3.4.5. Summary of media use patterns

Media use in this group provides an interesting array of support patterns for collaborative work. The asynchronous Webboard provides a continuous, class-wide background of communication, bringing students in contact with each other’s ideas and input two to three times a month. The communication is diffuse, sent to and from the whole class, not between specific pairs. On the other hand, synchronous IRC provides a more dynamic communication environment, with different class members taking more prominent positions in IRC communication over the term. IRC use increases over the term, suggesting that it was becoming the norm for class wide, non-team based communication.

While IRC connections between class members increase and change over the term, Email connections decrease and quickly become team-based. By mid-term, Email is used almost exclusively among team members rather than among class members. Thus, Email provides specific project-based support among specific sets of class members. It is not used as a means to communicate with the class as a whole.

Face-to-face interaction is limited to the one on-campus weekend. Interaction patterns show that it is not used as a spontaneous, informal means of communication. Instead, it appears to be used in a more controlled, scheduled manner to accomplish class work set during the on-campus weekend. In this capacity, the face-to-face weekend serves a learning goal, rather than a social goal. During the face-to-face interaction, the emerging and dominating team structure is not apparent. Therefore, students are meeting and exchanging information with new and different sets of others. This is likely to provide them with the opportunities for learning that a collaborative learning environment requires, i.e., exposure to more and different opinions and ideas from their own, or from those of their team members.

Thus, each medium provides different forms of support for collaborative work: diffuse, stable, class wide support (Webboard); dynamic and increasing interactivity (IRC); team-based peer-to-peer communication (Email); and non-team-based, scheduled, time limited interaction (face-to-face).

4. Discussion

Collaborative learning requires input and exchanges among members of the learning group whether a work group or educational group. As such, it lends itself to a social network analysis since exchanges are the basic unit of analysis for this approach. In examining this CSCL group, the social network approach shows where and when subgroups form and for what reason; who is
prominent in the network and who bridges between subgroups; and how the different media support these distance learners in their collaborative work.

4.1 Supporting work

CSCL groups have work to do and projects to finish. As such they operate much like other CSCW groups. They need to maintain themselves as groups and to find means of communicating that allow them to accomplish their work. The CSCL class examined here appears to have used a variety of media to fill particular niches in their need to support their work and the class. The Webboard, IRC and face-to-face meetings support work by the group as a whole, providing information exchange as well as short-term task support. Email serves a different function, providing a means for subgroups to operate as longer-term, task focused teams.

Although each medium has different characteristics, each may be considered a “permissive” medium, allowing free exchange of information and ideas, unconstrained by technological rules or data forms. Some are constrained by time and place. Synchronous IRC sessions may exclude class members who are not available during the live session times; synchronous face-to-face interaction excludes those who are not co-located. However, each retains a degree of flexibility that allows norms to develop based on usage, rather than on technological features. In this class, some norms are established by the instructor; for example, the Webboard was established for discussion of questions posted by the instructor and appears to have been used in this way over the whole term. Other norms of communication among class members developed over time: exchanges became more participatory via IRC over time, while exchanges via Email became more task focused.

4.2. Informal communication

Do any of these media support “informal” communication about work, the types of exchanges that support informal learning among peers and which promote a collaborative environment? Since each of the media is “permissive” in terms of the content, with some more permissive than others in the timing of exchanges, it is possible that each supports such interactions. While it is difficult to assess the formality versus informality of the exchanges that take place via these media, some patterns of use suggest some media may be more likely to be used for informal exchanges than other media.

It is apparent from usage patterns that the face-to-face on-campus interaction is not reported as a means of informal interaction, i.e., students report meeting each other in scheduled rather than unscheduled meetings. Their limited time together constrains their exposure to informal encounters. Thus, we can see that distance groups cannot depend on time-limited face-to-face interaction to accommodate informal communication needs. These must be met while they are at a distance.

It is also unlikely that the Webboard was used for informal communication. The steady, class-wide use of the Webboard suggests it was not used for spontaneous input, nor for interaction by specific pairs.

One medium that lends itself to “informal” communication for this class is IRC. As a synchronous medium, and with students gathered simultaneously for “live” sessions, students could spontaneously exchange ideas with each other. However, since the exchanges are likely to have been focused on the topic of discussion for the week, this medium might not have provided for informal exchange about work in general.

A more likely possibility is Email. Although asynchronous, exchanges via Email were not constrained to weekly class topics as were the Webboard and IRC. Moreover, because it is asynchronous, students could send comments to others at any time or place, increasing the spontaneity of the communication. If Email is the support for informal communication, then the usage patterns show that such exchanges are likely to be limited to team members. Geographic constraint on who interacts with whom has been replaced by team-based constraint. Although accomplishing team based communication is a reasonable goal for distributed groups, an overemphasis on team interaction can limit exposure to informal contact among all members of the group. It also raises the possibility that while computer-mediated distributed groups may be able to recreate clique structures based on task, they still are not creating a group-wide informal communication structure.

4.3. Future research

This research presents results from one class of students working with one instructor. Teaching styles, group dynamics and media use are likely to differ from class to class. Future research includes further examination of the intra-group communications of this class, exploring the relationship between collaborative work networks and those for exchanging information or advice, for socializing, and for emotional support. Future research also includes collection of network data from other classes, and following up such data collections with interviews to explore such things as the “informality” of exchanges, what specific tasks were involved in the “collaborative work” and how individual assignments as well as the group projects benefit from such collaboration.
5. References


